Developing a Method to Search for the Causes of Uncertainty in a Nascent Transport Planning Project

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

The transport planning decision process is, in theory, underpinned by rational analysis of travel behaviour and application of transport economics but project outcomes do not always follow the results of that analysis. Uncertainty is evident at all stages of the project development; as the concept emerges and as it moves through the subsequent assessment and decision processes. This research has investigated and demonstrated a method that identifies uncertainty focussing on the early stages of the project lifecycle and also provides an understanding of the factors that drive it.

The method used a backcast scenario to elicit the causal relationships between elements of the planning and decision process in structured interviews with stakeholders. Qualitative analysis techniques were used to identify the active elements of the process, the causality between the elements was explored using the Cross Impact Matrix Model to evaluate their influences and dependencies and identify those driving uncertainty in the planning process. In this research, the Cross Impact Matrix Model was extended to analyse stakeholder opinions both individually and collectively, and investigation was undertaken into the parameter sensitivity of the analysis method.

The case study was based on a disused railway where several studies into re-opening it have resulted in contradictory views on its mode of use and on the achievable benefits. In the scenario used in the case study, the rail service is re-instated for light rail use in conjunction with a new sustainable urban area anchored on an existing small village.

The findings in this case study were that presence of strong leadership and collaboration between Local Authorities were the most influential determinants for progress and the prime causes of uncertainty were the economic environment, planning policies, and perceptions of passenger utility. Although these results emerged from a specific scenario, the methodology was demonstrated to be a powerful generic tool to identify the elements that create criticalities in planning for any scheme.

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I owe an enormous amount to my partner Sue who has given her support for the 6 years of this part time PhD project and encouraged me towards completion.

Finally I must acknowledge an anonymous university examiner who, in the 1970s, set an exam question: "*Random errors* [uncertainties] *are dealt with systematically, Systematic errors* [uncertainties] *are found at random. Discuss*". In this research, some 40 years later, it appears I am still answering that question; addressing the random nature of discovering systematic uncertainties.

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Glossary

BCR	Benefit Cost Ratio. The ratio of the present value of future net benefits of a transport scheme to expenditure on that scheme aggregated over a long period (Typically 20 – 60 years) and used to quantify the value of a scheme.
CBA	Cost Benefit Analysis. Assessment of a transport scheme, often including a BCR.
DfT	Department for Transport: A Government ministerial department with responsibility for transport provision in the UK.
Highways England	The organisation in England responsible for management of the trunk road network. Formerly known as The Highways Agency.
ITS	Intelligent Transport Systems.
LEP	A Local Enterprise Partnership.
LTA	A Local Transport Authority.
LTP	Local Transport Plan. A document updated by an LTA every five years which describes their transport priorities, strategies and plans. Each LTP contains: • LDF: Local Development Framework. • SCS: Sustainable Communities Strategy. • SEA: Strategic Environmental Assessment. • HRA: Habitat Regulation Assessment. • HIA: Health Impact Assessment. • EQIA: Equality Impact Assessment.
MCDA	Multi Criteria Decision Analysis.
RBO	Rank Based Ordering. A measure of the commonality of ordering of two sequences.
RMSE	Root Mean Square Error.
SECURE	Self Conserving Urban Environments. An EPSRC funded research project (Bell, 2013).
WebTAG	Transport Assessment Guidelines available from the UK Dept. for Transport.

Case Study Location

Map Source: One North East; Open Street Map

Figure 1-1 North East England

Chapter 1 Introduction

Transport planners design transport systems, be they road, rail, air or sea. On the face of it the task should be simple: Identify a transport need, design and optimise a solution to move people and goods efficiently, bid for and win the funding to build it, then, once built, use it and manage it.

There are well documented processes for assessing transport developments (DfT, 2016; Worsley and Mackie, 2015; Ortuzar and Willumsen, 2011; Berechman, 2009). The need for travel is assessed by estimating the number of trips in and out of an area based on land use and census data, these trips are then linked to form for example a commuter trip based on where travellers live and work. The mode of the trip, public transport or private car, is inferred from travel time, distance and cost data. Vehicles are then assigned to the transport network to model how drivers select their route and how their vehicles interact in the network. Once the planner has a model of the transport network, calibrated to represent the traffic of today, changes are made to reflect planned changes in travel demand, to the network itself or to the control systems used to manage it. The effect of those changes is quantified and the economic benefits assessed based on travel time savings and in recent years, environmental and social measures are also included (DfT, 2016; Banister and Berechman, 2000; Nijkamp et al., 1998).

The results of the assessment are then used by Local Authorities, National Authorities and Politicians to guide their decision making as they allocate funds from local and national budgets to improve the transport network.

1.1 Uncertainty in Transport Planning

The problem that presents itself is that there are several difficult questions contained in that brief description of a transport assessment: These include how is a need identified? Is the need predicted or is it observed? What technology will best serve that need and what analysis will best inform the design? What criteria are used to "optimise" the system? Who are the "people", what are "the goods", and where do they want to move to and from, both now and in the future? Finally what do we mean by "efficient"? Do we measure it in terms of time, money, economy, environment, or a combination of all of them? Then, winning the funding means competing for resources with other pressing needs and success relies on writing a sophisticated business case based on rational analysis and comprehensive modelling to seek approval from decision makers who are all too often beholden to a fickle electorate as they make that decision. Finally, once built, how the new initiative is actually used by travellers and by freight distributors is often observed to vary from the predictions made in assessment.

Transport models are the decision support tools that underpin the business case written to support a transport development. Their role is to predict the future conditions in the transport network so that decision makers, the project budget holders, the network managers, the strategic planners and the politicians can make informed decisions based on assessment of the relative costs and benefits of proposed alternative developments. Transport models simulate the movement of goods and people by simulating their need to travel, their choice of how to travel, their time of travel, and then, on their journey, how they interact with the transport system to realise that journey and to arrive at their destination. The perceived benefits delivered by the transport development are calculated, aggregated over a period of time, typically measured in decades, and compared to the costs of building and managing the new transport asset. Comparison of the costs and the benefits will allow a rational decision to be made and the project may, or may not proceed. In the UK, the Department for Transport's (DfT) WEBTAG (Web Transport Analysis Guidance) (DfT, 2016) provides a set of globally respected comprehensive guidelines as well as detailed prescriptions concerning how to make these assessments.

However, transport models can only predict the future transport conditions by making a set of assumptions about the future technologies of transport, about the growth or decline in transport demand and the perception of how we value transport in terms of travel times, environmental concerns and social justice. Transport developments may then have a long gestation period; in the media and in the transport planning professional literature, we see many examples of significant delay in schemes coming to fruition. High profile developments such as a third runway at Heathrow airport (Grekos, 2014), HS2[1] (Divall, 2017) and the Aberdeen Western bypass (Transport Scotland, 2017) suffer lengthy procrastination lasting decades with deferral and delay seeming to be expected at every stage of the approval process.

[1] High Speed Rail Line 2

Then, by the time a major development is completed, environmental and social changes may affect how we travel and invalidate the decision criteria used to approve it. Forster (1995) describes how, in Birmingham in the early 1900s, a car based travel network was designed for the city centre with wide fast urban ring roads and spokes into the city. In the 1950s, during the post-war reconstruction of the city, these plans were actioned with the intent to cater for the car wherever possible. Construction finished in the 1980s just as the city's perception started to change and it began to regard the inner ring road as a restriction on development constraining it to the active inner area and isolating other areas. The radial spoke roads were converted to urban boulevards with greater pedestrian use and (aborted) road user charging proposals introduced in 1989. Now, in the early part of the 21st century, we have discussions on when will be (or when was) "peak car" and we believe we are in a phase of declining car use. In the relatively short time it took to construct the Birmingham ring road network, opinion started to change about whether it was the right thing to do, car use may have peaked, and how those roads are perceived and used has changed.

Similarly, changes occurred during the 1970s oil crisis when OPEC countries lowered their production and hence raised the price of oil. In the UK, this had an effect on government policy forcing major changes and policy reversals with a move back to funding and developing rail travel, temporary fuel saving speed restrictions, and a change in taxation of fuel. For travellers, it also bought about a change in travel patterns with a reduction in private leisure mileage (Parish, 2009). All significant changes in the transport related ecosystem, brought about by an event which was unforeseen by most.

As well as predicting the environment for travel, predicting the demand for a transport development also carries with it some uncertainty. In Brisbane (Ferguson, 2011), multiple predictions were made of the traffic flows in the planning stage. After opening, the achieved figures were just 24,000 per day compared to estimated levels of 57,000 (environmental estimate) and 100,000 (economic estimate). The nett result was legal action to recover some of the AU$700M losses against the (single) consultant responsible for both the predictions. Flyberg (2003) documents similar serial failures in estimating potential patronage of large transport projects such as the UK Channel Tunnel, the Danish - Swedish Oresund Link, and the Danish Great Belt link. While a few specific projects are mentioned here, Bain (,2009 #64) discusses many more examples of travel demand forecasts and undertakes analysis of 100 large scale projects which had financial input from The World Bank and from large fund investors. This revealed a ratio of achieved traffic to forecast traffic with a range of 0.14 – 1.51, a mean of 0.77 and standard deviation of 0.26. A range of accuracy is to be expected, but the finding that the average forecast was optimistic by 23% shows there is a systematic bias in the forecasting procedures producing significant errors. Similar results were found by Maldonado (1990), quoted in Xiao et al (2013) who found a 68% average error in the 15 year prediction of airport throughput in 22 airports in New England (USA), with a range of -34% to +210% error.

When presented with a rational assessment of a proposed project, decision makers are then expected to act on it. Lindblom (1979; 1959) describes how any policy or plan must exist in a complex ecosystem of complementary and competing projects which defeats rational analysis. Similarly, Rittel and Webber (1973) explain why rational analysis is almost bound to fail when presented with a "wicked problem"; described as one with no clear definition, no quantifiable end, and potentially inconsistent and irrational stakeholder behaviour. Decision makers, therefore, must bring in other information and their decisions are not necessarily in conformance with the transport assessment results. Marsden and Reardon, (2017) looked at the process of developing and applying transport policy in a metastudy of research into policy generation, specifically to study how policy is generated and evaluated in a complex cross-disciplinary system. Their finding is that most research is conducted in isolation of policy makers and that there is little understanding of the dynamics of governance of transport policy, both in the formal evaluation and in the less formal compromises in decision making between stakeholders.

Clearly there is a significant level of uncertainty in transport planning which encompasses the future environment in which planned developments must operate, the accuracy of the assessment of the proposed developments, and the actions of the decision makers based on their perception of the assessment presented to them. This level of uncertainty brings in another aspect to the decision making process; the political environment. If the future is uncertain and the assessment may be challenged, then the decision is made based on other factors. Wachs (1985) and Vigar (2017) discuss the significance of the political dimension to decision making. Wachs (1985) comments that the majority of the research has been in the technical aspect of transport studies and that more is needed on the social and political dimensions and Vigar (2017) argues that while successful project implementation requires technical, local, and empirical knowledge to support the decision, political acumen is also required to actually make the decision to proceed. Prospect Theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1974) reveals how decision maker's judgments are influenced by risk and uncertainty leading to choices which depend on the presentation of the assessment process as much as the actual technical knowledge included in it.

The effect of the decision maker is illustrated by a study comparing the results of Cost Benefit Analysis (CBA) for multiple projects with the choice of which projects are funded. A study by Welde et al. (2013) reveals that the correlation between those selected for funding and the Benefit Cost Ratio, which quantifies their value, can be weak and indicates that the result of the transport modelling exercise is not necessarily the key factor in project selection. Indeed, one interesting observation in contemporary modelling comes from two independent surveys of modelling practice in Brinkman (2003) and in (Naess, 2013) both of which found some ambiguity from transport modelling practitioners in agreeing they are under pressure to obtain results that satisfy their clients, but without acknowledging that this would occur. However, in the words of a Danish Member of Parliament interviewed by Naess (2013): "*I refuse to believe that those carrying out this work (modelling) are not influenced by knowing that the result they arrive at is to be used by agencies that will subsequently order new studies*". It is worth noting that in Flyvberg (2003) (Fig 2.2, Page 13) a graph of the traffic predictions plotted against the construction cost estimates for the Great Belt Link and for the Oresund Link shows a remarkable correlation of a rise in predicted use (both step change and constant increase) as the predicted costs rose. Flyvberg neglects to comment on this correlation.

In summary, we have a set of well-developed transport models of increasing complexity which attempt to model our travel patterns and journey aspirations. Their role is in providing evidence for decision making to assist planners and politicians to make the most rational decision about a transport development proposal based in sound analysis. However their reliability and the value of their results is often doubted, with the risk of models being ignored when decisions are taken, being used to justify decisions already taken, or the analysis they embody being subordinate to political influences.

The transport decision process therefore consists of much more than rational analysis of an individual transport problem and a suitable solution. Developments exist in a complex ecosystem of policies and infrastructure with competing demands on resources and with changing and contradictory assessment criteria. The efficiency of evaluation and implementation of transport policy also requires more investigation with Marsden and Reardon (2017) concluding "*We need to not only be able to map the decision making systems and formal structures of power but also recognise the more informal networks and sub-systems of actors that coalesce around policy issues…. if we are to understand and advance the state of the art of transportation policy study, there is a need to engage with substantive questions of governance which pay greater attention to context, politics, power, resources and legitimacy*".

Vigar (2017) summarises the problem by looking at the knowledge required of decision makers in transport and initially identified three rational knowledge based threads related to analysis, local knowledge, and best practice. In the paper, Vigar (2017) acknowledges a reviewer's advice to add a fourth significant thread related to operating in a political environment and acting on a wider stage than just transport. Similarly, Forster's PhD thesis (1995) was written in response to Wachs'(1985) proposals for research into the political and social dimensions of transport planning as well as how the decision process is influenced by them and Wachs (1985) summarised the situation thus: "*To the extent we collectively accept a single paradigm of transportation planning and decision making – the rational comprehensive model - we concentrate our resources on the refinement of technical methods, while ignoring the rich potential for research on the political and social dimensions of our field".*

The message is clear, the problems of identifying uncertainty in a transport project cannot be limited to quantifying the uncertainty in the analysis, we must include the entire decision process and be prepared to move from the statistical analysis of the transport models and quantifiable data to include also the more abstract uncertainty in the decision maker's reasoning. This informs the research gap addressed in this thesis.

1.2 Formulating This Research

Guidance for the project came from the International Conference on Uncertainties in Transport Project Evaluation (UNITE) in Copenhagen in 2013 which discussed uncertainty in transport planning (UNITE, 2013).There were 12 conference sessions summarised as:

- *Technical*: Two conference sessions considered model algorithms and parameterisations with an emphasis on travel choice functions in traffic forecasts
- *Modelling*: Four conference sessions dealt with uncertainty in simulations and estimations, modelling guidelines and analysis of the model outputs.
- *Evaluation*: Six conference sessions were concerned with ex post evaluation of forecasts, robustness in decision support, the political context of project evaluation, communication, and bias in model commissioning and use of the results.

Hence, in a conference on transport planning uncertainty, half the conference sessions discussed technical issues and modelling with emphasis on the application of models rather than the algorithms in the models. However, the other half of the conference focussed on the decision process and the associated uncertainty - with the basic premise that decision making is flawed and the advice given by models is either ignored or inaccurate. This conference helped formulate the goal of this PhD research which was to look for the sources of uncertainty in the wider context of decision making, especially in the context of a nascent project, rather than to restrict the search for sources of uncertainty to the assessment process.

Rowe (2001) crystallises the problem when describing a generic strategy for managing uncertainty. Stage 1 is to develop a model to support the decision and to identify its parameters however, Rowe (2001) offers little guidance as to what that model may be, but in steps 3 – 6 of the strategy (Step 2 being data collection) proceeds to use it. Van Geenhuizen and Thissen (2007) expand on Rowe's management strategies defining the model in terms of boundaries, inputs and valuation of outputs but like Rowe, they do not discuss the nature of the model. Rasouli and Timmermans (2012) observed the difficulty in translating the attributes of a scenario exercise (a model of the decision process) into the variables of a transport assessment exercise (a model of the transport activity); conflating the model of the decision in a policy and political context with the model created for decision support in an economic or environmental context emerged as a challenge which has yet to be addressed.

Similar strategies of "first devise a model, and use it in uncertainty analysis" have been proposed by others (Rasouli and Timmermans, 2012; Cheung and Polak, 2010; Duthie et al., 2010; Kloprogge et al., 2009; Rodier and Johnston, 2002). These authors also refer to a single model for both the uncertainty analysis about the decision process and for assessment of the project in decision support, hence making the assumption that the same model can be both wide enough to include the political decision process as well as the technical assessment process. Sensitivity and uncertainty analysis literature, however, overwhelmingly focusses on the latter assessment modelling process (Duthie et al., 2010; Do and Rothermel, 2008; Refsgaard et al., 2007; Clay and Johnston, 2006; Cacuci et al., 2005; Rodier and Johnston, 2002; Zhao and Kockelman, 2002) leaving the political decision process unaddressed (Wachs, 1985).

1.3 Research Gap

The goal of this PhD research was to devise and trial a novel approach to identify the critical aspects of a project that contribute most to the uncertainty within the decision making process for the project. The research would not be constrained by a requirement to use the same model, or the same form of model, in assessing uncertainty as would be used in assessing the potential benefits of the proposed transport development.

The techniques used, and linked together by this research, are derived more from a business strategy background rather than specifically a transport modelling background and join a scenario planning exercise with an abstract systems Cross Impact Matrix Method model. This model has a long history from three sources, (Vester, 2012 ; Godet et al., 2009; Gordon, 1968) but little published literature concerning its application. In this research, the model was extended to include a new dimension of accessing uncertainty from multiple stakeholders and the model robustness was studied and quantified, thus confirming the empirical advice offered by its early developers.

This method was not intended to contribute to a "Go / No Go" assessment of a proposed development. Instead it was intended to assist planners in analysing why a project may be stalled in the planning process or why approval was given, or not given, contrary to advice derived by rational technically robust analysis. In identifying the aspects of the project which contribute most to uncertainty, this method offers strategic transport planners insight into why attributes of the project acquire that uncertainty status, and hence indicate how that may be changed to reduce the uncertainty in those attributes which in turn reduces the risk of non-delivery of the project.

Therefore, the wider problem, addressed in this research, is to devise and trial a method to determine where uncertainty lies in a transport planning project with a focus on the decision making environment rather than the decision support process.

1.3.1 Objectives

The research objectives, stated succinctly are therefore:

- To research a method which provides a quantified insight into the uncertainties in a proposed transport project.
- To provide this insight in the entire scope of the proposed project without limiting the analysis to the project assessment stage.
- To investigate the uncertainty inherent in the method and provide confidence that its findings were robust under changing parameters in the method.
- To identify the strengths and weaknesses of the proposed method and to offer guidance for its future development.

In positioning this research, there was no stated explicit intention to contribute to the decision to proceed or not with a proposed transport project, the objective was to gain understanding of the uncertainty within a project with the intention that, with this understanding, uncertainty could be reduced or mitigated. There was also no requirement imposed on the methodology to direct it towards specifically to transport planning, a generalised methodology would be developed and in the light of comments by Wachs (1985) and Lindblom (1979; 1959), and, during the course of this research, confirmed Vigar (2017) and Marsden and Reardon (2017) neither would the methodology be restricted to the uncertainty in a proposed development in isolation. The assessment of uncertainty would also include the political and policy ecosystem surrounding the transport development under evaluation.

The most relevant literature that would guide the research as the methodology was developed was Robinson (1990), Giaoutzi et al. (2011) and Dreborg (1996) introducing the concept of backcasting. Vester (2012) and Godet (2011) who developed the Structural Dynamic Model and Tuominen et al. (2014) and Usher (2013) for steps on the road to a multi-stage method incorporating quantitative analysis of scenario based qualitative data with the intention to evaluate uncertainty.

1.3.2 Innovation

The approach adopted in this research was generic: to identify a subject for study, collect data about that subject, to use that data in building a model of the study subject and to report on the areas of uncertainty in the case study. Simultaneously, the robustness of the model was assessed to ensure the reported uncertainties came from the structure of the case study, not from the parameterisation of the methodology.

The innovation in this research was to draw together components of the analysis from multiple fields and integrate them to become a unified model, specifically in data collection using scenario planning, in qualitative analysis techniques, and in strategic systems modelling.

1.4 Thesis structure

The following chapters in this thesis will discuss the background to the project, the software written for the project and the case study used in this research.

- Chapter 2: Literature Review.
  The literature review presents the many definitions and taxonomies of uncertainty in a transport project including uncertainty in the application of transport models, the uncertainties in those models and the uncertainties in the decision process which utilises the outputs of transport models. How both quantitative and qualitative factors are taken into account is discussed before reviewing methods of scenario planning, consultation and elicitation which are intended to identify the uncertainties in the decision.
- Chapter 3: Designing the Methodology.
  Techniques identified in the literature review are researched in more detail and this chapter describes how they are linked together to form an integrated method to identify the drivers of uncertainty in a transport project.
- Chapter 4: The Cross Impact Matrix Methodology Software.
  This chapter describes the requirements analysis, the design and implementation of the bespoke software written for the project. This software implements the structural dynamics Cross Impact Matrix Method model with the extended functions required by the proposed methodology.

- Chapter 5: Case Study Selection.
  During this PhD research, a review was undertaken of the Local Transport Plans (LTP) in the North East of England which each Local Authority is mandated to produce and update every five years. This chapter briefly describes that review and notes that one proposed transport development stood out as an anomaly in the LTPs with multiple different plans for it and divergent business cases to support those plans. The Leamside Line was therefore identified as a suitable case study for this research.

With the preparatory stages complete, this thesis now moves into application of the proposed method on the case study identified by review of the LTPs of the North East of England.

- Chapter 6: The Normative Scenario.
  The first stage of the method is to write a forward looking normative scenario. This chapter describes the process of eliciting information about the scenario, organising it, and writing the scenario.
- Chapter 7: The Elicitation Exercise.
  This chapter describes the data gathering required for the uncertainty analysis through structured interviews with stakeholders based on the normative scenario. This chapter then describes coding the data, rationalising it, and linking the coded variables for each stakeholder.
- Chapter 8: Sensitivity Analysis.
  This chapter investigates the sensitivity of the analysis to examine the robustness of the Cross Impact Matrix Method as its configuration parameters are varied and recommends a set of parameters to be used in the subsequent analysis of the case study.
- Chapter 9: Leamside Line Case Study Analysis.
  This chapter forms the output of the method for this particular case study. The analysis is conducted in three stages: (a) To identify the most influential variables and the drivers of uncertainty; (b) To review the beliefs of the stakeholders and combinations of stakeholders and; (c) To examine the effect of a project management action, such as negating the effect causality link, on the uncertainties in the project.

The final chapter reviews the project and makes recommendations for future work.

- Chapter 10: Conclusions and Recommendations.
  In this chapter, conclusions are drawn in three areas: (a) What was learnt about the integrated methodology? (b) What was learnt about the Leamside Line as a nascent transport project? (c) A reflection on the project and how the methodology may be improved in future applications.

Chapter 2 Literature Review

This chapter reviews the literature concerned with methods of managing and understanding uncertainty in transport planning. It is intended to introduce the tools employed in transport modelling, assessment, and decision making, then examine their methods of handling uncertainty specifically differentiating between the different classes of uncertainty, from bounded uncertainty that can be rationally analysed, to unbounded uncertainty, akin to that which Donald Rumsfeld referred to as *"the unknown unknowns"* (Rumsfeld, 2002).

This chapter is divided into four sections. Section 2.1 presents a definition of uncertainty in the context of transport planning. Section 2.2 reviews transport models and the developments in those models to address uncertainty in model variability and model incompleteness and section 2.3 similarly reviews uncertainty in the decision process including analytical frameworks and their extension into decision making where "soft" criteria based in stakeholder perceptions are included as well as "hard" criteria based in quantified values. Finally, section 2.4 introduces qualitative methods used in assessing planning projects and policy developments in an uncertain environment.

The areas of literature drawn on include: planning and policy making both in transport and in other areas such as environmental modelling, strategic business management, operational research, economics and economic modelling, and risk analysis.

The main themes of the literature review will be brought together in Chapter 3 as the foundation upon which the methodology adopted in this research has been developed.

2.1 Definition of Uncertainty

Before studying uncertainty in a transport project, the first question is: How do we describe and differentiate the different forms of uncertainty in this context?

The dictionary definition of uncertainty (Chambers, 2008) is:

> ***uncertainty****: the state of being uncertain.*
> ***uncertain****: adjective 1 not sure, certain or confident; 2 not definitely known or decided; 3 not to be depended upon; 4 likely to change; 5 (often uncertain of something) lacking confidence; hesitant*

In the main body of the transport planning literature, the dictionary definition is often assumed and investigations into the sources of uncertainty implicitly refine the concept according to the class of uncertainty under discussion. However Lipshitz and Strauss (1997) provide a taxonomy of uncertainty which includes two quotes of note: the first from Argote(1982) - *"there are almost as many definitions of uncertainty as there are treatments of the subject"* and second from Downey and Slocombe (1975) -" *The term uncertainty is so commonly used that it is all too easy to assume that one knows what he or she is talking about when one uses it".* Lipshitz and Strauss (1997) then list 14 "*conceptualisations*" of the term from the pre-1997 literature which describe uncertainty in terms of probability, future knowledge and events, and inadequate grounds for decision using the words "*risk*" and "*ambiguity*" as synonyms for uncertainty.

Some authors, when discussing uncertainty, do provide their own definitions:

> *"A person is uncertain if s/he lacks confidence about the specific outcomes of an event or action. Reasons for this lack of confidence might include a judgement of the information as incomplete, blurred, inaccurate or potentially false or might reflect intrinsic limits to the deterministic predictability of complex systems or of stochastic processes."* (Refsgaard et al., 2005).
>
> *"Any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system.*"
>
> *"An inability to forecast*" (Courtney, 2001).
>
> "*The state of a lack of information"* and "*as a result it is difficult to make decisions*." (Kikuchi, 2005).
>
> "*Difficult to define because it touches on many different aspects."* and *"… in a broad sense refers to all we do not know and all we do not know to a full extent"* (van Geenhuizen and Thissen, 2007).
>
> *"The absence of information."* (Rowe, 2001).
>
> *"A situation of inadequate information, which can be of three sorts: inexactness, unreliability, and border with ignorance."* (Funtowicz and Ravetz, 1990).

"*Risk assesses known probabilities, uncertainty is when we cannot objectively get the probabilities.*" (Berechman, 2009).

"*A capricious term used to encompass a multiplicity of concepts: Incomplete information, ambiguous information, linguistic imprecision, variability and uncertainty in or preferences and hence our decisions*." (Morgan and Henrion, 1990).

"Discord or dispersion, due to evidence supporting mutually exclusive alternatives.", "Non-specificity or imprecision, due to evidence supporting nested alternatives.", and "Fuzziness or vagueness, due to evidence not supporting sharp definition of alternatives". (de Jong et al., 2007)

To supplement their qualitative definitions of uncertainty, De Jong et al. (2007) also offer a table of quantitative definitions including: Variance, 95% confidence interval, percentiles, t-ratios, RMSE error, correlation, and "*a landscape of possible futures*".

Researchers have attempted to devise an overarching taxonomy of uncertainty in transport planning and in environmental planning. One class of research is focussed on generating a canonical taxonomy applicable in multiple classes of project (Rasouli and Timmermans, 2012; Mattot et al., 2009; Refsgaard et al., 2007; van Geenhuizen and Thissen, 2007; Kikuchi, 2005; Walker et al., 2003; Courtney, 2001; Rowe, 2001; Lipshitz and Strauss, 1997; Morgan and Henrion, 1990). Another set of authors classify uncertainty as a side effect of placing their research in context (Cheung and Polak, 2010; Duthie et al., 2010; Beser Hugosson, 2005; Khisty and Arslan, 2005; Refsgaard et al., 2005; De Neufville, 2003). All taxonomies are similar and yet all are different in the sense that some researchers look at the problem as a system with inputs and outputs, others as steps in a process; some focus on the model and the different levels of variability in the data, parameters and results. Some studies concentrate on communication and assessment of the outputs; some are abstract, while others are more relevant to a single class of problem; and some focus on the assessment of the development project in its present environment only, while others expand uncertainty to include both the present and predicted future environment.

Simply comparing similar concepts within two taxonomies reveals the issues in devising a classification scheme to which the many facets of uncertainty may be allocated. Both Walker et al. (2003) and Rasouli and Timmermans (2012) devise a scheme for classifying uncertainty in modelling. Walker et al. (2003) discuss “modelling uncertainty” as four different types (context, inputs, algorithm uncertainty, and parameter uncertainty). Rasouli and Timmermans (2012) offer a simpler scheme defining two types of uncertainty (input, and modelling) where input corresponds to Walker et al.’s (2003) inputs and context, and modelling corresponds to Walker at al.’s algorithm and parameter uncertainty. Broadly these categories are in agreement; when discussing inputs, both refer to data variance, sample bias and systematic errors and when discussing models, both refer to parameterisation and to the completeness of the algorithms that define the model. However, while Rasouli and Timmermans (2012) in discussing models only refer the problem of oversimplification and the selection of type of model suited to the analysis of the problem, Walker et al. (2003) include software bugs and technical error as a source of model uncertainty too. Then, when discussing data, Rasouli and Timmermans (2012) now introduce coding bugs and observation errors as a source of uncertainty whilst Walker et al. (2003) only associate the statistical handling of data variability with uncertainty. Both refer to uncertainties are due to errors but while one author sees errors in the model and not the data, the other sees errors in the data and not in the model.

Another issue identified by Rasouli and Timmermans (2012) is the need to translate the actions and reactions that describe a scenario into a set of variables in a model. In their classification this is an input issue, in Walker et al.’s (2003) classification, it is in a different category as a model completeness issue. Similarly, parameterisation also moves across classification boundaries; is a parameter a model input or a model attribute? Examination of just these two papers with superficially similar classifications reveals different interpretations of the type of uncertainty and allocation of similar concepts to different categories.

In discussing uncertainty in the modelling process, all researchers identify two major classes of modelling uncertainty. The first is that which can be dealt with analytically such as stochastic variance or parameter sensitivity and is found in the attributes of the model, its algorithms, parameters and data. The second is that which describes the uncertainty in the future environment for the proposed development and the assessment of the proposed development. Here the uncertainty is not in how the proposal is modelled, but what is modelled in assessing the proposal and how is it envisaged to fit into the future economic, social and technological environment.

Researchers also draw a distinction between uncertainty in modelling and assessment and uncertainty in decision making. Wachs (1985) is explicit about this split between rational analysis and the social and political dimensions of transport policy, Berechman (2009) also regards the political influences as equal in importance to the decision as the technical assessment process while Cascetta et al. (2015) describes an iterative decision making process which combines rational analysis, consultation with stakeholders and communication to decision makers with the option to change the project objectives as stakeholder engagement evolves. While Cascetta et al. (2015) approach this from the rational analysis perspective, Gudmundsson (2011) approaches it from the stakeholder's perception perspective and regards a transport decision as a knowledge process in which the results derived by rational analysis must earn trust to be used in the decision process. Vigar (2017) similarly refers to four states of knowledge, three based in analysis, best practice and the local situation, the fourth being embedded in what is politically feasible and acceptable to decision makers. Khisty and Leleur (1997a; 1997b), Barfod and Salling (2015) and Nijkamp (1998) further this element of the transport planner's function by discussing how it is evolving from numerical assessment into a communicative consensus building role.

For the purposes of this research, three threads of discussion of uncertainty in a transport project that emerge from the literature will be investigated further. These are:

1. *"Modelling uncertainty"* which is found in the inherent variability in stochastic models, in data used by the models, in the sensitivity of models to their controlling parameters, and in the suitability and completeness of the model for the task.
2. "*Decision making uncertainty*" which is due to the varying beliefs, values, and actions of the stakeholders and decision makers.
3. *"Future environment uncertainty"* which is found in forming the framework for a transport policy or a transport infrastructure development and manner in which that policy or development will interact with this future environment.

The first thread will be investigated further as discussion of uncertainty in transport models examining the stochastic uncertainty, the sensitivity of transport models and the transport model developments made in reaction to the issues of suitability and completeness in Section 2.2.4. The second thread will look at the decision process and the progress in that field in decision making under uncertainty in Section 2.3.2 and the third thread will discuss qualitative methods of managing uncertainty in Section 2.4.

2.2 Transport Models

This section first discusses the purpose and use of different classes of transport models then reviews the techniques used to manage uncertainty within those models.

Transport models are intended to provide a decision support function; quantifying the effect on the transport network of changes in the road network, to the signals and ITS operations including urban traffic management controls as well as changes to the demand on the network when land use or travel patterns change. Models simulate the movements of goods and people from origin to destination based on their activities and the associated demand for travel which is governed by land use and demographics. The resulting demand is assigned to the transport network to assess the performance of the network. The benefits of the proposed transport development are evaluated and compared to the costs of building and managing the new transport asset. The resulting Benefit Cost Ratio (BCR) is then used in decision making. There are many professional guidelines in use worldwide which advise on the selection of the type of transport model to use (Austroads, 2010; FHWA, 2004a) and in applying the model (DfT, 2014b; Road and Maritime Services NSW, 2013; TfL, 2010; MOTOS, 2007; FHWA, 2004b; FHWA, 2004a; Traffic Simulation Committee Japan Society of Traffic Engineers, 2002). Models range in size from small models which use the assignment stage only and are built to study the effect of detailed changes in road layout and signal optimisation to regional or national scale transport models which are used to study the effect of major infrastructure developments, and may also embrace the effect of land use changes or transport policy decisions (Bamford, 2006).

2.2.1 Four Step Transport Models and Traffic Assignment Models

Traditional transport modelling estimates the travel patterns of populations and assigns their trips to the transport network in a four-step process which: in step 1, determines how many trips will be made to and from land use zones; in step 2, links those origins and destinations; in step 3, determines the mode of travel(bus, private car, walk, cycle); and finally in step 4, assigns those trips to transport network (Ortuzar and Willumsen, 2011). In the UK, databases such as TEMPRO, the National Trip End Model (DfT, 2017b) provide data and forecasts for the demand for travel to the year 2051 and act as a common base for consistent modelling. There are however many assumptions inherent in the process concerning the choices made by travellers and their use of the network. Validation of these assumptions is complicated due to the unobservable nature of the traveller's decisions in the first stages of a four step model. This was demonstrated by Zhao and Kockelmann (2002) and later by Manzo, Neilson and Prato (2013) in examining how models were calibrated to agree with observed data by investigating how the variability in the four stage modelling process was propagated through the stages. Both found that errors in stages 1 – 2 - 3 amplified as the process progressed, but then reduced in stage 4 as the predicted demand was assigned to the transport network. In reality, it is only at stage 4, where travellers and vehicles are assigned to the network and become visible as passenger numbers on trains, or as cars counted on the roads, that the model can be calibrated.

An assignment model is the last stage of a four step model process. At this stage, vehicles are assigned to the transport network, their routes are chosen to minimise overall delay in the network, and the resulting journey times, network speeds, and flows estimated (Ortuzar and Willumsen, 2011). Detailed descriptions of the application of a static assignment model, using aggregated flows, may be found in the UK Department for Transport's WebTAG guidance (DfT, 2014a) and Barcelo (2010) provides a comprehensive review of dynamic assignment models using individual vehicles (microsimulation) in both commercial software and open source software.

After the model has been completed, the outputs are used in decision support where travel cost savings and the value of environmental impacts are compared with the costs of building the scheme (Banister and Berechman, 2000). For example, the UK Department for Transport enumerates the costs it uses in transport scheme evaluation in WebTAG (DfT, 2016) producing tables allocating costs to the value of time for different travellers, a monetary value to accidents, and the value of a tonne of carbon emissions in a future "carbon market". These costs are aggregated for future years and discounted to a base year value. Similarly the costs of construction and operation are assessed for future years and discounted to the same base year. Comparison of the two estimates of cost and benefit indicates the overall value of the project. The addition of the value of emissions to the valuation process is relatively new. In previous years economic assessment of transport developments was conducted solely on travel time savings. Now, in addition to environmental issues, there are proposals to include the value of "Social Justice" in assessment[2] which places a monetary value on the provision of travel to communities where demand may, at present, be low but it is considered important to provide transport to support local economic development rather than favour projects where demand is already high, possibly due to prior economic development. This does, however, make the assumption that transport provision promotes economic development yet research by Mapuro and Mazumder (2017) and observations in Banister and Berechman (2000) question that assumption with Mapuro and Mazumder (2017) reporting that it the direction of that causality is context sensitive and Banister and Berechman (2000) arguing that transport developments may change the location of economic activity, but not necessarily add to it.

The evolution of the methods of assessment, the questioning of the assumptions in the modelling and the development of new transport technologies such as autonomous vehicles (Centre for Advanced Automotive Technology, 2018) or Mobility as a Service (MaaS Alliance, 2018) add to the uncertainty inherent in using models to predict emerging transport patterns and emphasise the use of forward looking derivation of future scenarios, as discussed in Section 2.4.1.

2.2.2 Quantitative Risk Analysis

Risk is a specific form of uncertainty. In the context of transport planning, the dictionary definition of risk as the "*chance or possibility of suffering (financial) loss*" is proposed as the most appropriate (Chambers, 2008). Flyvberg (2003) describes extreme cases of financial risk in large projects with examples of large cost overruns, 196% in the case of the arterial tunnel project in Boston Mass., and large errors in estimates of the use of a transport development quoting ratios of predicted traffic to realised traffic between 2:1 and 20:1, Bain (2011; 2009) similarly describes the systematic error in forecasting use of primarily tolled transport developments finding a ratio of achieved traffic to forecast traffic between 0.14 – 1.51, with a mean of 0.77 and in Brisbane, losses on a tolled tunnel were estimated at $(Aus.)1.3bn (Ferguson, 2011). The Edinburgh Tram project also demonstrates risk in construction and finance with cost overruns of 100% from initial forecasts and with construction delays of 3 years (Scottish Government, 2017).

[2] Conversation between the Researcher and the Department for Transport Official responsible for WebTAG.

Financial risk analysis therefore is a key part of transport planning and falls into two broad categories: 1) the risk of lower income due to inaccurate patronage forecasts, and 2) the risk of cost overruns in building the project. The first case has already been discussed in the sections on transport modelling and prediction; the second case on construction risk is discussed briefly here.

Rowe (2001) in describing how to manage uncertainty focusses on financial risk and gives five options for dealing with it: 1) ignore, 2) limit though contractual negotiation, 3) purchase insurance , 4) provide margins for contingency, and 5) directly understand and manage. Option 1 is discarded in all but the most trivial cases, options 2 and 3 simply pass the risk to others, and option 4 soon raises the question of what margins to use. Only option 5 is pro-active and seeks to manage uncertainty by identifying and analysing the issues, then devising and applying actions to address them. Lipshitz and Strauss (1997) describe a similar set of actions of suppression, acknowledgement, and reduction. Loosemore et al. (2006) provide a comprehensive review of techniques to quantify project risk based primarily in quantifying costs, estimating variance and risk of variation, then combining these measures to give a likely range of costs to construct an infrastructure development. These techniques are encapsulated in software such as @Risk (Palisade, 2011) and their application is discussed in (Laird and Venables, 2017; May and Haldane, 2011; Lemp and Kockelman, 2009; Jeon and Amekudzi, 2007; Schade and Schade, 2005; De Neufville, 2003; Flyvberg et al., 2003; Morgan and Henrion, 1990; Kahneman and Tversky, 1979). In summary, there is an extensive body of literature on the methods used to quantify financial risk in construction management and established practice, and software to implement those methods.

Loosemore at al. (2006) however also state that: *"… in discussing risk management, it is essential to uncover the primary drivers of risk, and that this is not just a mathematical process to quantify risk; it is also a process of systematic rigorous creative thinking with tools dependent on understanding the human behaviours in the system.* " This comment extends the understanding of financial risk from quantification of known cost components, for which Loosemore et al. provide templates, into questioning if the risk is properly understood when the problem is a "wicked" one (Rittel and Webber, 1973). The classes of uncertainty identified by Loosemore et al. (2006) are similar to those identified in modelling: The first is quantifiable uncertainty about costs estimates, parameters and data, the second is uncertainty about the completeness of the risk assessment and its ability to include human behaviour and unpredicted problems akin to the uncertainty inherent in model algorithm completeness.

2.2.3 System Dynamics Models

System dynamics models are derived from control theory and non-linear dynamics. They are used to uncover and represent feedback processes which determine how a human organisational system works. These models are often used in the context of scenario analysis and mediated modelling and in analysing complex systems (described in section 2.4.3).

Systems dynamics models and soft systems analysis methods have been developed over several decades (Pfaffenbichler, 2011; Pfaffenbichler et al., 2010; Sterman, 2000; Checkland, 1999; Flood and Carson, 1993; Patching, 1990). The models have evolved over time; initially there was a hope that in examining multiple questions, a "General Systems Theory" would emerge (Flood and Carson, 1993) that would reveal a consistent structure to a framework of concepts and interactions across all disciplines and that this would provide a meta-level unified framework to describe systems and hence facilitate generic solutions. This grand aim of a unifying "metascience" never came about but a methodology of describing business organisations evolved and with it various checklists emerged (i.e. CATWOE: Customers, Actors, Transformation, World, Owner, Environment) (Checkland, 1999), a methodology based on examining the network of interactions of the facets of a system through their causal relationships was developed, and there was an emerging realisation that it was more important to discover and focus on the underlying problem than focus on the problem as initially presented to the analyst (Patching, 1990). As an illustration of this, Checkland (1999) offers an example of how the different views from different stakeholders affect a project: Was Concorde a technological project to build a supersonic airliner, a business project to build a profitable travel asset, or a political project to assist the UK in gaining entry to the EU? The systems dynamics model for each view would look quite different.

Systems dynamics modelling, as described by Checkland (1999) and Patching (1990) is capable of simulating the properties of the system as it examines the causal interactions between the properties of the system without need to simulate the detail of those interactions. It is therefore very different from an activity based model or a microsimulation which simulates the actions of the constituent objects (travellers or vehicles) and aggregates them to model the overall system (Zheng et al., 2013; Barcelo, 2010; Ettema and

Timmermans, 1997). Checkland (1999) differentiates between these two model paradigms naming them as “soft” and “hard” systems but then argues that the distinction should not be solely made by describing hard systems as those based on physical goals and reductionist scientific methods, and soft systems as those based on human behaviour in an unstructured world but perhaps instead the distinction should be made on the analyst’s stance on the problem by asking the questions: Is the analyst dealing with an understandable system to be accurately modelled or a complex system to be explored? Does the analyst have a prediction goal or a learning goal, and, if it is a learning goal, will that able the analyst to make predictions with better understanding? This mirrors Lindblom’s (1979) thoughts on a pragmatic approach to modelling policy systems and the difficulty of understanding complex interactions within the policy network and Khisty and Arslan (2005) also advise the analyst to use soft systems methodologies in the “*face of bounded rationality and unbounded uncertainty”* i.e. when the system is complex, not fully understood, and hence defies a comprehensive complete rational analysis.

Flood and Carson (1993) add methods to system modelling although, as with much of the early work in the field, it is still documented conceptually rather than in a representative manner. In their taxonomy a system is broken into a set of elements with changeable attributes and a set of relationships between elements. The goal of the systems modeller is to develop methods which describe the relationships between elements of different objects and show them as causal loops. Figure 2-1 shows an example of a causal loop diagram indicating the relationships between the elements identified in the system under analysis with a “direction of causality” shown as a “+” or a “-“, i.e. as the measure “Local Air Quality” increases, the “Incidence of cardiovascular and respiratory diseases” moves in the opposite direction and decreases, indicated by a “-“ sign.

Sterman (2000) implements this as a software tool with general applicability to many areas, although business systems modelling forms the primary theme of the book. Sterman (2000) formalises the concept of causal loop modelling with positive and negative feedback loops. Figure 2-1 shows an example of a small feedback loop diagram taken from a systems dynamics model used to study the interaction between road transport and public health. The concept of a causal loop is then extended to quantify the interactions between elements by adding delays in process reaction and “stock and flow” measures in which an attribute of a system element accumulates or dissipates over time. Figure 2-2 shows a sample of a systems dynamics model in which the relationships and delays the interactions (flows) between those elements are used to quantify the values (stock) of a quantity. Sterman (2000) also discusses model calibration, an aspect of systems modelling which is not discussed in the literature more oriented to business strategy.

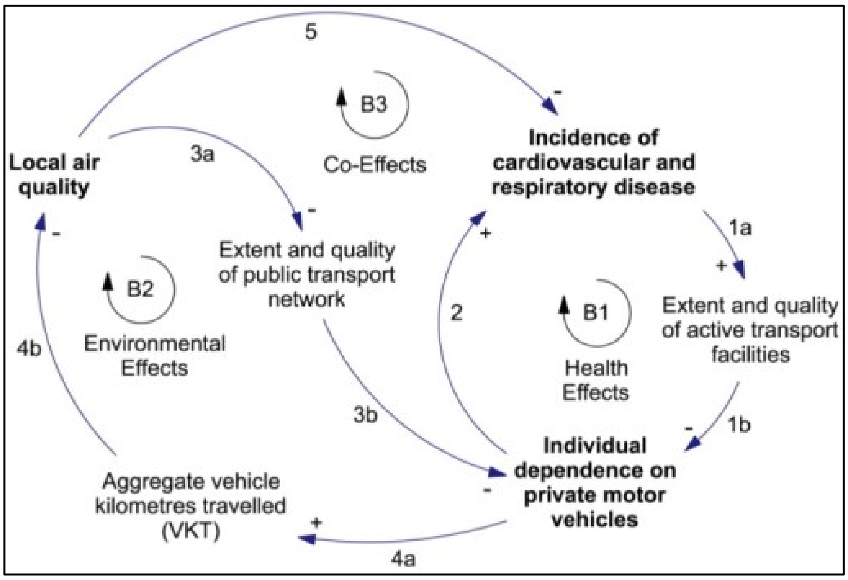


Figure 2-1 Causal Loop Example. Taken from Proust et al.(2012)

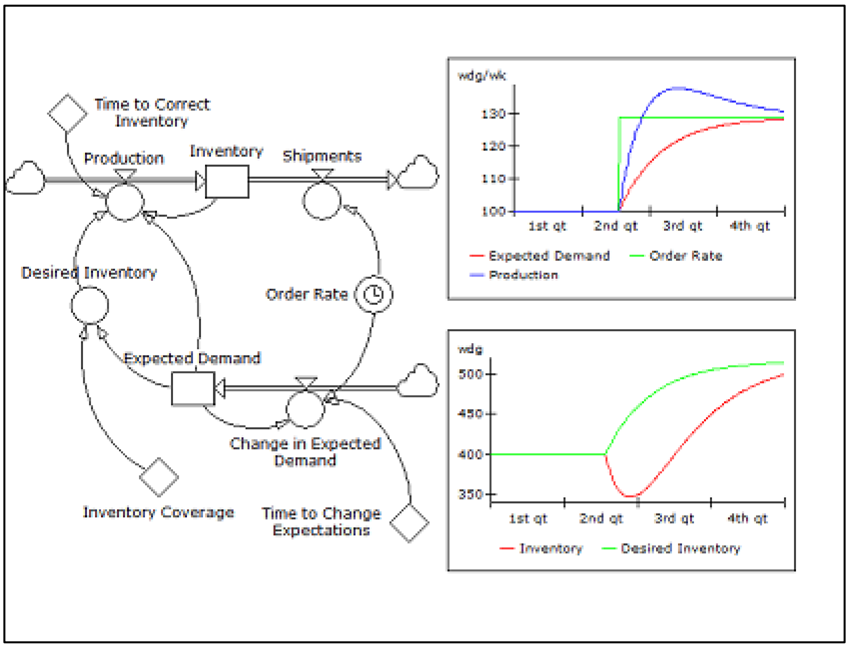


Figure 2-2 Stock - Flow Example Taken from Powersim (Powersim Software, 2012)

Several software systems are available which implement causal loop system models (ISEE Systems, 2012; Powersim Software, 2012; Simulistics, 2012; Ventana Systems, 2012; XJ Technologies, 2012). All implement the concepts of causal loop diagramming with stock and flow models as described by Sterman (2000) and all provide added features such as graphical output and through automated modification of parameters, sensitivity analysis is enabled. The key feature differentiating early work in systems modelling by Checkland (1999) and Patching (1990) and the basic stock and flow models (Sterman, 2000) is the quantification of the measures. More recent developments in the contemporary software products (i.e. Vensim (Ventana Systems, 2012)) include the ability to model objects individually rather than solely as classes of objects and hence to quantify the relationship between individuals. This capability provides the ability to calibrate a system dynamics model and is the key step in its transformation from a learning tool to stimulate thought and understanding into a rational analysis modelling tool able to simulate a system and provide numerical results.

With these developments of systems dynamics software, the distinction now to be made between a systems dynamics model and a conventional model is not a technical one of the modelling software and the ability to graphically draw up rule based actions, the distinction is in the behavioural level of those actions, the level of aggregation of the actors and the level of abstraction of the actions.

Systems Dynamics Models: Transport Based Examples

ALCES (A Landscape Cumulative Effects Simulator) (Carlson et al., 2010) is an example of a large land use planning project. It is built using the systems dynamics software "STELLA" (ISEE Systems, 2012). This models the strategic options in resource management and land use in Alberta and is linked to scenario planning exercises. ALCES is used by planners to evaluate the potential outcomes associated with their choice of land-use options at a strategic level by quantifying different actions or indicators in an area where an action is an activity (i.e. mining) and an indicator is an environmental measure (i.e. risk to moose population).

Other models have been used to examine the issues surrounding urban area increases in population. Shen et al. (2009) examine the relationships between population growth, housing density and transport provision in Hong Kong. While Shen's model is simple, in that single variables are used to describe territorial attributes such as land use patterns or road and rail provision, it is also complex, in that many interactions between variables are identified. Chen et al. (2009) describe a similar model of Jilin City in China. As with the work in Hong Kong (Shen et al., 2009) the model has a simplified representation of the transport network with just basic measures of capacity and load.

The MARS project (Metropolitan Activity Relocation Simulator) (Pfaffenbichler, 2011) on the other hand, is a more sophisticated transport and land use model with stated goals of providing an urban environment sustainable transport policy decision support tool quantifying travel mode choice vehicle miles travelled and transport capacity utilisation. MARS uses causal loops to model traveller behaviour, the area to be investigated is divided into zones and the population, land use, and travel availability parameters in each zone included in the model thus demonstrating the use of specific instances of objects (i.e. land use areas) in a systems dynamics model rather than limiting each class of object in an interaction to a single global stock and flow. MARS does not explicitly include a road or rail network, its principal levels of aggregation is the population and activity within a zone and the travel time between zones by different transport modes. Changes in travel time are inferred from changes in trip volumes or in one extension to MARS are taken from an existing static assignment transport model (Koh and Shepherd, 2009). MARS is significantly more capable than the models developed by Chen et al. (2009) and Shen et al. (2009) as it includes traveller behaviour models which are sensitive to travel mode availability and is specifically designed to allow the planners to study the effects of transport policy and infrastructure provision as an intervention to the growth in tailpipe emissions resulting from travel activity.

The MARS model operates at city or region level, by contrast the ASTRA model (ASsessment of TRAnsport Strategies) (Fiorello et al., 2010) operates at country or at European scale. It links a population model to a macro economic model and a set of regional economic models to an EU wide passenger and freight transport model and an environmental assessment model. ASTRA is programmed with the same technology as MARS – Vensim (Ventana Systems, 2012) although it claims to be operating at the practical limit of the software with current desktop computing technology. Its strength is claimed to be in modelling the interactions between the effects of multiple policies and complex traveller reactions.

As systems dynamics models mature in transport applications however, Shepherd (2014) in a review of 50 examples of transport related systems dynamics models conclude that after significant experience in application, their primary purpose is not to provide precise estimates and forecasts of activity but instead, they are more suited to providing a holistic model to examine interactions between actors in policy and infrastructure developments such as in mediated modelling exercises, described in Section 2.4.2.

2.2.4 Modelling issues

Despite widespread guidance on the use of models, when Rodier (2007) investigated the use of activity based microsimulation models and four stage land use models in the US, the considered view of ten experts with a background in transport and environmental policy was that models themselves as well as the modelling processes were not of adequate quality, citing that they lack the variables to represent the salient changes in road networks and transport policy and second; even if they had those variables, the models lacked the behavioural responses, such as departure time choice, destination and travel mode, which travellers make in response to the state of the transport network. The experts also cited a poor understanding by decision makers of the applicability of the outputs, that models were being applied out-with their original scope and that uncertainty in results was poorly communicated. Similar observations can be found commenting on the effectiveness of transport models and the inadequacy of their predictions in other investigations (Pfaffenbichler et al., 2010; Coombs, 2009). Pfaffenbichler's (2011) finding on the trustworthiness of transport models found that, of 102 transport practitioners, none had very high confidence in the output of transport models, 11% had high confidence and the majority stated they had medium or poor confidence with 9% stating very poor. Note that Pfaffenbichler (2011) was referring primarily to four stage aggregated models in this survey.

Coombs' report (Coombs, 2009) into the suitability of UK regional models was particularly excoriating. Of thirty models examined by evaluating their compliance with DfT WebTAG guidelines, none had a good demand module, only seven had a good highway module nine had an adequate highway model and fourteen had a poor highway module, a very simplified highway module, or no highway module at all, just three had a good public transport module. Coombs however notes that they are still used for transport assessments simply because little else is available.

Annema (2011), in reviewing 42 strategic level transport planning projects, comments that predicting the future in non-linear phenomena such as traffic congestion is imprecise and using more developed models does not necessarily give better predictions. The issues identified were that the models assume business as usual in their extrapolations and this is rarely the case. Moreover, the inaccuracy in prediction is not due to major events or shocks but attributed to interaction of slow cultural and economic changes with resulting policy shifts. Kloprogge et al. (2009) discuss the assumptions made in (environmental) modelling, analysing them through their hard quantifiable measures and their soft sociological measures to focus on their contribution to uncertainty in the model and in their subjective value laden-ness for stakeholders.

In specific instances, (i.e. tolled infrastructure) modelled results have been shown to be imprecise with both systematic errors in prediction and wide ranges of variance between predicted and observed patronage (Bain, 2011; Naess, 2011; Bain, 2009; Flyvberg et al., 2003) Bain citing a ratio of achieved traffic to forecast traffic between 0.14 – 1.51, with a mean of 0.77 and Flyvberg quoting ratios of prediction to patronage as high as 20:1. Post opening reviews by Highways England, the Authority with responsibility for developing and managing the strategic roads network, (Highways England, 2016) show that while prediction is improving and 93% of road improvements achieve their objectives and predictions of soft benefits (such as social integration, environmental improvements and traveller satisfaction) are largely met; 26% of schemes have an error of greater than 50% in journey time savings and only one in three predicts the economic benefits with under 50% error.

Uncertainty in Transport Models

This experience of the use of models shows the perception of uncertainty manifests itself in two ways: the completeness of the model; and the uncertainty in the results of the model.

The first is described by Walker (2003), as model structural uncertainty, the uncertainty due incomplete representation of behaviours and relationships in the model and as model technical uncertainty, by Mattot (2009) stemming from erroneous knowledge or inadequate models, which can be reduced by improving algorithms and modelling practice, by Rasouli and Timmermans (2012) as oversimplification or incompleteness of the model, by Morgan and Henrion (Morgan and Henrion, 1990) as deficiencies in the functional form of a model i.e. traveller behaviour, vehicle behaviour and by Rodier (2007) who explicitly states the causes of incompleteness in transport models as:

> *First, models lack the variables to sufficiently represent the quality (for example, spatial resolution, time, and cost) of alternatives to highway investments. Second, even if the models could represent these supply variables, they are unable to adequately show how changes in these variables influence individuals' location, destination, mode, and departure time choice.*

The second form of uncertainty is described by Mattot (2009) as irreducible uncertainty due to the inherent variability in the modelled system and by Morgan and Henrion (1990) as uncertainty in technical scientific economic or political quantities entered into the model. Rasouli and Timmermans (2012) discuss input uncertainty where variability and error in the inputs leads to uncertainty in the model output, Kikuchi (2005) refers to inputs, and by implication the model outputs, as having uncertainty due to both random error and systematic error in measurement. Uncertainty in the results derived from the model is also attributed to the selection of values for model parameters (Refsgaard et al., 2007; Cacuci et al., 2005; Walker et al., 2003) although Mackie and Preston (1998) and Bain (2009) observe that this parameter uncertainty is also effected by choices made by the modeller to satisfy the requirements of the stakeholder commissioning the model who may have a preference for a particular result.

The same problem is summarised in the context of financial risk analysis (section 2.2.2) by Loosemore et al. (2006) who extend the consideration of uncertainty to include both quantitative and qualitative factors, and hence demonstrating the value of parallel analysis of both types of uncertainties.

Methods for dealing with uncertainty in transport models (Note, not in the use of the results, merely in the calculation of the results) therefore will be dealt with in two subsections, one on model variability reviewing how uncertainty in data and parameters is managed and how the sensitivity of the model results on those inputs and parameters is quantified, the second subsection reviews developments in transport models to address the issues of completeness at a strategic level, i.e. by discussing the emergent classes of models rather than the detailed function of any individual model.

Model Sensitivity

A model is a representation of a physical system with a set of inputs, algorithms, and hence a set of outputs, the algorithms within a model are a parameterised representation of the actions of components of the system and hence control how that system is represented. Stochastic uncertainty exists if the model employs a “Monte Carlo” method simulation (Hammersley and Handscomb, 1964) and this uncertainty, due to stochastic modelling, is well understood and described in many statistical textbooks i.e. (Robert and Casella, 2004). However, even if a model was described to be complete, uncertainty would exist due to “parameter uncertainty” and “input uncertainty” (Rasouli and Timmermans, 2012; Walker et al., 2003) respectively referring to the values of the parameters which control the model algorithms and the accuracy and inherent variation in the observed inputs to the model. Therefore this subsection will focus on parameter and input uncertainty.

Data for transport models is traditionally taken from roadside observations (Ortuzar and Willumsen, 2011), and increasingly from automated sources such as mobile telephone data harvested from traveller’s handsets (Borzacchiello et al., 2013). When looking at data to evaluate the uncertainty it carries, the analyst must consider how it was collected and for what purpose. The NUSAP (Number, Unit, Spread, Assessment, Pedigree) framework is offered by the environmental modelling community (van der Sluijs et al., 2005) to quantify the “hard” characteristics of data , the <u>N</u>umeric value, the <u>U</u>nits, and its <u>S</u>pread, being the statistical distribution as well as the “soft” characteristics of <u>A</u>ssessment and <u>P</u>edigree where assessment refers to a qualitative judgement of the data such as its propensity to systematic errors or optimism (or pessimism) bias and pedigree refers to subjective judgement on the quality and scientific status of the data. In the NUSAP process, (van der Sluijs et al., 2005) the development of a pedigree matrix enables the analyst to systematically query the quality of the data with specific emphasis on its applicability to the modelling task and by implication query the modelling assumptions.

Parameter uncertainty is assessed through experiment with the models. Saltelli et al. (2008) define two aspects of parameter uncertainty. *Sensitivity Analysis* is the study of the relative importance of different input factors on the model outputs and *Uncertainty Analysis* focuses on quantifying the uncertainty in the model outputs. Combining the two will apportion the uncertainty in the model to the different parameters that control the model algorithms. Assessing parameter sensitivity requires multiple tests to be undertaken to examine the change in model outputs as parameters are systematically varied and hence to quantify the effect of the incremental change in parameter value on the outputs (Saltelli et al., 2008 ; Cacuci et al., 2005; Morris, 1991). The simple means of assessment of parameter sensitivity is to vary One At a Time (OAT) while holding the rest constant (Morris, 1991), however, when parameters interact and jointly affect outputs, a simple OAT technique is inadequate and more complex techniques are required to cover the multidimensional parameter space such as probability sampling (which simply selects combinations of parameter values at random), stratified sampling (which divides the parameter space into subareas and conducts probability sampling in each area), and Latin hypercube sampling (which divides the parameter space into a multidimensional grid and ensures at least one test is run in every row of each dimension) (Saltelli et al., 2008; Cacuci et al., 2005). Sobol (2001) provides methods to estimate the influence of individual parameters or groups of parameters on the model outputs and the MUCM project (Managing Uncertainty in Complex Models) (MUCM, 2011; O'Hagan, 2011a) provided tools to undertake the parameter space sampling and tools to facilitate running the sensitivity analysis experiments using Bayesian emulation to predict the results from a complex model without the run time costs normally incurred in running the model.

Model sensitivity analysis therefore can be undertaken in a strictly analytical manner and can assess which parameters the modeller must focus on to achieve model calibration and to generate a robust model, one which is not oversensitive to a parameter value. Analytical sensitivity analysis however makes the assumption that the model is complete and the algorithms capture the transport system behaviour. As noted in the literature, further uncertainty exists due to model incompleteness (Rasouli and Timmermans, 2012; Mattot et al., 2009; Rodier, 2007; Walker et al., 2003; Morgan and Henrion, 1990) which implies that detailed parameter and input sensitivity analysis will not resolve the questions of model uncertainty if the completeness of the algorithms and activity in the model is in doubt.

Model Incompleteness

Two reactions to the perceived short comings of the traditional four stage transport model are noted in the literature. The first reaction is to move towards more detailed models such as activity based models (Zheng et al., 2013) and microsimulation models (Barcelo, 2010). The second is to move towards less detailed and more highly aggregated systems dynamics models (Shepherd, 2014; Avineri, 2005; Sterman, 2000; Checkland, 1999). These two reactions will be discussed here in the following subsections.

Detailed Models

A conventional model uses aggregated numbers of trips, between land use areas or zones and has no recognisance of individual travellers. In order to increase the fidelity of transport models, agent based demand models of transport activity have been developed based on discrete modelling of the life choices and hence the transport desires and trips of individual travellers. (Zheng et al., 2013; Schwarz et al., 2010; Davidson, 2007; Miller and Salvini, 2002; Ettema and Timmermans, 1997) In doing so an agent based activity model is able to model the reason for the trip, the mode choice of the trip, (by private car, by public transport) as well as the availability of the transport mechanism, all of which control the individual's ability to travel to and from places where activity takes place, i.e. residence, work, leisure, shopping. As an activity model is based in the desire to travel rather than the observed trips, it also gives the ability to model the unsatisfied need to travel and hence include that trip if the means of travel becomes available. Activity based models, subject to the availability of data, are able to make more detailed predictions of how and why people chose to travel.

Similarly when modelling the supply side of the transport network, a microsimulation model will model individual vehicles as they move through a road network, each obeying detailed behavioural rules expressed as route choice, speed choice, lane choice, gap acceptance at junctions, and reaction to traffic signal and ITS control. There are many products available, Barcelo (2010) describes the major commercial and open source products and gives an authoritative overview of the algorithms to route a vehicle through the road network and model its interactions with other vehicles in its environment.

Rodier (2002) noted that use of an agent based model implies that the individual is the unit of analysis rather than the zone; the demand for transport is therefore not fixed but responds to supply and there is a more explicit representation of decision and choice activities. Similarly, in a microsimulation model (Barcelo, 2010) the unit of analysis is the individual vehicle and hence the model is able to represent the detailed dynamics of congestion through vehicle interaction and to include the control measures which correspond with current trends in road transport: for example, to reduce congestion through active management rather than to add more road space (Stevanovic et al., 2017).

These detailed models address the issues of over simplification of travellers and their desire to travel by modelling the transport intentions of each individual rather than the observed level of trips made within a population and hence intend to model the travel activity of that population with high accuracy. They are however data intensive and consequently expensive to build and maintain. The US Federal Highways Agency and other similar agencies provide guidance on selection of a model type appropriate to the transport planning study (DfT, 2016; Austroads, 2010; FHWA, 2004b)

Aggregated Models

The move to more aggregated models is illustrated by the use of system dynamics models which integrate transport models into the policy ecosystem looking at transport as a component of a wider social economic system. These models were reviewed in section 2.2.3. Shepherd's (2014) meta-study of 50 transport related system dynamics models draws the conclusion that they are most appropriate for investigation into the effects of holistic relationships between travel, technology and policy at an aggregated level and in developing an enhanced understanding of the system for planners and policy makers, rather than evaluating quantitative results.

Model Incompleteness Summary

Moving away from a conventional four step aggregated transport model into more detailed model types with agent based and microsimulation models, or into more aggregated models with systems dynamics is intended to address the problem of model incompleteness, by extending the model algorithms in one of two directions, into greater detail (i.e. activity based and microsimulation models), or into wider scope (i.e. systems dynamics models). However Sterman's (2002) reflections on models "*All Models are Wrong: Reflections on Becoming a Systems Scientist*" states that models are only a representation of reality and are often simplified. Sterman's narrative recognises the importance of uncovering hidden assumptions but then comments that many systems dynamics models contain only a subset of system interactions. Maparu and Mazumder (2017) similarly cast doubt on the direction of influence used in a systems dynamics model, specifically in the relationship between transport provision and economic benefit. Clearly there is a feedback loop and the two move together, but which leads and which lags is less clear, and is discovered to be dependent on the particular economy and transport system in question. This has implications for the causality based structure of a systems dynamics model.

Similarly, in a review of agent based activity models which was intended to provide authoritative guidance for modellers in the US, Zheng et al. (2013) state *"Predicting the behaviour of the overall system based on its constituent components is extremely difficult (sometimes impossible) because of the strong possibility of an emergent behaviour."* In effect a comment on the impossibility of attaining model completeness as traveller reactions change over time.

Similarly, both divergent types of model require relevant and accurate data. Sterman (2002) asks why data relevant to systems dynamics models were not measured; with the response that as the boundaries of such model are intrinsically wider, no-one thought it was important. In activity based models, Miller and Salvini (2002) comment on the completeness of data, this time not in the scope, but in the coverage of the data and also in the level of disaggregation required.

In essence, whether the move to more detailed agent base activity models or to all-encompassing systems dynamics models was made to resolve issues of modelling at an appropriate scale and to adequately simulate the problem under analysis, the same classes of uncertainty remain, merely with different types and sources of uncertainty within those classes. These developments in modelling cannot be regarded as a panacea to solve the problems of understanding uncertainty in transport planning.

2.3 Decision Process

This section discusses the methods of using the results of a transport project assessment in decision making both as a rational quantified analytical process and as a more qualitative process which introduces uncertainty into the decision processes. This section then reviews the frameworks for decision making under uncertainty.

2.3.1 Analytical Decision Making

In an analytical decision making process, the multiple criteria by which a decision will be made are quantified and that relative values can be assigned to each criterion. The utility function then used in Multi Criteria Decision Analysis (MCDA) is:

$$\mathrm{U} = \mathrm{a} * \mathrm{C}_1 + \mathrm{b} * \mathrm{C}_2 + \mathrm{c} * \mathrm{C}_3 + \cdots$$

Where $C_{1,2,3..}$ are evaluated measures for each identified criteria relevant to the decision and a,b,c,… are relative weighting constants. The rational decision is made in favour of the proposal that yields the maximum value of U, in effect balancing and valuing the multiple factors that influence the choice to be made (Belton and Stewart, 2002).

A simple application of the MCDA process makes the three assumptions: (1) that all relevant factors are known, (2) that all can be quantified, and (3) that a set of weights can be agreed which accurately reflect the relative values of those factors. Van Wee and Tvasszy (2014) writing in Priemus et al. (2014) challenge these assumptions in an evaluation of decision making on very large projects. They draw an analogy between a Cost Benefit Analysis (CBA) and an MCDA exercise, observing that both provide weights for known factors (such as a value for travel time savings, a value for air quality, the cost of construction) and the result is a quantified value for the project. Van Wee and Tvasszy (2014), then criticise the process identifying issues in all three sets of assumptions; the derivation of the quantified measures, the values of the weights attached to them and the uncertainty that the set of relevant measures is complete.

In order to address these issues, MCDA techniques have been extended to manage circumstances where quantifying the factors in a decision and determining the weights for them is uncertain. Huang et al. (2011) reviewed 300 projects in environmental sciences that used MCDA in some form classifying the MCDA methods used. The most relevant are discussed here in more detail:

- The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) (Brans et al., 1986) method is used to rank-order a finite set of alternatives. Each factor is given indifference and preference threshold and a weighting function. Pairwise comparisons are made and factor weights inferred though linear programming. Behzadian et al. (2010) provides a review of 197 applications of the method revealing a wide range of applications. Hyde et al. (2003) studied the performance of the method when there was uncertainty in the values of the factors and their thresholds showing that there is an improvement over conventional MCDA analysis under uncertainty in a range of probable scenarios.
- ELECTRE (ELimination Et Choix Traduisant la REalité also ELimination and Choice Expressing REality) is a family of methods used in MCDA based on rank ordering using

a set of true criteria or alternately using a set of “pseudo criteria” which have uncertain values. Fuzzy pair-wise comparisons are made between decision options and a reference choice where the comparison may imply a definite preference, indifference or non-comparability (i.e. no comparison). Figueria et al. (2010) describe the method, which is designed to operate when: criteria may be related; a loss on one may not necessarily be offset by a gain on another; and when a small difference may not be significant, but an accumulation of small differences could be. Govindan et al. (2016) reviewed 686 papers on the use of the method and identified that elicitation of the weighting values is key to the application of the ELECTRE family of methods (apart from ELECTRE IV, which does not require weights) and draws attention to a research gap in examining the robustness of decisions under variations in the weight parameters.

- ANP (Analytical Network Process) is an extension of the AHP (Analytical Hierarchy Process) (Saaty, 2000). The ANP process structures a problem as a hierarchy of influences and effects, elicits judgements based in stakeholder’s ideas and emotions and represents them numerically to structure the elements of the decision; hence finding the priorities in the decision through paired fuzzy comparisons. Saaty (2010; 2000) considers the strength of the ANP method to be in its ability to work with “soft” measures of comparison as well as “hard” measures where “soft” measures are based in thoughts and hard measures are tangible observations. Saaty summarises this thus: *“Hard measurement must be consistent with what is known in nature whereas soft measurement must be consistent with what is known in the mind”* Barfod and Salling (2015) provide an example of the AHP process in transport appraisal specifically on the Oresund link between Malmo and Copenhagen.

In summary, two issues remain outstanding in a MCDA style analysis: The first is the issue of completeness, that all factors are represented, commented on by Loosemore et al. (2006). The second is the derivation of weights, or in the PROMETHEE method, agreement on the pairwise ranking (Govindan and Jepsen, 2016). Both issues encapsulate the societal uncertainty as they depend on the knowledge of the different factors and their relative importance to the stakeholders in the project.

2.3.2 Decision Making under Societal Uncertainty

There is a theme in the literature that notes that transport planning is no longer compartmentalised and modular, it has become a complex politicised decision process with multiple views and stakeholders involved. Te Brömmelstroet and Bertolini (2008) discuss the interaction between planners and modellers finding that the tools used to support planning focus on the assessment of options more than the generation of options. The reactions to this observation are, from the planners that reliance on intuition and experience is adequate, and from the modellers that more sophisticated models are required. Khisty and Leleur (Khisty and Leleur, 1997a; Khisty and Leleur, 1997b) attempt to bridge this gap as they argue that the relationship between transport analyst and the decision makers is changing as decisions are made using "*soft*" qualitative information as well as the more established "*hard*" quantitative assessment.

Lami (2014) quantifies this introduction of the "softer" information through a discussion of the concept of "affordance" as a perceived utility as described by Norman (1999) in relation to the factors in an MCDA exercise. Affordance is an intangible quality based on the perception of its utility where that perception varies even though the material asset may remain constant. Affordance can be unique to each stakeholder in the decision process and that affordance may change as the stakeholder's understanding of a situation develops. Thus the concept of affordance has parallels with Saaty's (2000) comments on "*hard*" and "*soft*" measures and Lami's (2014) description of a decision, being one made with factors that are different for every stakeholder and varying over time. Affordance in effect describes the components of a "wicked" problem (Rittel and Webber, 1973) , one which evolves as efforts are made to understand it.

When assessing the case for a transport development, the future environment in which the development will exist must be considered. Gray and Begg (2001) in discussing transport options for Scotland, and Worsley and Mackie (2015) on transport policy and decision making in the UK both comment that the environment for transport policy development encompasses more than solely transport related considerations, making firm the thoughts of Lindblom (1979; 1959) on the complex interdependencies of planning, transport and economic policies. To assist in assessing developments in an uncertain future environment, Chatterjee and Gordon (2006) and the UK Department for Transport's Scenario Planning Toolkit (DfT, 2007) both provide a set of pre-prepared scenarios for transport planning describing possible futures. Both sets of scenarios include political and societal dimensions which are as strong as those based in transport technology.

Similarly Vigar (2017), Forster (1995) and Wachs (1985) all focus on the introduction of a political dimension to decision making with Vigar classifying the influences on decisions in four categories, three based in rational knowledge and experience and the fourth based in political criteria which are subject to "*its own rationality*", an assertion verified by Welde et al. (2013) which showed the results of a conventional Cost Benefit Analysis had a limited influence in the selection of a project for implementation implying that other criteria had been more influential in decision making.

2.3.3 Decision Making Summary

This section has reviewed decision making methods based first in a simple MCDA analysis where weight factors and quantities are known, moving on to more complex MCDA techniques which allow for numerical uncertainty in weights and values and enabling more robust decisions with uncertain data. Shortcomings are then identified in two areas: The first is in coping with the different and changing views of multiple stakeholders and the need for stakeholder engagement and consensus building. The second area is concerned with completeness of the decision process; were all factors known and included, and will there be events in the future which invalidate the assumptions and analysis made in the decision process. This class of uncertainty is addressed in the next section – Section 2.4.

2.4 Qualitative Methods of Managing Uncertainty

Qualitative methods complement the rational analysis paradigm of transport modelling. They are based in systems analysis, expert knowledge and consultation, and in future visioning employing different scenario planning techniques. A qualitative system hence allows analysis where there is a higher level of uncertainty; in the model, in the data, and in predictions of the future conditions where transport developments will ultimately function.

The literature reviewed to this point has focussed on modelling and rational decision processes, but in each context, when addressing the issues of uncertainty, then uncertainty has been classified as either a quantifiable entity, such as stochastic variance, parameter sensitivity, or choice of MCDA coefficients, or as a non-quantifiable entity such as the completeness of the analysis or imperfect knowledge of the future. Qualitative methods of managing uncertainty are intended to address the latter class of non-quantifiable uncertainty.

2.4.1 Scenario Planning

Scenario planning is identified in strategic management literature as a technique to describe an uncertain future and hence to alert managers and planners to the range of possible futures such that the plans they devise in policy, in business strategy, or in physical developments, are robust under different, yet feasible futures. This enables evaluation of options to establish which are more likely to be profitable in a commercial setting, or socially beneficial in a public administration setting under a plausible range of potential future scenarios. There is an extensive body of literature and text books describing scenario planning in practice and the techniques used to develop and use scenarios (Chakraborty, 2011; Giaoutzi et al., 2011; Godet et al., 2009; Lindgren and Bandhold, 2009; Marchais-Roubelat and Roubelat, 2008; Wright et al., 2008; Harries, 2003; Peterson et al., 2003; Chermack et al., 2001; Godet, 2000; van der Heijden, 1996; Porter, 1980).

Scenario planning however takes a number of forms, and Nijkamp et al. (1998) observed that the word “scenario” is an overloaded term that encompasses a range of planning methodologies. Nijkamp et al. (1998) identified three classes of how the word scenario, and hence scenario planning, may be defined in a transport assessment context. These are:

1. A single technological or physical approach, i.e. a new technology implementation or road layout.
2. A compound transport / land use package, a multifaceted integrated plan.
3. A behavioural framing approach where background issues concerning transport behaviour i.e. spatial, economic, sociological factors, are mapped out to describe the future and used to identify compatible plans and policies.

Borjeson et al. (2006) propose a similar categorisation to that described by Nijkamp. They first discussed scenarios in a philosophical, epistemic, and technical paradigms before settling on a functional classification of predictive, explorative and normative scenarios described as “*what will happen”, “what can happen”* and “*how can a specific target be reached”*. Similarly, Courtney (2008; 2001) discusses four levels of uncertainty associated with different scenarios. The first category occurs when the future is well understood, with a single view of events, and the second, when there are a small number of mutually exclusive and collectively exhaustive alternate futures. In Courtney's third category, the range of values of each element is such that point forecasts cannot be reliably made and the fourth is when uncertainty is highest and the structural elements of the system are not known. Walker et al. (2003) in discussing uncertainty in transport planning describe a transition of level of knowledge from determinism to ignorance to include "*statistical uncertainty*" where numeric values are changed and "*scenario uncertainty*" where context changes.

Many transport modelling projects fall into Nijkamp et al.'s (1998) category 1 or 2. At level 1 the term "scenario" describes the system as a set of selected options, i.e. known changes to the transport network, the demand on the network or the control systems operating it. The uncertainty corresponds to Courtney's (2001) level 2; there are a limited set of possible outcomes and to Walker et al.'s (2003) statistical uncertainty when changing numeric values and scenario uncertainty when creating the context for the development.

At Nijkamp et al.'s (1998) level 2, where the proposed development integrates with a more complex environment a scenario is more than a simple option test as there is greater complexity and it is no longer possible to test all plausible eventualities. Bartholomew and Ewing (2010) refer to transport scenario planning as a process linked to land use planning with the term scenario used to describe a particular combination of land use and transport options selected by the planner; the planner's role is then to select plausible combinations from the multitude of possibilities. DfT WebTAG Unit 3.15.5 (DfT, 2010) which outlines how to deal with uncertainty in transport planning similarly refers to scenarios as a range of development options clustered into a small set of combinations. This process advice combines two levels of scenario uncertainty, the most complex being the clustering of development options into a set of contextual scenarios the least complex being the use of a prescribed range of forecast growth levels within each of the contextual scenarios. Both equate to category 2 in Nijkamp's list but in Courtney's categorisation, this has moved from level 2 uncertainty, where inputs are known and the physical aspect of the scenarios can be completely described, to level 3, where the number of options is large.

Scenarios in Nijkamp et al.'s (1998) category 3 in the context of strategic management have been defined in several ways and form a technique collectively known as "Scenario Planning". In this context, Porter (1980) defines a scenario as "*discrete internally consistent views of how the world will look in future which can be selected to bound the probable range* *of outcomes that might feasibly occur*" Van der Heiden (1996)defines scenarios as "*a set of reasonably plausible but structurally different futures*" Similarly Lindgren and Bandold (2009) observe that a scenario "*is a well worked answer to the to the question 'What can conceivably happen*?". The level of uncertainty here corresponds to Courtney's (2001) category 4 where there is much greater uncertainty about the exogenous inputs to the system, the proposed life of the development is long and it is not possible to predict a range of futures, merely to devise some sample speculative narratives of what the future may be. Table 1 shows the approximate overlap in scenario uncertainty described by these authors.

<table>
<tr><td>Walker et al. (2003)</td><td colspan="5">Statistical Uncertainty</td><td colspan="2">Scenario Uncertainty</td><td colspan="3">Recognised Ignorance</td><td>Total Ignorance</td></tr>
<tr><td>Nijkamp et al. (1998)</td><td colspan="3"></td><td colspan="2">1</td><td colspan="2">2</td><td>3</td><td colspan="3"></td></tr>
<tr><td>Borjeson et al. (2006)</td><td colspan="2"></td><td colspan="3">What will happen</td><td colspan="2">What can happen</td><td colspan="3">How to reach a target</td><td></td></tr>
<tr><td>Courtney (2001)</td><td>Sole view</td><td colspan="3">Multiple known views</td><td colspan="2">Unreliable forecasts</td><td colspan="5">Unknown taxonomy of futures</td></tr>
<tr><td>Van Der Heijden (1996)</td><td colspan="5"></td><td colspan="2">Descriptive Scenarios</td><td colspan="4"></td></tr>
<tr><td>Lindgren & Bandold (2009)</td><td colspan="5"></td><td colspan="3">Descriptive Scenarios</td><td colspan="3"></td></tr>
<tr><td>DfT</td><td colspan="5">Quantified demand ranges</td><td>Option selection</td><td colspan="5"></td></tr>
</table>

Table 1 Scenario Types Overlap

The next section includes a discussion of the most appropriate class of scenario used to address different levels of uncertainty.

Scenario Types

Predictive scenarios are forecasts or answers to "what if" questions in response to planned events, similar in scope to Nijkampf et al.'s (1998) level 1. The difference is made between "forecast" scenarios where inputs fall in a continuous range and "what if" scenarios where an event will cause the future to go down one path or another, i.e. if a particular development proceeds or not. The scenarios described by WebTAG (DfT, 2016) in simple option testing and in the DfT treatment of uncertainty (DfT, 2010) fall into this category where the transport analyst is required to form a set of self-consistent development options then test them with a transport model under a small set of prescribed demand growth predictions, in essence the options to be tested are both prescribed and well understood.

Explorative scenarios are distinguished from predictive scenarios by changing the question from "*what will happen*" to "*what can happen*". These are similar to Nijkampf et al.'s (1998) Level 2 scenarios. Borjeson et al. (2006) then expand this category to describe scenarios as "external", focussing on exogenous variables outside the control of the scenario actors and "strategic" where the actions of the scenario actors do influence the scenario development.

External scenarios separate the future environment from the strategic options and assume the actors have little control over the wider environment, the environment and the options are assumed to be independent of each other. One school of thought in scenario planning (Lindgren and Bandhold, 2009; van der Heijden, 1996; Porter, 1980) makes a clear distinction between the scenarios in which external forces are dominant and the company strategies which are derived internally, independent of the scenarios. In this mode of scenario planning, the scenario environment is deemed to be largely out-with the control of the company and the scenarios are the multiple futures in which strategies are tested. Godet (2000) reinforces this with the observation that *"There is an important distinction to be made between scenarios of the general environmental and scenarios of actors' strategies."* and draws a clear difference between the two. However, Godet's "La Prospective" (Godet et al., 2009) develops a proactive approach, or *"foresight with more proactivity"* and does not necessarily separate the foreseeable future from the actions of the company. La Prospective does not distinguish between possible scenarios, desirable scenarios and realisable scenarios and therefore embraces the idea that the actions of the company can positively influence its own future environment. Godet (2009) has also classified scenarios as situational, i.e. those which describe future situations and developmental, i.e. those which describe a sequence of events which lead to, and may achieve, a future situation which once again implies that while scenarios and strategies are distinct, they may be interwoven. This is counter to the more externally oriented scenarios as described by van der Heijden and others (Lindgren and Bandhold, 2009; van der Heijden, 1996; Porter, 1980).

Borjeson's (2006) third category of "Normative" scenarios initially break from Nikampf et al.'s (1998) level 3 classification by focussing more on the goal, i.e. how to achieve a particular outcome, than on scope i.e. the range of behaviours included in the scenario, as described by Nijkampf et al. (1998). However as Borjeson's (2006) narrative unfolds, the factors to be included in an example of the scenario process extend to the same background issues of society, environment and economics as described by Nijkampf et al. (1998), effectively bringing the two classifications back together. Borejson (2006) brings more process to these Level 3, or "Normative" scenarios by subdividing them into "Preserving" scenarios where the current situation is adjusted and "Transforming" scenarios where the prevailing environment is blocking the intended change. In transforming scenarios, the concept of ***backcasting*** is now introduced to supply a number of target fulfilling images of the future with a discussion of the changes required to achieve those targets.

Backcasting

Dreborg (1996) and Robinson (2003) describe backcasting as a scenario study which goes beyond what is possible when forecasting from the present. Backcasting studies employ explicitly normative scenarios and are more concerned with the route (or routes) to reach a stated goal than with forming a range of goals. Backcasting is not designed to facilitate discussion on a range of futures, but instead to examine the relative effect of the component policies and sub goals that form the normative scenario that describes a desired outcome.

Giaoutzi et al. (2011) refer to two classes of scenario process. The first, "forecasting", starts from the present and moves to a number of plausible futures based on a set of key contextual and policy elements elicited from expert analysis. The complementary process, "backcasting", describes an ideal future and from that, identifies the policies that must be implemented to reach it and the context in which they must have existed. In a mixed mode scenario analysis, identifying the policy and context elements through backcasting followed by a forecasting exercise that varies them, yields a set of future scenarios. These will often be different from the target originally described. Marchau and van der Heijden (2003) describe the same process as rendering an image of a desired future and identifying the path to it. If the path cannot be found, then the image cannot exist and therefore must be adjusted.

Courtney (2001) describes a similar backcasting method for managing what he describes as level 4 uncertainty; when it is not possible to identify a plausible range of futures by projecting forwards from the present. The method is to move backwards from a hypothetical end case to ascertain what the analyst in the present believes will need to happen to allow the end case in the future to be achieved. Khisty (2000) refers to this as abductive inference. Abduction is a process of forming a hypothesis which includes new ideas and building a case in which that hypothesis may be true. Khisty (2000) applies it to a situation where a planner begins with a claim about the future and works backwards to find the information and assumptions to support the claim. The process of abductive reasoning, while providing a weak argument for causality, provides a strong method for reducing the number of elements contributing to the outcome of the planned development. It also promotes consistency in the chain of reasoning that describes the events leading to the putative end state.

A similar method is described in the applications of the DfT pre-prepared scenarios (DfT, 2007), in this case referred to as "reverse engineering" in which workshop participants are invited to:

- identify five events that have to occur if a particular scenario is to happen,
- discuss the impact and probability of each event, and,
- describe how to identify the events as they happen.

Subsequently the workshop participants also seek to predict the reaction of stakeholders to those events and any corresponding consequential actions. Svenfelt et al. (2010) used a similar method to discuss the means of realising future scenarios which were developed independently. Two contrasting scenarios were used and two sets of actions discussed, each one enhancing the discussion of the other. Svenfelt et al. (2010) introduce the added dimensions of different groups of stakeholders taking different views of the scenarios and that these groups also require different motivations to take the actions necessary to achieve the goals described in the scenario.

Scenario planning in use

Scenario generation projects, for example (van den Brink, 2009; Strachan et al., 2008; DfT, 2007; Chatterjee and Gordon, 2006), provide "pre-packaged" scenarios of the future in selected fields. These are often designed to simulate thinking in policy maker and business managers without the time or cost of deriving a set of scenarios specific to that policy or business area. However, scenario planners (Lindgren and Bandhold, 2009; van der Heijden, 1996; Porter, 1980) argue that the value in scenario planning is in the learning process of developing the scenarios and their value is greatly enriched if the knowledge embedded in the scenarios is owned by the analysts who derived and use them. Pre-packaged scenarios are useful to provoke discussion or to provide a loose framework for option analysis. The DfT scenario toolkit in particular (DfT, 2007) emphasises that the scenarios it presents are not an end in themselves, instead they are intended to act as a framework to stimulate creative activity in workshop participants (DfT, 2007), These scenarios were subsequently used in the VIBAT project (Visioning and Backcasting for Transport for London) (Hickman et al., 2009) to evaluate the robustness of a package of carbon reduction policies under different future scenarios and hence refine the choice of options in the policy package.

The analysis component of the scenario process is less well defined in the literature dedicated to corporate management scenario planning. Van der Heijden (1996) refers to a "Strategic Conversation" based on scenarios as a common understanding of the future and relies on management intuition and judgment to both generate and evaluate possible strategies. An equal amount of effort is expended in understanding the dynamics of the company through organisational learning as in evaluating the future scenarios.

Lindgren and Bandold (2009) refer to developing strategies as a company vision, akin to the ubiquitous mission statement, but with caveats that it must be realisable. Causal loop analysis is suggested but with the proviso that models are simple and quantification is only recommended, not mandated. The greater strength in the modelling process is assumed to be in the process of generating the model and understanding of the reaction of the system and its sensitivities rather than in any numeric results which is in concord with the principles of mediated modelling discussed in section 2.4.2. Courtney (2001) proposes "management flight simulators" as suitable tools to analyse stakeholder actions. In fact, these also focus on the learning process as stakeholders participate in a game based in the subject of the analysis. The game is repeated many times with different input conditions and the effect of different reactions from the players to the game conditions and to the actions of the other stakeholders develops an understanding of the potential outcomes. Courtney (2001) observes that in strategic business management, the learning process from the game playing is often as valuable as the results derived from the game. This view is reinforced by Patching (1990) who describes the purpose of systems methods in terms of understanding, analysing, and learning about the system.

Similarly, the goal for the policy maker using backcast scenario planning techniques is to identify the critical endogenous policy factors that will be most likely to achieve the stated goal under different exogenous circumstances. The value in the scenario analysis is in the elicitation of the changing policies and conditions that will lead to that goal.

2.4.2 Consultation and Elicitation

Consultation and elicitation techniques are used in situations when modelling is felt to be inadequate as the system being analysed is known in an empirical sense but not known in an analytical sense. It is based on the premise that the combined knowledge of experts may be used in predicting future conditions where modelling fails. Cooke's classical method (Cooke, 1991). and O'Hagan's SHELF (SHeffield Elicitation Framework) process (O'Hagan, 2011b) mathematically combine quantitative values elicited from experts with the goal of finding an average value for a measure with a confidence value placed on it which together reflect the magnitude and range of the elicited values. Similarly, Delphi processes, mediated modelling and multi stakeholder deliberation about a scenario elicit qualitative information from multiple stakeholders and experts with the dual goals of communal learning about the system being analysed and consensus building about how it operates. Scolobig and Lilliestam (2016) review stakeholder engagement methodologies in environmental decision making and comment on the difficulties in representing the heterogeneity of stakeholders' perspectives, dealing with their value based issues, and ensuring all views are represented, rather than those of the dominant stakeholders. Scolobig and Lilliestam (2016) find that when the problem is contested, a plural rationality approach is recommended, to identify an acceptable solution through facilitated discussion. This section is therefore focussed on plural rational approaches to stakeholder elicitation with an emphasis on managing and quantifying the differences in stakeholder's views.

Expert Elicitation

Expert elicitation is a technique to formulate an opinion on a subject with significant levels of uncertainty or where data is unobtainable. It is a consensus building tool which also quantifies uncertainty by parameterising the best guesses of experts in the field or in related areas (Cooke, 2013 ; O'Hagan, 2011b; Cooke, 1991). Cooke (1991) quotes the simple example of a number of sports journalists (16) whose individual predictions on an essentially random event, the weekend football games, were unreliable but where the consensus opinion was consistently more accurate. Booker and McNamara (2004) give an overview of a very similar process in which experts iterate to a consensus value through both a process of visual display of the range of inputs, the responses to those inputs, and through elicitation of the reasons for that range. In subsequent discussions of the ranges of elicited variables, the elicitation team must probe the experts for their reasons for the choice of ranges and share those reasons with other experts to refine the estimation of likely values.

Experts are not perfect in their judgements and are held to be susceptible to bias due to using simple heuristics of representativeness, availability, misinterpretation, optimism, self-promotion and anchoring (Tversky and Kahneman, 1974). Methods of expert elicitation therefore strive to remove these by calibrating expert opinions based on their responses on a related topic, which can be readily verified, and by merging the judgements of a number of experts to a rational consensus based on their calibration ranking (the accuracy of their answers to the calibration question) and their information ranking (the entropy in their answers). Booker and McNamara (2004) use a qualitative graphical technique oriented towards interacting with the experts to refine the estimates while Cooke (2013) describes three statistical techniques; a “classical” model of weighted combinations, a Bayesian model which modifies a prior estimate, and a psychological scaling model based in comparative measures.

Forty-five examples of expert elicitation are quoted in the TU Delft Expert Elicitation data base (Gossens and Cooke, 2008) taken from technology areas such as nuclear power, aerospace and the chemical industry, the health care profession and environmental assessment including volcanology. Other more recent examples of expert elicitation are found in Usher and Strachan (2013) who elicited the values of six national drivers of energy demand in the UK, in Bamber and Aspinall (2013) predicting the future sea level rise due to ice sheet melt and in Scourse et al. (2015) estimating appropriate weighting factors to use in risk assessment of tectonic issues in nuclear waste repositories. In each of these cases, weighted estimates of the range of values of several measures were elicited from experts and formally combined to provide a central value and plausible range. Examples from Scourse et al. (2015) and Usher and Strachan (2013) are of further interest in the research presented here as Scourse et al. (2015) also used the exercise to elicit gaps in scientific knowledge relevant to the long term predictions and Usher and Strachan (2013) elicited the reasons for the expert’s estimates along with the factors, and causalities affecting those estimates. However neither author made any attempt to merge opinions on those gaps and reasons; the focus of their research remained on the numerical analysis. This is one of the key research gaps to be addressed in the research presented here.

Multi-stakeholder Deliberation

Multi-stakeholder deliberation described by Tyler (2009) is a technique to engage the public as well as the policymakers in a reasoned public debate over an issue to achieve a robust consensus. While open public policy deliberations were practiced in the forums of Athens and Rome, Tyler (2009) comments that modern policy making is more bureaucratic, more technologically complex and more professionalised and political leaving many stakeholders with little influence in the policy making process. Multi-stakeholder deliberation is intended to resolve those problems by creating a participatory process designed to motivate those individuals and organisations with an interest in the policy outcome to take part in planning and developing policies. Tyler (2009) makes a clear distinction between unstructured debates; such as broad informal discussions, media based talking shops, or presentations by experts; and a structured transparent approach with comprehensive representation, expert facilitation, guided by explicit procedures and in a setting that respects and values plurality of opinion and interests.

Daniels and Walker (1996) refer to multi-stakeholder deliberation as a process of collaborative learning in which a structured open debate is held with participants from the community. The process may start with an exchange of best case and worst case predictions to set boundaries and with a set of educational sessions to present the science or sociology of each of the stakeholder group's interests. The goal is to develop a mutually acceptable solution involving stakeholders throughout the whole process rather than derive a set of solutions and merely ask the stakeholders to select from a list.

Collaborative learning in a complex policy development programme encourages a systems approach supported with rational planning analysis where appropriate. The systems approach allows for disagreement between stakeholders in perception of the issues while accommodating a single best solution, a situation described by Lindblom (1959) where he observes that individuals with different ideologies can agree on a policy, despite not agreeing on the values against which they make their judgements.

Delphi Method

The Delphi method (Linstone and Turoff, 2002; Turoff, 2002) is a means of structuring a group communication such that a group decision is reached encompassing a wide range of opinions. It was developed by the RAND Corporation in the 1950s to obtain the most reliable consensus of opinion of a group of experts and takes its name from the home of the Greek Oracle at Delphi. The four stages are: exploration of the subject under discussion to find the boundaries of the problem; reaching a common understanding of the problem; identifying disagreements and evaluating them; and reporting the integrated considered group opinion.

Linstone (2002) describes the basic Delphi process. In each round, an expert facilitator gives a set of questions to a group of experts and stakeholders and summarises their responses. The next round includes that summary and members of the group may opt to vary their answers or query the reasoning from others. It is expected that the process will converge on a consensus response after a small number of rounds. One aspect of the Delphi process is the anonymity it gives to the participants to reduce the likelihood of dominant participants in the exercise over riding the views of less confident participants or the less confident participants merely following the views of the more senior contributors. Within the Delphi process it is important to follow minority opinions and dissension to a logical conclusion both to ensure that all aspects of the decision are included and to keep all experts engaged.

Turoff (2002) extends the Delphi process to include a “Policy Delphi” intended to assist policy makers by having an informed group present a list of options and opinions with potentially strong opposing views. Unlike a conventional Delphi, the goal is not to arrive at a consensus decision but instead to list the available options with a sub goal of uncovering underlying assumptions and external information used by the experts. Each feature in the discussion is rated against agreed quantities such as (a) desirability, whether it is preferable or not that this happen, (b) feasibility, whether it is possible or not, (c) importance, its perceived influence on the situation, and (d) on the expert’s confidence in the assessment.

The key difference between the conventional Delphi process and a scenario planning exercise is in the output. The former reaches a decision based on a consensus opinion over a single outcome whereas a scenario planning exercise requires no consensus, embraces multiple outcomes and provides a framework for options to be evaluated. The Policy Delphi fits between these two. It does not necessarily reach a single view of the future but it does provide a framework for a more informed decision making process.

In a study of potential strategies in Transport Telematics, Hojer (1998) merged scenario backcasting techniques with a Delphi process to elicit expert opinion concerning the feasibility of three scenarios in ITS technology. The derivation of the scenarios provided images of the future, the Delphi process was used to describe the path from the present to each potential future and in doing so, refined the visions of the future, the policies implemented to arrive at these futures, and encouraged the search for alternate policy paths towards a beneficial future.

Mediated Modelling

Mediated modelling takes the techniques of systems dynamics models, the principles of elicitation and multi stakeholder deliberation and combines them. In essence the method uses the structure of a systems dynamics model as a tool to create understanding of a complex non-linear system and to learn from that exercise how the subject of study is structured and hence how to scope the subsequent investigation. The mediated model is intended to assist in devising the solution to the problem being studied, not to evaluate a specific solution (Jorgenson and Fath, 2011; van den Belt, 2004). There are several examples of use of mediated modelling in environmental sciences and in policy formation Van den Belt(2012) describes mediated modelling in environmental consensus building, Guimarães Pereira et al. (2009) focus on river basin governance, Forgie and Richardson (2008) use mediated modelling stakeholder engagement in diverse and conflicting policy development while Thompson et al. (2015) use the medium of a collaboratively developed systems dynamics model to examine the greenhouse gas emissions and combines scientific and stakeholder knowledge.

Ruth (2015) criticises mediated modelling as expensive to run, requiring expert facilitation on workshops with significant stakeholder engagement and a perception from the rational analysis community that it is a “soft” method with weak recommendations – a criticism that can be aimed at most qualitative modelling and elicitation methods. Ruth (2015) however also observes that a successful exercise can be effective in uniting disparate groups about a solution to a complex issue.

2.4.3 Complexity Theory

Weaver (1948) is widely referenced as the source of work in complexity theory by introducing the concept of “*organised complexity*” to problem definition. “*Organised complexity*” is described as a level in between “*organised simplicity*”, those problems which can be completely analysed and “*disorganised complexity*”, those which defy stochastic analysis, and exhibit unpredictable behaviour. Weaver queried the boundaries of science by challenging analysts to extend the scale of problems that could be analysed rationally (Weaver was writing in 1947-8 as early computers were being developed) but also predicted a branch of science oriented to analysing complex systems that would not rely on a complete rational understanding of the system, nor would it rely on stochastic analysis of an aggregate model of the system but instead would find an intermediate mechanism to analyse a complex system.

A complex system has multiple definitions; a summary of definitions of by Holland (2014), by Colander and Kupers (2014) and by Cairney (2012) yields the following list.

A complex system is one which -:

- Is self organising in that entities in a complex system will react individually and the system behaviour will emerge from these individual actions.
- Is adaptive in that entities in the system modify their behaviour as the system evolves.
- Crosses functional disciplinary boundaries.
- Exhibits chaotic behaviour in that small changes in the system operation or in its initial conditions may have large effects on its behaviour and hence make the system unpredictable due to the difficulty is specifying it in adequate detail.
- Exhibits both top-down and bottom-up behaviour simultaneously.

It is worth noting that Holland (2014) expressly draws a distinction between *complex* systems and *complicated* systems. The latter may have superficial attributes of complexity but ultimately can be completely analysed; a system with a large number of component parts and with intricate interactions between them may be described as complicated, but if it is bounded and its actions predictable, it does not qualify as a complex system using the description provided above. This parallels Weaver's (1948) description of how expanding the boundaries of what can be analysed rationally (complicated systems) cannot be extrapolated to include all systems (complex systems). In many respects "complex systems" exhibit the same attributes as "wicked" problems as described by Rittel and Webber (1973); intractability due to non-linear and non-repeating behaviour, imperfect boundaries, and changing behaviour over time.

Manson et al. (2012) discuss the application in geographical modelling of agent based models in complex systems and the emergent behaviour they exhibit through modelling the actions of many individuals as they make their individual decisions about how they behave in their own environment. McAdams (2008) too, frames complexity theory in urban planning in terms of agent based analysis but also includes visionary super-agents as disruptors in the system - i.e. technology, influential individuals, unforeseen events - and argues that as long term deterministic planning is uncertain other approaches based on models which embrace complexity are required.

Flood and Carson (1993) discuss complexity in terms of systems theory, made concrete in systems dynamics models to analyse the system (see section 2.2.3) and in mediated modelling (see the subsection above on mediated modelling). The emphasis in Flood and Carson (1993) is on analysis of the connectivity of interacting elements identified in the system and the boundaries of the system. Cairney (2012) reinforces this view on understanding connectivity as a precursor to understanding complexity *" as a network of elements that interact and combine to produce systemic behaviour that cannot be broken down merely into the actions of its constituent parts".* Cairney (2012) regards complexity theory as having value in understanding political choices on intractable policy problems where rational analysis fails observing that policy may be influenced by many forces, but with many variables and the uncertain influences of these variables on policies, analysis is intractable. Cairney is critical of authors who offer some advice on understanding complex systems, but only in general terms such as *"map the landscape" "identify the protagonists" "model the struggle"* but with no prescriptions how to do this. Cairney instead recommends instead: *"In depth qualitative studies of practitioners combining significant periods of observation with multiple interviews may be usefully combined with mathematical modelling … examining patterns which emerge from interactions of people and institutions"* but observes that these techniques have yet to emerge.

In summary, complexity theory has evolved from systems science and two approaches are proposed to understand complex systems, one founded in systems dynamics concepts to describe the system explicitly though the connectivity and interactions of its key components, the other using agent based activity models to simulate the emergent behaviour of its individual actors. In this respect of understanding complex systems by analysis, the issues have been covered at the end of section 2.2.4 in the discussion referring to the bi-lateral developments in transport models which move one way into more aggregated systems dynamic models, which are intended to include cross discipline policy action in the evaluation, and move the other way into more disaggregated agent based models which are intended to uncover the emergent behaviour of individuals. The key point to take from a review of literature on complexity theory is that it is primarily a study of connectivity either between systems components at a macro level embodied in a systems dynamics model or between individual actors at a microscopic level in an agent based model and that Cairney (2012) identifies a research gap in quantifying those connections and interactions.

2.4.4 Structural Dynamics Models

A structural dynamics model moves modelling to a higher level of abstraction above conventional transport models and systems dynamics models. The model was initially developed by Gordon in 1968 (Gordon, 1968) using a cross impact matrix of influences. The initial motivation to develop the method was in observing that in a Delphi exercise, there was no assurance that all influences had been accounted for. The method Gordon (1968) developed explicitly required that all influences were considered by systematically working through a matrix of the variables in the system and stating if *X enhanced Y*, *inhibited Y,* or was *unrelated* to *Y.* This model assumes that a bounded list of variables can be identified and that a probability can be found where if *X* occurs, then *Y* will occur with a probability of P_{xy}. The matrix is then "played" through multiple iterations in a Monte Carlo simulation to determine likely outcomes.

Vester (2012) and Godet (2011) developed the methodology further to use the cross impact matrix with a goal to understand the system more than to understand the outcome. Both authors defined a structural dynamics model as one which uses a cross impact matrix to construct a network of causalities (where X influences Y) and, by studying those causalities, to identify the key elements that control the system's evolution. The methodology was designed to stimulate discussion within an analysis team and guide the investigation into the most relevant areas. The task of providing a definitive analysis of the system was deferred to more detailed models.

Godet (2011) developed the structural dynamics model further still, by using indirect links as well as direct linkages such that if X influences Y and Y influences Z then X has indirect influence on Z and a higher influence rating than it would have had if Y had no influence on Z. Godet's software allows for a depth of 9 in the influence tree, though the documentation suggests 4 -5 is a reasonable maximum depth.

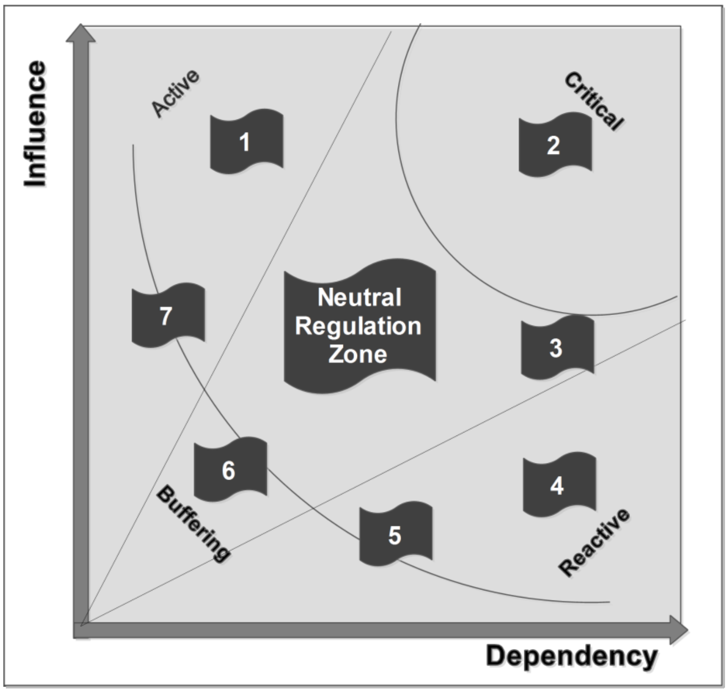


Figure 2-3 Influence Dependence Space (After Vester (2012))

The Cross Impact Matrix Method offers a means of structural analysis based on a sparse matrix of dependency between the variables identified in the scenario analysis. The result is a two dimensional graph of influence and dependency where Godet (2011) describes the variables that fall into the upper right quadrant being both highly influential and highly dependent and are the likely cause of instability in the system. Vester (2012) further categorises variables by their position in this space as shown in Figure 2-3 where variables in zone 1 are the most influential and crucial to initiating the system, those in zone 2 are highly influential and also highly dependent and therefore these are held to be the critical variables and the drivers of uncertainty in the system. Zones 3 and 4 contain the indicators of system outputs while zones 5 and 7 contain the sluggish indicators, and the weak control levers respectively. Zone 6 holds those variables which are least important. Finally, the neutral zone in the middle contains the control variables which regulate the system.

Godet (2011) then looks at the distribution of the variables in the system and infers the stability of the decision system from that shape as illustrated in Figure 2-4.

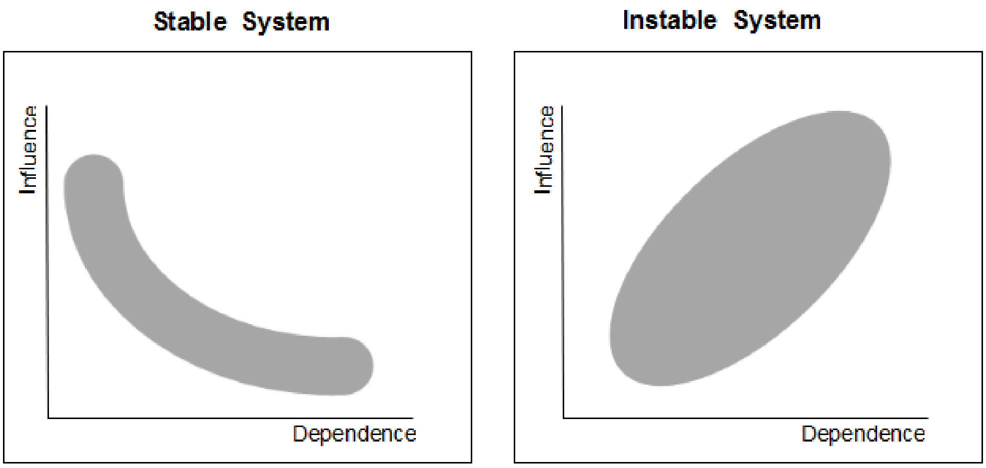


Figure 2-4 System Stability (After Godet (2011))

Variables in the shaded area in the left side configuration in Figure 2-4 are either active (high influence/low dependency), reactive (low influence/high dependency) or buffer variables (low ranking on both scores). A graph with the lower quadrant “banana” shape such as this indicates a stable system. In the right side configuration in Figure 2-4, variables are active (high influence/ high dependency), buffer variables (low ranking on both scores) or controls (mid-range in both scores. The presence of variables in the upper quadrant indicates a less stable system.

Neither Vester (2012) nor Godet (2011) quantify the overall system – the discussion is limited to identifying the role in the system of the variables with the expectation that once these roles are identified, actions will be taken to leverage, emphasise, or reduce these roles to modify the system to the advantage of the system designers or those who have to operate within it.

Structural Dynamics Models: Examples

Gordon’s (1968) two examples are based on predicting the use of nuclear weapons (the paper was published during the cold war) and on the evolution and demand for a wide range of emerging and predicted transport technologies. Their paper discusses the subjective nature of the assignment of probabilities and the application of probability distribution functions. The approach recognises that a more comprehensive and systematic method should be used to develop the initial list of variables and that differing views must be accounted for in developing the matrix which emerges. What this paper does state, as the root of the methodology is that "*in the two cases examined, this analysis has led to some insight about the future which was not available by inspection of the items alone*". The point made by Gordon (1968) concerning the inclusion and analysis of differing views has formed a key part of the method developed in the research reported here.

Other applications of Vester’s (2012) and Godet’s (2011) approach are found in Cole (2006), in Amaya-Moreno et al. (2014), in Castellanos-Nieves et al. (2011) and a similar technique is found in Muric et al. (2013). Cole (2006) used an impact matrix to analyse the issues in developing policy for a water catchment area in New Zealand by developing and interpreting a cross impact matrix in collaboration with local stakeholders. This was used as a precursor to systems modelling to focus attention and limited resources on the most critical areas. Cole’s conclusion was that with further development in classification of variables; refining the strength of impact; and in visualising outputs; the method would yield valuable results.

Amaya Moreno et al. (2014) used the method to understand the interaction between genes and their role in the system where the precise interactions are unknown and there is insufficient data to find a unique solution to the linear dynamic model that describes the system. Vester's (2012) method was used here to *"...identify prominent outliers, that is, the most active, reactive, buffering and critical genes in the network*". The results of the analysis are then used to focus future research into the most active, rather than the most passive genes. Amaya Moreno et al. (2014) also observe that by using this method, additional information was derived that would not have been found using correlation analysis and the impact matrix analysis did more than simply classify active and passive variables. Muric et al. (2013) used a similar method of evaluating connectivity to assess criticality in IT networking hardware.

Castellanos- Nieves et al. (2011) used Godet’s (2011) structural analysis methods to guide their recommended actions in response to a scenario analysis exercise. While this paper is weak in that it simply describes the benefits of using text values rather than numeric in a user interface to Godet’s (2011) analysis in an attempt to differentiate the strength of relationships, it points towards commercial developments in pre-conditioning analysis in large dataset data mining exercises (Pentaho, 2011).

One weakness in the documented examples of the use of the Cross Impact Matrix Method is the reliance on focus groups and single workshops to generate both the lists of variables and the impact between them. Amaya Moreno et al. (2014) were dealing with a scientific issue and were able to operate in a rational environment. However, when dealing with “wicked” problems of policy and infrastructure development with multiple stakeholders, quantified measures are unavailable and qualitative assessments are required. Gordon (Gordon, 1968) mentions the use of Delphi techniques, but only that this would be desirable, not that it was undertaken. Cole (2006), uses participative workshops but makes no comment on the effect of the group dynamics of the workshop and Godet (2011) too assumes an expert driven listing of variables along with stakeholder workshops to provide the source of the cross impact matrix. The existing uses of the cross impact matrix techniques in a structural dynamics model assumes a single set of dependencies and make no attempt to include multiple sets of dependencies from different stakeholders contrary to Gordon's (1968) advice.

2.5 Methodological Frameworks

Methodological frameworks to assess transport projects seek to provide decision support to quantify the benefits of a proposed development. Uncertainty, if it is incorporated in those methods, is typically referenced in terms of a quantifiable range of results, or as an assessment within a set of defined scenarios. For example, the advice offered in the UK Department for Transport WebTAG Unit 3.15.5 (DfT, 2010) advocates selecting a small number groups of defined options, labelling each set as a "scenario", and modelling that scenario under pre-determined growth factors. This approach addresses the issue of uncertainty as a single parameter; the growth in travel demand and also contains the scope of the problem within number of scenario options. The MOTOS project (MOTOS, 2007), which also seeks to provide guidance for development of large scale transport models, widens the handling of uncertainty to include data acquisition, modelling sensitivity and completeness in both demand and assignment modelling. Here the uncertainty in demand modelling adds a more sophisticated approach than that evident in the DfT advice (DfT, 2010), the MOTOS advice however is largely silent on exogenous effects of changing technologies, changing economies and on different scenarios for the future. Essentially it assumes that the future is an incremental, undisrupted, extension of the present.

Nijkampf et al. (1998) discuss transport planning as an evolving field where there are growing pressures on the transport network to embrace new requirements in assessment criteria, in transport technologies, and in societal developments such as the desire to travel and the need for sustainable travel. Recognising that transport planning decisions are not made in isolation, Worsley (2015) Banister and Berechman (2000), and Ortuzar (2011) place projects for assessment into a policy framework in which policy levers are pulled and transport projects are approved to achieve those goals. Within the UK, the Department for Transport mandates that every Local Authority must provide a local contextual framework for such policy interventions and infrastructure developments This framework is documented in a Local Transport Plan (LTP) which sets out the authorities specific local goals and assessment criteria and places their planned transport developments within that plan (DfT, 2009).

May et al (2005) codify a transport decision making contextual framework into a "Decision Makers Handbook"; an output from the EU "PROSPECTS " (Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems) project (EU, 2003) which provides a generic process framework for policy interventions and infrastructure developments within such a local policy framework. This handbook refers to the process of decision making from the early inception of a project, the need for a stable political environment for a project and differentiates between those projects which are (a) "*Vision led*" with an individual having both the ambition and the powers to implement development, often a Mayor or planning leader, (b) "*Plan led"* where rational analysis of observed problems and set priorities leads to an optimal solution and (c) "*Consensus led*" where plans evolve in discussion with stakeholders and are refined through shared understanding and knowledge. Emberger, et al. (2008) found that the consensus led approach, either solely or in tandem with the plan led and vision led approaches, dominated in European transport policy and planning and that with some differences in culture, types of vehicles, policy priorities and economic environment, the same was true in other (i.e. Asian) environments. Jeon et al. (2010) add the consideration of uncertainty into both the assessment and decision stages of such a transport planning framework including sensitivity analysis to help understand the interaction of the uncertainties in modelling and assessment and in decision making.

Khisty and Leleur (1997a; 1997b) discuss the role of the transport planner as a communicator and facilitator interacting with the public and the professionals to develop proposals. Cascetta (2015) makes this concept more explicit describing a consensus led decision making process with three strands, one to organise the process, one to formally engage stakeholders and the third to enable changing perceptions as the outputs of technical analysis are communicated reinforcing the dominance of the consensus led approach. Jeon et al. (2010) demonstrate a graphical representation of the decision criteria to demonstrate their relative weighting for the different development options related to one proposal as a tool to promote engagement. Bartholomew (2007) however reviewed 80 transport proposals with claims to scenario planning based consultation and observed that only a minority actively involved citizens in developing scenarios and eventually selecting options and hence deduced that scenario planning was still evolving as institutional structures mature and public engagement has still to become more pro-active in developing proposals rather than being reactive in commenting on them, reflecting the comments made by Khisty and Leleur (1997a; 1997b) and Cascetta (2015).

Game theory is proposed as a basis of innovative assessment frameworks. Wang et al. (2015) developed a game theory based modelling framework to assess new infrastructure and market development (specifically in biofuel distribution), observing that a system designed assuming zero uncertainty is found to be suboptimal as scenario and parameter uncertainty is introduced. Alumar et al. (2012) came to the same conclusion using a game theory based approach to design of hub and spoke distribution networks when including uncertainty in transport costs and demand. Both Xiao et al. (2013), and Chen and Lui (2016), assessing placement and capacity of airports and marine ports respectively, used game theory base frameworks to model optimal capacity and location of port facilities, examining the impact of investment decisions under both uncertain demand and uncertainty about the reactions of competing ports, once again with the same conclusion that assuming perfect knowledge results in less efficient investment decisions.

These developments in game theory base assessment bring new factors into transport assessment; the impact of competing developments and the effect of risk adversity in investment, but there is yet no evidence of these frameworks being used in public sector infrastructure developments which hereto have relied on traditional cost benefit analysis techniques.

2.6 Summary

This literature review has established how uncertainty is defined, how it is managed in the rational analysis process of traditional transport modelling and how it is managed in the decision process that surrounds the project assessment. Research which develops a taxonomy of uncertainty has been reviewed and three classes of uncertainty have emerged: (a) the uncertainty due to the inherent variability in models and data, (b) the uncertainty due to the perceptions of the stakeholders in decision making and (c) the uncertainty in the future environment for the proposed transport development.

The purpose of this research is to examine a methodology to identify the causes of uncertainty in a transport project and to include all stages of the project from inception to approval. It must therefore embrace the second two forms of uncertainty: The views of stakeholders and their values and beliefs about the development; and the different scenarios in which the development may exist in the future. These two forms, of completeness and perception are not specific to any one aspect of transport planning, they are found in modelling of all types, in risk analysis, and in analytical decision making frameworks.

One common theme emerges in all areas; that the problem of addressing uncertainty cannot be readily bounded. Complexity theory offers a framework to examine the structure of complex systems and moves towards agent based models to find emergent unpredicted behaviour as well as moving to systems dynamics techniques to study connectivity and causality. In transport modelling, we see efforts to extend modelling techniques to offer greater detail or greater scope but both streams of development continue to contain uncertainty in the completeness of their algorithms and scope. In decision frameworks, developments extend the methods to provide more robust decisions which include *“hard”* and *“soft”* measures but the frameworks still have issues with changing human perceptions and with the completeness of the analysis. Similarly in scenario planning, techniques exist to provide analysis of future scenarios from the present moving forward; but it is recognised that as uncertainty about the future environment a different technique (backcasting) is more appropriate. Here a normative future scenario encourages analysts to query the route to it starting from that future looking back and hence not constrained by the boundaries assumed today.

The message is clear, that the techniques adopted to examine uncertainty in transport planning in the research presented here should not impose constraints on the analysis, i.e. by focussing on uncertainty in any one part of the process but instead should be capable of considering the entire process and be capable of seamless extension into areas associated with the transport planning problem

In the next chapter, techniques will be described in more detail which are intended to identify the two classes of uncertainty described above while not imposing constraints on the process limiting it to subsets of the transport planning field. These techniques will be bought together to develop an integrated method designed to address the causes of uncertainty based in the transport planning process.

Chapter 3 Designing the Methodology

The aim of this research is to design and trial an integrated method to identify and qualify uncertainty in a transport project. This chapter describes the design of that method by taking the issues identified in the introduction and supported by the literature review to scope the bounds of the types of transport planning project which the method is to address. Next, the choice of components of the integrated method, again based on the literature review, and how they should be connected is discussed. The remainder of the chapter then expands on the chosen components, explaining how they are to be used and, where required, how they are extended.

3.1 Scope

A transport project has four stages: 1) *Inception*, where the project is first conceived, 2) *Assessment*, where the benefits of the project are quantified, 3) *Approval*, where funding is identified and won, and 4) *Implementation*, where the new development is built or the new policy is enshrined in action or legislation. There are many texts describing the process (DfT, 2016; Worsley and Mackie, 2015; Ortuzar and Willumsen, 2011).

At the *inception* stage, the project or policy is first identified in terms of the overarching policy goals and policy levers and in terms of the national and regional structural plans. Each local authority in the UK is required to produce a Local Transport Plan (LTP) and update it every 5 years. The Department for Transport documents the mandatory plan development process but allows for considerable flexibility in the local goals and how they are implemented and assessed (DfT, 2009). Cascetta et al. (2015) include the inception process as the “problem and opportunity” in their framework for planning under uncertainty. It can readily be argued that the inception stage is the most uncertain as many proposed projects will immediately fall at this stage before any formal assessment is undertaken and will never graduate beyond the status of an un-investigated idea. However, a project that achieves a preliminary assessment should be able to be included in analysis by the proposed method as the goal is to identify uncertainty and the nascent stage is where significant uncertainty exists.

At the *assessment* stage, the impact of the proposed development is quantified by comparing costs and benefits (see section 2.2). Uncertainty at the assessment stage is contained in the modelling process and in the understanding of the future environment of the proposal. In defining a taxonomy of uncertainty, the literature differentiates between these two classes of uncertainty, reviewed in section 2.1 as that due to a quantitative method of modelling and that due to qualitative methods of determining the future environment for the proposal and hence, what to model.

At the *approval* stage, decision makers take the results of the assessment, bring in their own knowledge and values, and their own understanding of external pressures from stakeholders and from the policy and infrastructure environment to make a decision to proceed or not and to fund the development or not (section 2.3) and Marsden and Reardon (2017) identify a significant gap in evaluating how policy decisions are made in existing policy driven contexts.

Finally at the *implementation* stage, for a construction project, managing construction risk in terms of cost and time overruns is a problematic process (Flyvberg et al., 2003) but is also well understood in engineering disciplines (May and Haldane, 2011; Jeon and Amekudzi, 2007; Loosemore et al., 2006) with software to quantify risk (Palisade, 2011). In this context, risk is defined as a quantifiable assessment of known probabilities compared with uncertainty defined as working with an incomplete set of unknown probabilities (Berechman, 2009).

In scoping the method described here, the implementation risk was not included. The goal was to uncover the reasons for uncertainty in transport planning, from inception to approval. Also, there is also a large body of literature and methods concerned with the assessment of uncertainty found in the rational analysis stage of project assessment referring to the stochastic nature of models, and the sensitivity of model outputs to their inputs (Section 2.2.4). The scope of the method devised here therefore did not focus on this quantifiable sensitivity and stochastic analysis in detail, though it remained cognisant of the use and understanding of the results of a modelled assessment.

The stated goal of the method designed here did not include any requirement to give decision support in the form of advice whether to proceed or not with a proposal. Instead, the goal was to identify the causes of uncertainty and give planners and decision makers guidance about how to best direct their efforts to reduce that uncertainty. This may lead to a more robust decision concerning the transport proposal, based on situational understanding of the dynamics of the uncertainty in the decision based on an analytical foundation, but it does not constitute guidance on whether the decision should be to proceed or not to proceed with the proposal.

The method designed in this research was intended to analyse the uncertainty in a project at both the inception stage, where a project must find its niche in the current and future policy and infrastructure ecosystem, and at the approval stage when decisions must be made. This is in effect in agreement with observations made by Wachs (1985) and by Marsden and Reardon (2017) who comment that research into the rational analysis of a project is in hand, but research into the social and political dimensions of transport planning is lacking. The method designed here however extends that latter research requirement into explicitly identifying uncertainty in the project under analysis rather than into understanding processes.

3.2 Methodology: Overview

Therefore the scope of the method was defined as being to analyse the causes of uncertainty in the inception and approval process, and, in the assessment process as well as the uncertainty due to the future environment of the project. This corresponds to what Walker et al. (2003) refer to as scenario uncertainty, van Geenhuizen and Thissen (2007) refer to as input uncertainty, system boundaries and outcomes, and Gudmunssen (2011) refers to as the uncertainty in knowledge and learning. The area to be analysed also fits Rittell and Weber's (1973) definition of a "wicked" problem, one which defies rational analysis.

The strategy adopted in this research to devise a method to identify uncertainty was a generic one:

1) Describe the system with a model:
    a) Describe the required outputs,
    b) Identify the necessary data,
    c) Devise or identify a suitable algorithm.
2) Gather the data:

a) Identify the sources,
b) Devise a means of gathering the data,
c) Encode the data,
d) Validate the data.

3) Analyse the system:
    a) Obtain results,
    b) Analyse results,
    c) Understand the application of the algorithm, its robustness and sensitivities.

These steps are elaborated on in the following subsections.

3.2.1 Proposed Model

The outputs required of the model are a list of the components of the planning project that contribute to the uncertainty in the project, with a set of reasons how they reach their positions on this list. Therefore, the primary input must be the list of components of the project and the task of generating that list must too be a part of the data gathering exercise as an analyst investigating the uncertainty in the project, would impose artificial constraints if he or she attempted to pre-determine what should or should not be on that list.

The model types described in the literature review are first; simulation models of a transport system; second; system dynamics models of a transport system at a higher level of abstraction including its relationship with the policy ecosystem; and third, structural dynamics models of the relationships between the entities forming a physical or abstract system, specifically the Cross Impact Matrix Method. This method is expressly designed for the class of analysis described here and therefore forms the basis for the model selected. This in turn leads to the second set of inputs required by the structural dynamics model, namely the set of influences between the identified components of the project.

Maparu et al. (2017) differ in opinion from Worsley and MacKie (2015) to demonstrate a relevant issue in deriving these influences. Worsley and MacKie (2015) state that in transport assessment, providing better transport leads to an increase in economic activity. Conversely, Maparu at al. (2017) challenged that assumption and found that there was no clear relationship and in some cases the converse is true where transport planners are responding to the economic realities. They concluded that the causality is dependent on the situation. This implies that pre-ordained causality should not be used in the Cross Impact

Matrix Method but that causality should be identified in parallel with the list of system components.

The selection of a structural dynamics model therefore determines the required inputs to be a set of variables describing the systems and the causality between those variables. Furthermore, the source of both of these sets of data is to be from the project data collection exercise and not imposed on the process by the analyst working with pre-conceived externally derived knowledge.

3.2.2 Proposed Data

Khisty at al. (2000) propose a means to tackle “wicked” problems based on forming a hypothesis which includes new ideas and building a case in which that hypothesis may be true. In practice this begins with a claim about the future and works backwards to find the information and assumptions to support the claim. This process of abductive reasoning, provides a method for reducing the number of elements contributing to the outcome of the planned development and promoting consistency in the chain of reasoning that leads to the putative end state. It is Lindblom’s incremental approach (Lindblom, 1979) applied to “wicked” problems and with a presumption that if working from the present forwards is difficult, then working from an ideal future backwards may lead to the solution.

Robinson (1990) describes a method of analysing the feasibility of policy goals using a backcast scenario. In Robinson’s method, the objectives, specific goals, constraints and targets are identified in the present policy system. Normative scenarios are then constructed to describe the route to the desired outcome and the steps on that route subjected to an impact analysis to examine the effect of exogenous variables. The differences between the desired view of the future and the outcome after the impact analysis are used to refine the goals and the route. The key elements of Robinson’s method are the back cast scenarios and the analysis of the route to the goal, not just identifying the goal. Backcasting is described by Dreborg (1996) as applicable to complex societal issues when dominant trends are part of the problem, external influences are strong, and time horizons are long enough that choices can be made to influence the path to achieve a desirable outcome. The purpose of the backcasting scenario analysis is to identify and study those choices.

This research indicates that a backcast scenario technique is advised as a tool to develop the list of components of the system as well as to understand the causalities between those components,

Scenario planning exercises are primarily designed to be participative, to engage stakeholders in a shared learning exercise, and to build a common language and understanding about the issues addressed in the scenarios. However, this does require significant and simultaneous participation of stakeholders and the engagement of potentially many different organisations. In an active project this may be possible but in a nascent project with strong buy-in from some stakeholders, but little or no buy-in from others and with no current plans to take any action, it is difficult to see how this would be achieved. The method designed here therefore could not implicitly rely on multi-stakeholder workshops or similar large participatory exercises, it had to be able to function through contact with stake holders individually. Indeed, understanding the different views of the multiple stakeholders is held to be one aspect of identifying uncertainty and that requires avoidance of the problems of motivational bias and group-think as identified by Booker and McNamara (2004) .

Means to cope with the problems of lack of simultaneous participation are provided by Hojer (1998), Zimmerman (2012; 2011) and Tuominen et al. (2014). Hojer (1998) introduced the concept of a backcasting Delphi study, in this case with a large number (~100) of international experts from 20 countries and with significant difficulty in gathering them together for a participative exercise. Hojer (1998) claimed the benefits of using a backcast scenario are that a scenario creates a narrative that is readily accessible to participants from different disciplines, and that the repeated rounds of communication in the Delphi study allows the stability of the participants responses to be verified. In a similar backcast scenario project, Zimmerman (2012) used a process based on individual interviews, similar in structure to a round of a Delphi study, to examine an existing scenario. In that project, elicitation was based on individual discussions of the scenario as it was not assured that multi-stakeholder workshops could be held, and also the individual opinions of the different stakeholders were of more interest than a consolidated opinion which would be the result of a multi stakeholder workshop. Tuominen et al. (2014) used multiple backcast scenarios based on policy packaging, each evaluated by multiple stakeholders, including school students, for a “fresh outlook” to determine a plausible path to achieve the stated goal. This project is relevant to the research presented here as it also examines the associative relationships between the elements of the scenarios, although it does not use these relationships to study the uncertainty in the scenarios.

3.2.3 Proposed Analysis

The results of a structural dynamics model, specifically the Cross Impact Matrix Method is a classification of the components of the system according to both their impact in influence and dependency (refer to section 2.4.4). Those which are simultaneously influential and dependent are understood to contribute most to uncertainty (Vester, 2012; Godet, 2011; Gordon and Hayward, 2000). This set of influence and dependency tuples forms the output for the decision makers, but in terms of the design and application of the method, the analyst using it should be confident that the result is robust as the parameters controlling its algorithms are varied and hence the outputs are truly derived from the data and not an artefact of the choice of parameters. Therefore, in assessing the application of the integrated method, sensitivity analysis should be conducted as described in section 2.2.4 - Model Sensitivity.

3.2.4 Integrated Methodology

The integrated methodology developed for this research is therefore designed to link backcast scenario analysis with multiple stakeholders and carry out in depth analysis to determine the drivers of uncertainty is shown conceptually in Figure 3-1; an overview of the steps in the integrated method.

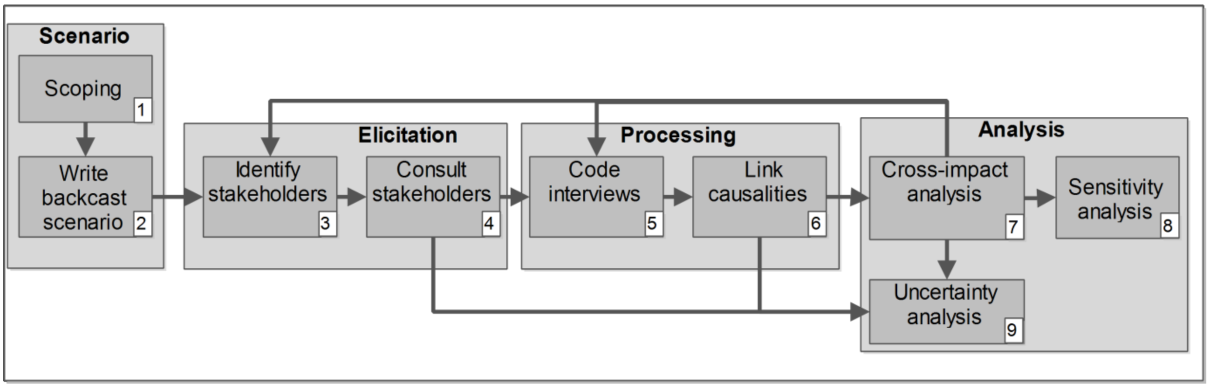


Figure 3-1 Method Overview (This study)

The stages are:

(1) Scoping the problem to derive an initial premise and the subject boundaries. These were used to prepare the normative backcast scenario.

(2) Identifying and consulting an initial set of stakeholders who have an interest in the project to prepare the scenario. These stakeholders, who share a similar view of an ideal future, were asked to describe their view of that future, and the events that must occur to reach it from the current situation. The knowledge gained was used to write the scenario which was structured as a narrative with vignettes to illustrate points with the intention to achieve a rapport with a diverse audience. Quantitative questions were included to complement the scenario and add a further tool towards eliciting uncertainty, as demonstrated by Usher and Strachan (2013).

(3) Identifying and approaching a further set of stakeholders to take part in the major part of the elicitation task. These stakeholders were taken from the transport and planning communities across the area covering the case study, but there was no requirement for them to share the vision described in the scenario. They were however familiar with, and have knowledge of, either the development described in the scenario or the processes of planning and policy that it engages and hence they were able to comment on the route by which the scenario may, or may not, be realised.

(4) Conduct and record open ended, one-to one interviews with this set of stakeholders to elicit their views of the scenario. The causalities between events described in the scenario, or introduced by the interviewee, were probed. Interviews were recorded, and the interviewer's notes were taken in the form of written notes and causal diagrams similar to those found in systems dynamics models.

(5) Study the recorded interviews in depth to extract the noun and verb phrases that describe the key elements and actions identified in the interviews following guidance from (Miles et al., 2014; Packer, 2011; Silverman, 2006). These were coded as variables using the NVivo software (QSR, 2014). Variables were added as required as the interviews progress and the system was regarded as approaching completeness when the rate of addition of new variables had reduced to near zero (Packer, 2011).

(6) Coding the causality between variables separately for each stakeholder by looking for linking words between variables in the interview recordings. This stage was unique in that it extended the existing Cross Impact Matrix Method by including the capability to hold the causality links for each stakeholder independently and subsequently combine them in investigative analysis of the causes of uncertainty.

(7) Undertake the Cross Impact Matrix Method analysis (Vester, 2012; Godet, 2011; Gordon and Hayward, 2000) to produce the Influence-Dependency graph using bespoke software written to support this research. Variable coding was reviewed to ensure consistency and the stakeholder recruitment was peer reviewed to ensure a representative sample of experts had been consulted. Further stakeholders were

sought where required and steps 4,5,6 repeated to include these new stakeholders. Variables were rationalised using both cluster analysis, where the similarity was measured through the number of common links, and through text analysis to identify those variables that represented similar concepts. These were merged where required modifying the outputs of stage 5.

(8) Undertake sensitivity analysis on the results to investigate (a) their stability as the number of stakeholders included in the analysis increased and (b) their sensitivity to those parameters used in combining their causalities.

(9) Perform the uncertainty analysis based on the Influence-Dependency graph from the cross-impact matrix analysis augmented with the notes from stakeholder interviews from stage 4. The causality links formed in stage 6 were then examined to understand how variables reached their status defined by the zone they occupied in the Influence-Dependency graph as described by Vester (2012) and shown in Figure 2-3 on Page 54.

Similar methods have been used in other research. Tuominen et al. (2014) developed a method which used multiple backcast scenarios and qualitative analysis to examine the choice of policy packages and produce "*informed estimates on the direction and magnitude of the impacts"* using a table of synergies and conflicts. However, that project sought to identify the most effective scenarios for more detailed modelling rather than to identify the causes of uncertainty in achieving the stated goal which was the motive behind the research reported in this thesis. Linking multiple methods has been described and undertaken in research by Cascetta et al. (2015) who described a model of the transport decision process which maps and links the roles of scenario generation, stakeholder engagement, modelling and assessment, and information and communication; bringing in hard factors such as transport network performance and soft factors such as politics and communication. With regards to the interviewer's notes, Van der Hiejden (1996) uses "Influence Causality Diagrams" a simplified form of a System Dynamics Model (Checkland, 1999), to understand the dynamics of a scenario and the effect of corporate strategy within each scenario and Usher and Strachan (2013) also derived very similar diagrams while eliciting values of six quantifiable variables related to energy policy and climate change.

3.3 Methodology: Scoping Stage

In the scoping stage, a problem orientation and an initial premise were prepared. These were used to define the problem to be addressed and to set the scene for the normative scenario.

3.3.1 Problem Orientation Statement

The problem orientation statement described the current situation. It is a statement of the present or base case though it may well include the future intentions of the stakeholders. It also draws the initial boundaries around the project and places the strategic goals of the initial premise in the specific context of the case study. The boundaries should not be over specified, van Geenhuizen and Thissen (2007), when describing a taxonomy of uncertainty, regarded project boundaries as having a key role in framing the issues and state that the boundaries should be inclusive of all stakeholders and not allow policy factors that should be internal to the problem to be externalised.

3.3.2 Initial Premise

The initial premise was a statement to outline the proposed solution to the problem. It was intended to give the same background about the project to each of the stakeholders consulted in drawing up the normative scenario such that they have a common base upon which to build and add their own contributions. It is generated by the project investigator and forms the basis of the scenario generation stage. The initial premise was written to describe the issue to be studied and was a statement of intent about the future direction of the issue, and described the long term strategic goal. It was however, not a description of any one particular scenario that would achieve that goal but a generic description of the goal. At this stage, the initial premise should not over-prescribe what is to become the normative scenario.

3.4 Methodology: Normative Scenario Construction Stage

Interviews with key stakeholders were conducted to describe the ideal future scenario. Stakeholders were presented with the problem statement and initial premise and were asked to describe their view of the future and the events that occurred to reach it. Stakeholders selected at this scenario construction stage were chosen to hold a similar set of views in concordance with the initial premise. After the interviews, the future normative scenario was written to include the necessary sequence of events that must have occurred to reach it.

Packer (2011) discusses the power of a narrative approach to research interviews citing examples from anthropology, history, psychiatry, psychology and philosophy all using narrative as a natural cognitive form to order, organise and communicate meaning, both as a means to set out the “what” of the events along with a discourse of the “how” of the events. In effect the semi-structured research interview becomes an exercise in developing a story about the issue. Marchais-Roubelat and Roubelat (2008) describe similar methods to construct a scenario which separates the end point from the road to reach it.

Scenario methods advocate describing the scenario as a “story”. Van der Heijden (1996) describes scenarios as “interesting and enlightening” stories of the future which link events in a consistent manner and construct a gestalt with which stakeholders can engage. Lindgren and Banhold (2009) express this as thinking in drama; adding players, events, scenes and motives. In short, this promotes a subjective third person narrative, or a “story”. Reissner and Pagan (Reissner and Pagan, 2012) quote, from an expert interviewee, a former manager and Professor Emeritus, that:

> *“A story almost demands a higher level of activity from the audience than a propositional thing, because if it’s propositional they can listen to the propositions and agree or disagree, or they can note them down and reflect on them, or note them down and just leave it until it’s revision time. Whereas, the story is, once again, it’s us in the moment, if they’re going to engage, there’s no real option but to engage now.”*

More briefly, Hannah Arendt, a political theorist from the first half of the 20th century stated:

> *“Storytelling reveals meaning without committing the error of defining it.”*
>
> *Hannah Arendt (1906-1975),*

This reinforces the methodology of “storytelling“ in scenario analysis to convey meaning but not to over prescribe it. However, it is recognised that this writing style is not favoured in scientific discourse or in engineering disciplines. Conversation with Reissner (Reissner, 2013) suggested that a style based on a report form but using vignettes to illustrate points and reach a rapport with a technical and lay audience could be tried but to phrase the exercise as an illustrative “*narrative*” rather than a “*story*” to overcome a degree of prejudice in the term.

This style is in accordance with that adopted by the UK DfT in a scenario workshop held in November 2012 to elicit, from an invited cohort of professional transport planners and strategists, including the researcher, the response required in the travel network to scenarios describing future developments in 3D printing in manufacture (whether commercial or hobby, ubiquitous, or esoteric) and in care of the elderly (whether state or community care, and with differing roles for technology). The two scenario reports (Birtchnell et al., 2012; Cook et al., 2012) both contain a rationale for the scenarios intertwined with a set of vignette stories to illustrate the implications of the scenario. Two examples are shown here: The first with an excerpt shown in Figure 3-2, "*Home Alone and Wired*", is taken from "Care Miles" (Cook et al., 2012), there are two extracts from the scenario in which a high level of state care is matched by high use of technology. The other example, shown in Figure 3-3, "*Only Prototyping"* is taken from "Freight Miles" (Birtchnell et al., 2012) is an extract from the scenario where commercial realisation did not match expectation and 3D printing became a niche market only.

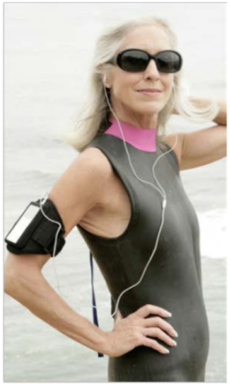
Both of these examples illustrate the use of images and small illustrative vignettes to bring a human interest to the scenario. Evidence from conversations surrounding the scenario at the DfT workshop indicate that the concept of a "chocolate consumption monitor" captured the participant's imagination and gave significantly more meaning to the scenario than the rest of the text describing it.

Scenario B: Home Alone and Wired

high state provision of care ● high engagement with healthcare technologies

Scenario summary

- In the scenario, the **shortage of care workers** coupled with the ageing population have made **both residential care homes and personal care at home unaffordable**.
- High divorce rates mean **single households are most common**. Informal care provided by spouses and children has been replaced by **technology enabled self-care**.
- The lack of care workers means **most care is provided remotely or via care-robots**. Most people live in **smart homes** equipped with monitoring technologies and the **state provides all people with a base level of technology**.
- The **need to travel for practical reasons has diminished** as people no longer need to make trips to GPs for routine check-ups, **3D printing** enables drugs to be printed at home and **online shopping** means most goods and services are delivered.
- However this has not resulted in a sharp decline in overall trip frequencies, as more active lifestyles in older age has **increased leisure travel**. There has been a shift to more sustainable forms of transport such as **public transport and cycling**, as these are seen as more healthy and efficient.



Relate: The main relationships considered in this scenario by participants were those between parents and adult children. If older people are self-caring, then will children be less inclined to visit as they won't feel the need to visit and check that everything is ok? There could also be potential breakdowns in trust between older people and their relatives if older people felt they were being forced into being under surveillance via monitoring technologies.

However, more positively, if the burden to care was removed from relatives and placed instead on care robots, then it might improve the quality of relationships and time spent with each other.

The other set of relations considered were between older people and robots (or more general human-computer interactions) – with participants noting that interaction design would become increasingly important in relationships, both between humans and also assistive technologies.

2030 newspaper headline

Suzi Mills taken to court for refusing to wear chocolate consumption monitoring bracelet

The greater expectations and pressure to be healthy and active means that there is significant social stigma attached to those who refuse to self-monitor. This attitude is helpful for insurance companies, who are also monitoring people's lifestyle behaviours.

Define: Participants described this scenario as being simultaneously the Age of Hypochondria, Surveillance and Empowerment. It was suggested that it would be remembered by future generations as the first connected older generation, but also as the most exclusive/exclusionary generation.

Figure 3-2 Extract from "Care Miles"(Cook et al., 2012)

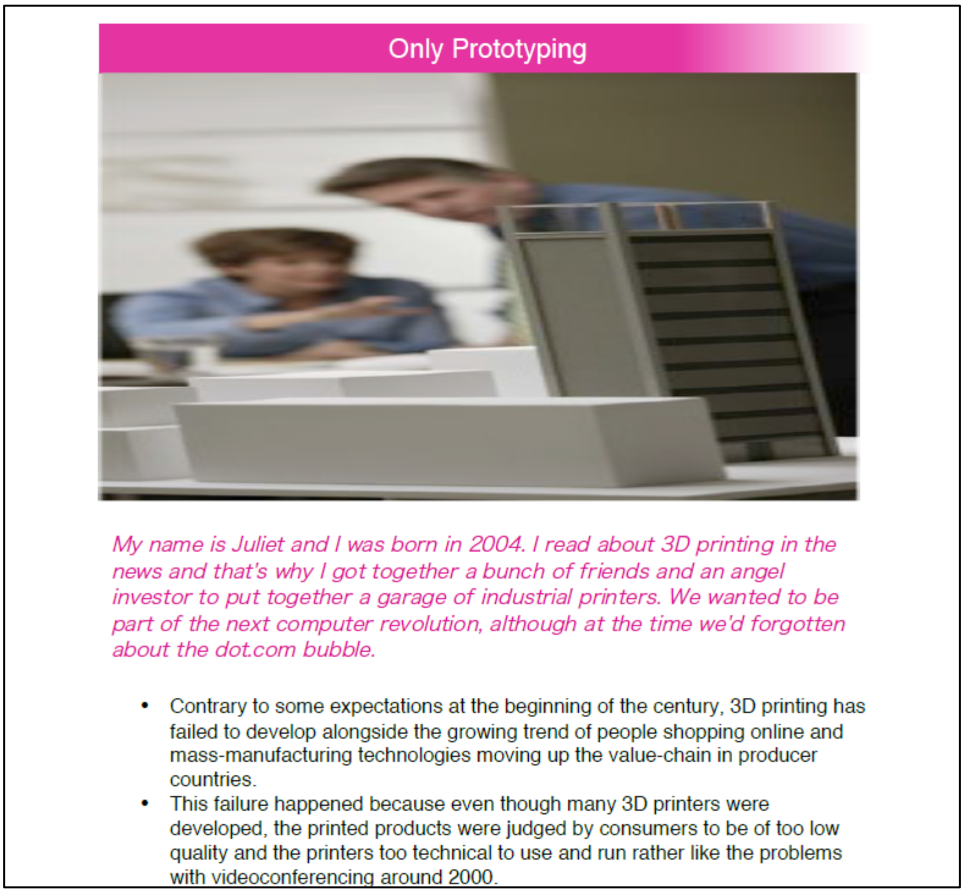


Figure 3-3 Extract from "Freight Miles"(Birtchnell et al., 2012)

3.5 Methodology: Elicitation Interview Stage

Packer (2011) and Silverman (2006) discuss the qualitative research interview in depth. Packer (2011) in particular is critical of the controlled interview with prescribed one sided dialog and an emphasis on quantification, using Likert scales, arguing that a qualitative interview should be based in conversation, albeit a conversation with a structure. The interview is necessarily asymmetric in that it is scheduled, it is led by one party, and the interviewer's and interviewee's motives for the conversation differ. Furthermore the interview is not an interaction between equals. Instead the interviewer chooses the topic and is advised to *"Consider with the utmost seriousness everything that they [the interviewees] say, while simultaneously casting a critical eye on the discourse"* while at the same time the interviewer is required to avoid personal involvement and bias. Hollway & Jefferson (2000) discuss the problem of subjective involvement, the relationship between interviewer and interviewee, and the difference in status in conducting interviews - in their case in an emotional topic. However, they offer little practical guidance in bypassing these problems apart from personal awareness and, if multiple researchers are available, peer review.

Introducing bias, through anchoring the interviewee's responses during the interview by quoting examples, was seen as a significant risk (Tversky and Kahneman, 1974). An interviewee discussing a theoretical future development will tend to anchor it in known current developments and while this is unavoidable, in an expert elicitation exercise, the anchors should come from the interviewee and not from the interviewer.

The researcher, therefore, has to be self-aware about these issues and to ensure the conversations, while led by the scenario, are open and only lightly steered to the central topic.

Notes were taken during the interviews in the form of causal diagram snippets. An example from the case study is shown in Figure 3-4. Interviews were also recorded and at suitable intervals such as breaks in the conversation or significant points being made, a time added to the notes. In the example shown in Figure 3-4, the points around the need for "unified approval" were made at 36:40 minutes into the interview and could therefore be readily located in the recording to clarify the responses as required.

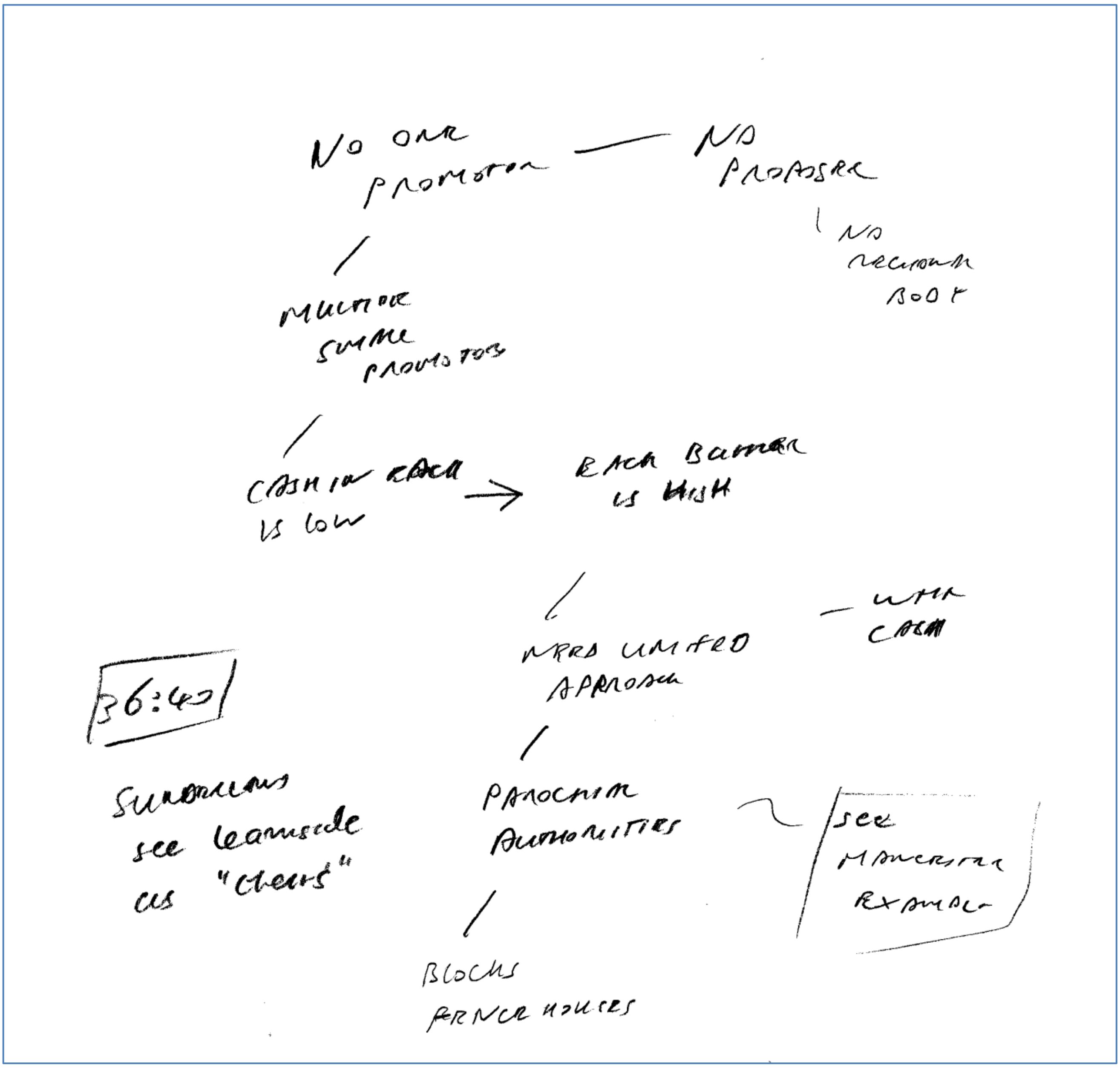


Figure 3-4 Causal Diagram Example (This study)

Recordings were either transcribed for later coding in parallel with the interview notes or variables were coded directly from the audio recording.

3.5.1 Quantitative Questions

The secondary part of the elicitation focussed on a small number of quantitative values which assist in describing the scenario. The method here was taken from Cooke (2013; 1991) and from the SHELF project (O'Hagan, 2011b) both of which describe techniques of eliciting and merging the value range for an unknown variable from several experts to find a central value and a range of uncertainty around it.

The essence of the method adopted was that the values were elicited as a central value, a ±25% range i.e. only a perceived 25% chance the value lies outside this range and a ±1% range, i.e. only a 1% chance the value lies outside this range. Cooke (2013) recommends using a “calibration” question to gauge the level of variance (entropy) a respondent may use and, assuming the calibration question has a known answer (or one that soon will be known), the respondent’s accuracy. In practice, if several variables are elicited, any one of them could act as a calibration question to estimate the respondent’s entropy though only those with a known value can be used to estimate accuracy. In this research project a single calibration question was asked and used primarily to introduce the interviewee to the variance banding concepts using a question out-with the research topic.

The expert opinions were merged using Cooke’s “classical” model (Cooke, 1991) where a most likely value for each variable was calculated and simultaneously, each expert was weighted according to their accuracy and entropy on the question. The analysis was undertaken using the EXCALIBUR software (Lighttwist, 2016) which implements Cooke’s (2013) methods. The two measures given for each expert are:

- The “*Calibration*” value which measures the statistical likelihood of the hypothesis that the realised values are sampled independently from distributions agreeing with the stakeholder's assessments. The larger this probability, the more the stakeholder is in agreement with the aggregated values.
- The “*Discrepancy”* measure which compares the relative information of each expert's assessment, per item with result of the analysis for that item and the scores are averaged over all items. The average scores (which are proportional to the relative information of the respective joint distributions if all items are independent) are output. This shows which experts agree or disagree most with the result. A lower score shows higher agreement.

During the discussion of these quantitative values, the interviewer continued to elicit causality based on the respondent’s reasoning as they derived the values. This technique is illustrated in Tuominen et al. (2014) although in that research, the focus was on the elicited values and there was little analysis of the causality. In the research presented here, that focus has been reversed.

3.5.2 Method: Variable Rationalisation

When the variables had been coded, a check was required to ensure that similar concepts had not been coded separately but could be combined to simplify the analysis. Two criteria needed to be satisfied before variables could be merged. These were:

1. That they were similar in their links and;
2. That they referred to similar concepts on re-examining the text.

The first criteria was addressed systematically, the second criteria was addressed by re-examination of the interview coding.

The techniques used were taken from "EnQuireR" (Cadoret et al., 2008) software used to undertake factor analysis in questionnaire topics and questionnaire respondents. EnQuireR uses measures of similarity to cluster variables, graphically or in a dendogram to reduce the number of variables to a set of common factors in the variables or respondents. It does assume input from a conventional Likert Scale questionnaire and this is not available in this project. However the requirement is that a measure of "distance" between two variables is calculated to enable the cluster analysis and in this research, the calculation of distance was based on the number of common links in the Influence-Dependency analysis rather than on the similarity of responses to a set of Likert scale based questions.

The initial distance calculation in EnQuireR is:

$$d_{(i,j)} = \sqrt{\frac{1}{J}\sum_{k}\frac{N}{N_k}\left(x_{ik} - x_{jk}\right)^2} \qquad 3.1$$

Where

- d is the distance between two variables i, j ;
- N is the number of respondents;
- N_k is the number of responses in category k
- k is the category
- J is the number of variables
- x_{ik} is 1 if x_i is in category k, 0 otherwise where a category k is the response to a questionnaire question.

The expression $\left(x_{ik} - x_{jk}\right)^2$ is therefore 0 or 1 if the respondents answer the same or 1 if they answer differently.

This is modified to use *x = true or false* to represent the presence or absence of a link between two variables. Links in both directions are considered and the use of the Boolean "and" operator in equation 3.2 implies that only the presence of a link is relevant, absence of the link for both variables does not imply similarity The Boolean expressions are interpreted as a value of (0, 1) for (false, true). The denominator in the summation is replaced with the number of combinations where at least one link is made.

The distance calculation is then:

$$d(i,j) = \frac{\sum_k \left(x_{ik} \& x_{jk}\right) + \sum_k \left(x_{ki} \& x_{kj}\right)}{\sum_k \left(x_{ik} \mid x_{jk}\right) + \sum_k \left(x_{ki} \mid x_{kj}\right)} \qquad 3.2$$

Where:

- x_{ik} is true if there is a link between variables *i* and *k.*

This measure was output by the bespoke project software for each variable pair based on the configuration of analysis parameters in use, specifically the selection of stakeholders to be included. The distance measures were subsequently used in cluster analysis based on an excel spreadsheet plugin (AladdinSoft, 2016).

Merging variables

Variables that were identified to be merged were processed in the bespoke project software by linking multiple variables and treating them as one. This was done either by creating a new variable and allocating those to be merged to it, or by subsuming one or more existing variables into another. In either case, the original data was kept by the bespoke project software so that decisions on merging could be readily reversed and also that the traceability back to the original interview notes and coding was preserved.

3.6 Methodology: Data Analysis Stage

The analysis stage used the notes, recordings and transcripts of the elicitation interviews; encoded them, and identified the variables and the causalities between the variables. It then evaluated the Influence and Dependency measures and hence identified the causes of uncertainty. Associated with this process was the analysis of the sensitivity of the Cross Impact Matrix Method to the parameters used to control the analysis. The goal of the latter stage was to investigate how robust was the method to changes in the calculation parameters and to ensure that the conclusions drawn from the uncertainty analysis were not unduly sensitive to the parameters used in that analysis

3.6.1 Coding Scheme

Coding is the process of identifying segments of text, data, or media as relevant to an entity such as a theme, concept, or physical object. The goal of a coding scheme is to classify the entities in the project and to describe them such that they are coded consistently across different data sources and media.

Lewins and Silver (2008) provide a practical taxonomy of coding schemes which cover both open and closed schemes. The "*open scheme*" is based in Grounded Theory (Calman, 2011) in which the scheme evolves as the research develops with no preconception of what is contained in the data prior to analysis whilst in the latter "*closed scheme*" the scheme is pre-determined before coding starts. Lewins and Silver (2008) categorise these as:

- ***Inductive*** coding schemes where the process is first an "*open*" coding to code every element in the data, next an "*axial*" stage to cluster codes, to merge some and to refine others and finally a "*selective*" stage to identify sections which typify the findings in the data.
- ***Deductive*** coding schemes where the initial "*descriptive*" scheme is prescribed before coding begins though subsequent "*interpretive*" and "*pattern*" stages will seek to refine this by clustering and merging before then looking for relationships and generating explanatory variables.

Both methods are iterative in that as coding proceeds the scheme is refined. The primary difference between the methods is the start point; whether it is in the data, or whether it is in the coding scheme.

The inductive process is similar to a less formalised method described by Hollway (2000), Packer (2011), and Silverman (2006). Noun phrases are identified and coded as "variables". As the number of interviews analysed increases, the rationalisation is refined in the variable list so each variable has a clear and consistent definition that applies across multiple interviews. The iterative nature of the coding scheme also indicates a measure of when an adequate number of interviews have been conducted; when the number of new variables used to code each interview approaches zero as new interviews are added (Packer, 2011).

In this research, the coding scheme was initially "*deductive*" for the physical elements of the scenario given that the topics of the interview conversation were prescribed. However the development of the coding scheme was then necessarily "*inductive*" for the resulting conversations regarding causality. The interview technique was intended to be open-ended, there was no prior knowledge of each individual's opinions or any desire to constrain their responses to a fixed set of variables. Indeed the goal of the elicitation interviews was to widen that set depending on responses.

3.6.2 Coding Software

In practice analysing multiple documents to find and rationalise common snippets of text is non-trivial with multiple stakeholders providing two documents per interview (the transcription and the interviewer's notes) and with a potentially large number of separate variables identified over the sequence of interviews. Manual techniques were found to be impractical as it was essential to be able to readily identify references to variables in multiple documents. For this reason Qualitative Data Analysis software (QDA) was sought.

QDA software is designed to classify segments of documents and media to extract common features from them. The documents may be text files or may be dynamic data feeds such as twitter or other social media. Other media includes images, audio and video. Coding may be manual or documents may be scanned automatically and text segments extracted. The coding scheme may be a fixed input or the software may be designed to allow the scheme to evolve as the project team's knowledge develops. As research projects of any significant size are conducted by more than one researcher, cloud based solutions, which allow multiple concurrent access to the data by many users, rather than sequential file sharing, are common. Several companies also provide transcription services which could be purchased from within their products.

The software selected for the research reported here was NVivo (QSR, 2014) after a subjective usability assessment. Details of the assessment that was carried out are presented in Appendix C.

3.6.3 Coding method

The coding method describes how to label the notes from the interview, whether these were in the form of scanned PDF files with causal diagram snippets, transcribed text from the recording of the same interview, or from un-transcribed audio files.

The theoretically ideal method is to look for common phrases and code them using a tightly prescribed scheme, this method would be eminently automatable but requires the sources to be formalised with standard language. This is not available in hand written sketched notes, verbatim transcriptions, or in audio conversations and hence some interpretation between raw data and coding scheme was inevitable. Also the software packages which parse social media documents rely on keywords or hashtags to identify concepts rather than infer them and that inference was not well developed. For example, a Sentiment Mapping demonstration project in the UK (UK Transport Systems Catapult, 2015) was intended to dynamically infer transport network performance from social media. While it could deduce the transport connection from the hashtags in the data, it struggled with natural language constructs, such as irony, to identify the sentiment of each message. A human analyst is better equipped to understand these concepts.

Whilst coding the discussion, the subject may be obvious from the current context but not always obvious in the text and furthermore, the context may have been established some distance from the text being analysed. Therefore it was felt that manual, subjective analysis, subject to post coding re-examination was preferable to using natural language processing software to simultaneously code the interviews, and develop the coding scheme, using an *inductive* methodology (refer to section 3.6.1).

The implication of this was that phrases in the interview notes were coded through selecting areas of the scanned paper document containing with the handwritten notes with the area covering one or more phrases. Additionally, context variables were coded by identifying them in areas of the notes independent of any specific written phrase. Transcripts were similarly coded with areas of text marked as variables or audio recordings selected by timed ranges of the recording.

As coding is susceptible to being quite subjective, reviews were essential to ensure that variables were used consistently. Also as understanding of the system emerged, variables were refined and points in the interviews re-assigned. The NVivo software tags each variable with the list of files where it is found and where it is coded in the notes along with a tag describing the functional group to which the variable is allocated. Hence, finding and comparing the locations where a variable was tagged was relatively simple and aided the process of checking for consistency in coding.

3.6.4 Linking

Links between variables were formed by searching the transcripts for link words such as "*because*", and "*therefore*". Causality, and the direction of causality cannot be inferred from simple adjacency of variables, a linking phrase or a link word should be present such as " *X is true **because** of Y"* or "*A is true, **therefore** B happens*"

Similarly links were identified in the causal diagram snippets using the lines drawn between each variable by the interviewer in the interview notes.

These links were interpreted as X influences Y from the context of the discussion, or from the stated causality in the transcript and were encoded in the bespoke analysis software. One of the existing Cross Impact Matrix Method practitioners assigns a strength to a link; Godet (2011) using a "Weak" - "Medium" - "Strong" rating for links with assigned strength values of 1-2-3 respectively. While the bespoke analysis software supported this, it was not used as there was little comparability between stakeholder's views in terms of strength, a problem not experienced by Godet as all stakeholders in his research are analysed in a single group. Strength was inferred in research carried out here solely through multiple references to causality between variables by multiple stakeholders.

3.6.5 Influence Dependency Calculation

The Cross Impact Matrix Method grades variables by Influence and Dependency to locate them in a 2D space.

The Influence I and Dependency *D* for each variable with indirect linking through multiple depths is then:

$$I_i = \sum_{d=1}^{depth} \sum_{j=1}^{n} s_d(i,j) * w(d) \qquad D_j = \sum_{d=1}^{depth} \sum_{i=1}^{n} s_d(i,j) * w(d) \qquad 3.3$$

Where $s_d(i,j)$ indicates there is a link of strength *s* between two variables on a path between *i* and *j* at depth *d* with *d-1* intermediate variables between variable *i* and the current link under consideration and *w(d)* is a configurable weighting factor for depth *d*. The strength is either defined as in equation 3.4 if *any* of the stakeholders *n* in the set *N* makes a link between variables *k,l* as intermediaries between variables *i,j* where $linked_d(n,k,l)$ is 0 or 1 if the link is present. Otherwise, it is defined as in equation 3.5 the sum of the number of stakeholders making the same link between *k,l* raised to the power *p*:

$$s_{d,i,j}(k,l) = linked_d(n,k,l), n \in N \tag{3.4}$$

$$s_{d,i,j}(k,l) = (\sum_{n \in N} linked_d(n,k,l))^P \tag{3.5}$$

The sum of strengths raised to a power will progressively reduce the effect of multiple stakeholders (*P*<1) or to increase the effect of multiple stakeholders (*P*>1). Note that *P*=1 is the simple sum of strengths and as *P* approaches 0, the effect of multiple stakeholders is reduced to a point where the link only has a strength allocated to it if one of more of the stakeholders makes the link, this case becomes, in effect, the same as in equation 3.4.

Figure 3-5 illustrates the derivation of the $s_{dij}(k,l)$ terms for the influence between variables *i* and *j* for the different steps at variables *k* to *l* with *N* stakeholders raised to the power *p* and weighted with weight *w(d)* assigned to the link where *d* is the depth of the link.

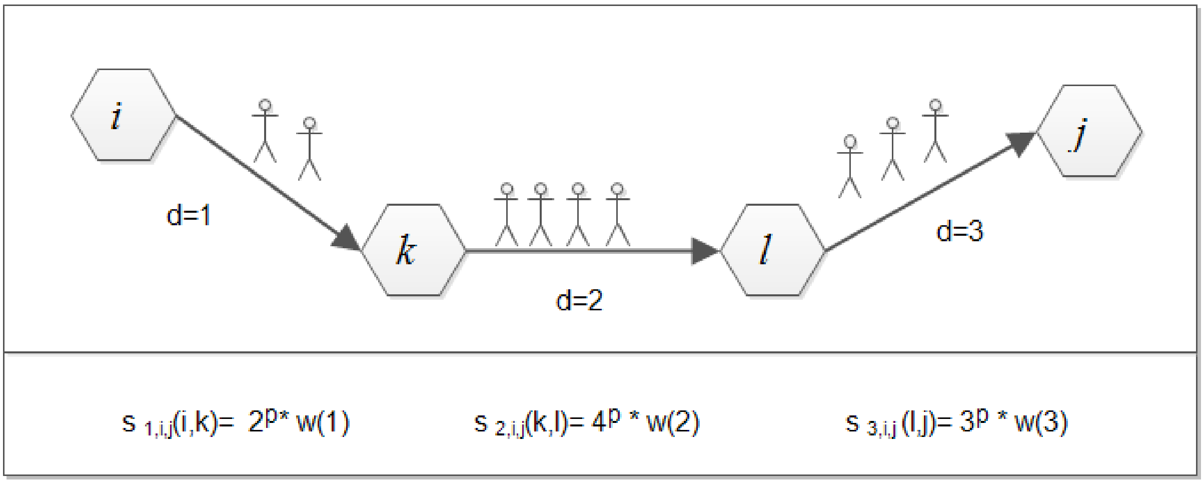


Figure 3-5 Summation Illustration (This study)

Link Potency

Each link has a number of causalities flowing through it, the link from *k* to *l* in Figure 3-5 may also carry causality on another chain i.e. variable *h* to *m* in the chain *h,k,l,m* where *h* and *m* are two other variables in the system. The link "*potency*" was defined as the sum of all the link strengths passing through a single link. The potency for the link between variables *k l* is shown in equation 3.6. The potency measures the relative importance of a link in the overall system.

$$Potency_{kl} = \sum_{links} s_{d,i,j}(k,l) \;\; for\ all\ d, i, j \qquad 3.6$$

Depth weight

The depth weight, the weighting factor to weight connections by depth, was parameterised so it could be controlled by one parameter to create a smooth curve where more remote depths were less weighted. The algorithm used was a normalised exponential of weights:

$$w(d) = e^{-\lambda d} \qquad 3.7$$

Where λ is the depth weighting parameter. Figure 3-6 shows the effect of varying the lambda parameter on the weight for each depth of influence.

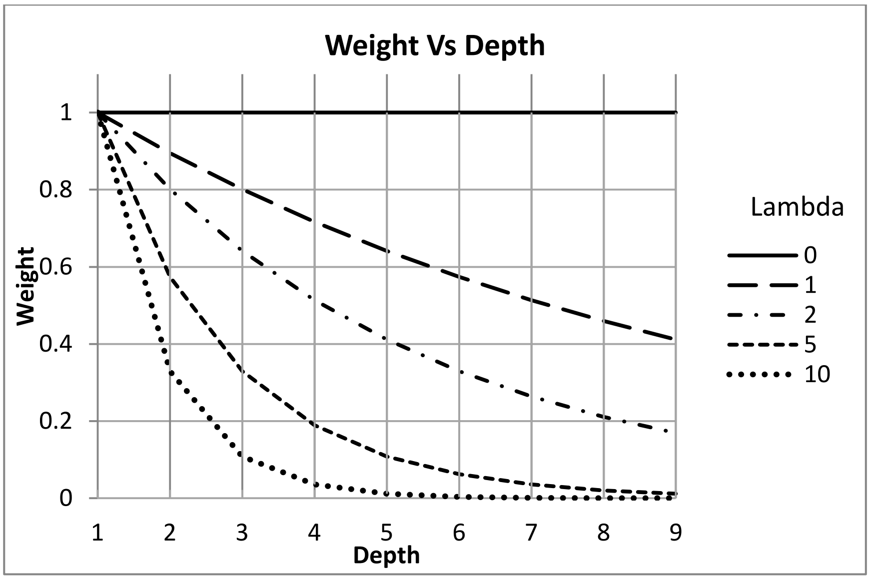


Figure 3-6 Weight Vs Depth of Influence for different values of Lambda

3.6.6 Variable Stability Measures

In order to evaluate the uncertainty function in the analysis for each variable, a measure of the uncertainty driver value was required corresponding to its position in the Influence-Dependency graph where values in the upper right quadrant score highly in the uncertainty measure.

Vester (2012) and Godet (2011) (See Section 2.4.4) describe the influence and dependency of variables and how their position in the Influence-Dependency graph reveals the nature of their role in the system but they make no attempt to quantify the stability of the system or to develop a stability index for individual variables. This measure was deemed to be essential to quantify the contribution to uncertainty for each variable and also to quantify the overall stability of the system, and hence suitable methods to evaluate such a measure were developed for the research reported here.

Cole (2006) uses three measures to quantify the location of a variable:

- Absolute Numerical Difference (AND) to determine if a variable is functional i.e. influential or dependent. If the AND score is high, the variable is high function either passive or active in the upper left or lower right corners. If the AND score is low, the variable tends towards being critical, or in the buffer zone. Cole makes no comment on the value of this measure when the variable has low I and D measures indicating it should be used after filtering low scoring variables.

$$AND_i = ABS(I_i - D_i) \qquad 3.8$$

- Quotient Score (QS) to determine whether the variable is influential (High QS) or dependent (Low QS).

$$QS = {}^{I_i}\!/_{D_i} \qquad 3.9$$

- Multiplier Score (MS) to determine whether the variable is active in the upper right quadrant or passive in the lower left.

$$MS = I_i * D_i \qquad 3.10$$

Based on Vester's (2012) classification of variables, two further indices are suggested:

- City Block (CB) metric, the sum of the Influence and Dependency where a variable at (1,1) will have the maximum instability measure. This is normalised to 1 to ensure comparability with Cole's measures.

$$CB_i = (I_i + D_i)/2 \qquad 3.11$$

- Inverse distance (ID), the distance of the variable from the (1,1) maximum instability point, normalised to lie between 0,1 then inverted to match the same ordering as the prior metrics such that 0 signifies a variable contributing little to instability and 1 signifies the maximum contribution to instability.

$$ID_i = 1 - \sqrt{\frac{((1 - I_i)^2 + (1 - D_i)^2)}{2}} \tag{3.12}$$

To ensure comparability between different configurations with differing numbers of variable and stakeholders, the Influence and Dependency values were normalised to 0 – 1 before the uncertainty driver measure was evaluated.

3.6.7 Aggregated System Stability Measures

Three stability indices were implemented based on the MS, ID, and CB measures these being selected as they measure the stability rating of variables whereas the AND and QS measures are related to the relative influence and dependency . Only those variables which were active, i.e. are linked in the system under examination, were included in the calculation also, where variables are grouped, only the master variable was included. The index was normalised by dividing by the number of active variables.

$$SI = \frac{\sum_{i \in activevars} Index_i}{count\ activevars} \tag{3.13}$$

Where:

- *activevars* is the set of active variables.
- $Index_i$ is the MS ID or CB index for variable *i.*

3.6.8 System Differences

The bespoke software included the ability to record a reference set with known parameters and a selection of stakeholders. The reference set was used to establish differences between the reference case and other cases by comparing the differences in the positions of variables, the ordering of the variables by their Influence, Dependency, and stability measures, and by the differences in the links.

Stability Differences

The stability differences were simply the arithmetic difference between the stability indices described in section 3.6.7.

Variable Position Differences

Two measures of difference in position were provided.

- The sum of squares difference is based on the geometric distance between the variables in the reference and test scenario.

$$VDiff_{ssq} = \sum_{Vars} \left(I_{test} - I_{ref}\right)^2 + \left(D_{test} - D_{ref}\right)^2 \qquad 3.14$$

- The difference in the zone where the variable falls in the Influence Dependency graph was calculated by dividing the graph space into a 3x3 grid and the difference is the count of variables moving zone. This was based on the zone scheme described by Vester (2012) and estimates the number of variables making a significant change of role. As a small move in I or D values may imply a change, a sufficient difference between values was required before a zone change was registered to have happened. Only the active variables were considered for this measure; those which have at least one link to another variable.

Figure 3-7 shows the zoning system. The upper and lower bounds of the zones and the delta value are set in the bespoke software interface. In Figure 3-7, if a variable moves from position A to B, it is not considered to have moved zone as the change in the value as it crossed a boundary was less than the minimum change required. As the variable moves from position A to positions C or D, it is considered to have moved zone. The index is then:

$$VDiff_{Zone} = \sum_{ActiveVars} v : where\ v\ crosses\ a\ boundary \qquad 3.15$$

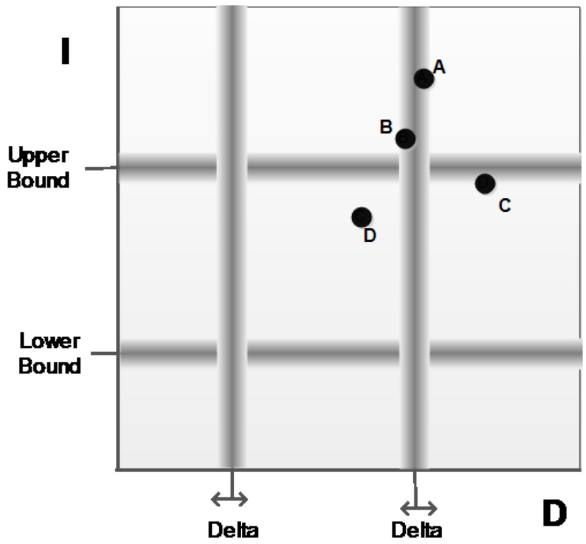


Figure 3-7 Zoning (This study)

Link Differences

Two measures of link difference are provided:

- The "sum of squares difference" is based on the difference in link potency defined in equation 3.6 which measures the importance of the link in the system. The difference between the test and reference sets is:

$$LDiff_{ssq} = \sum_{Links} \left(Potency_{test} - Potency_{ref}\right)^2 \qquad 3.16$$

- The "count difference" being the number of links which are made in one set but not in the other is:

$$LDiff_{Count} = \sum_{Links} \left(Presence_{test} \neq Presence_{ref}\right) \qquad 3.17$$

Ordering Differences

A measure of difference in ordering is provided based on one of the five measures for each variable. Godet(2011) and Vester (2012) both focus on the order of variables by Influence as their analysis is based on identifying the most important variables to evaluate and on which to focus on in the analysis. In the research reported here, the goal is also to analyse the instability in the system too and hence the measures that were used in rank ordering comparisons are as follows:

- Influence.

- Dependency.
- Inverse Distance Stability Index.
- City Block Stability Index.
- MS Stability Index.

There are two primary indices used to measure the rank order differences in two lists, here the variable lists in the reference set and in the test set Kendall's Tau and Spearman's Rho (Kruskal, 1958).

Kendall's Tau *(t)* measures the probability of two items being in the same order in the two ranked lists.

$$t = \frac{C - D}{n(n-1)/2} \qquad 3.18$$

Where *C* is the number of concordant pairs, for which the relative ordering is the same and *D* is the number of discordant pairs where the relative ordering is reversed.

Spearman's Rho *(r)* uses the rank difference between the lists for each variable.

$$r = \frac{cov(rg_x, rg_y)}{\sigma_{rg_x}\sigma_{rg_{xy}}} \qquad 3.19$$

Where $cov(rg_x, rg_y)$ is covariance of the ranked variables and σ is the standard deviation of the variable.

Webber, Moffat and Zobell (2010) discuss these two measures and make the observation that both weight the list equally. A difference in order in the 1st and 2nd elements is weighted the same as a difference in the 101st and 102nd. Also they observe that the variables contained in each list may differ. In the method being developed here, this will occur where a variable is active i.e. linked by one group of stakeholders, but not with another.

In Kendall's Tau and Spearman's Rho calculations, the missing variables are presumed to be at the end of the list although variants of these two measures allow for missing variables to be either ignored assumed concordant or placed at the end of the list. Webber, Moffat and Zobell (2010) provide a critical review of these options.

Webber, Moffat and Zobell (2010) therefore propose a Rank Based Ordering (RBO) measure which resolves these problems. This measure was adopted in this research as the same observations apply; changes in order between variables with low measures are less important than those with high measures and not all variables will be relevant in every case when the sets of variables in each configuration may differ.

The RBO measure takes the intersection of the two sets to depth *d* where the sets are the list of members 1:*d:*

$$I_d = S_d \cap T_d \tag{3.19}$$

It then finds an "agreement" overlap:

$$A_d = \frac{|I_d|}{d} \tag{3.20}$$

The agreement overlaps are summed for all *d* using a weighting for each term, where *p* is a decay parameter controlling the weight and $0 < p < 1$:

$$w_d = (1 - p).p^{d-1} \tag{3.21}$$

and:

$$\sum_{d=1}^{\infty} w_d = 1 \tag{3.22}$$

When p=0, only the first variable is considered, and as *p* approaches 1 the weighting becomes flatter until when p =1, the weight approaches 0.0 for each term and the number of terms is assumed to approach infinity.

The RBO measure for lists of length N is then:

$$RBO = \sum_{d=1}^{N} w_d \,.\, A_d \tag{3.23}$$

Where N may be arbitrarily large or may capped by (a) observing the asymptotic behaviour of the RBO measure or (b) to the length of the shortest vector of measures.

The effect of weighting parameter *p* is shown in Figure 3-8 for values of $0.1 < p < 0.95$ and d=1 to 20. Here we see that if p = 0.1, the first variables carry high weights (the value weights are 0.9, 0.09, 0.009…), whereas if p=0.95, the change in weighting between the first 20 variables is much less, from 0.05 to 0.019.

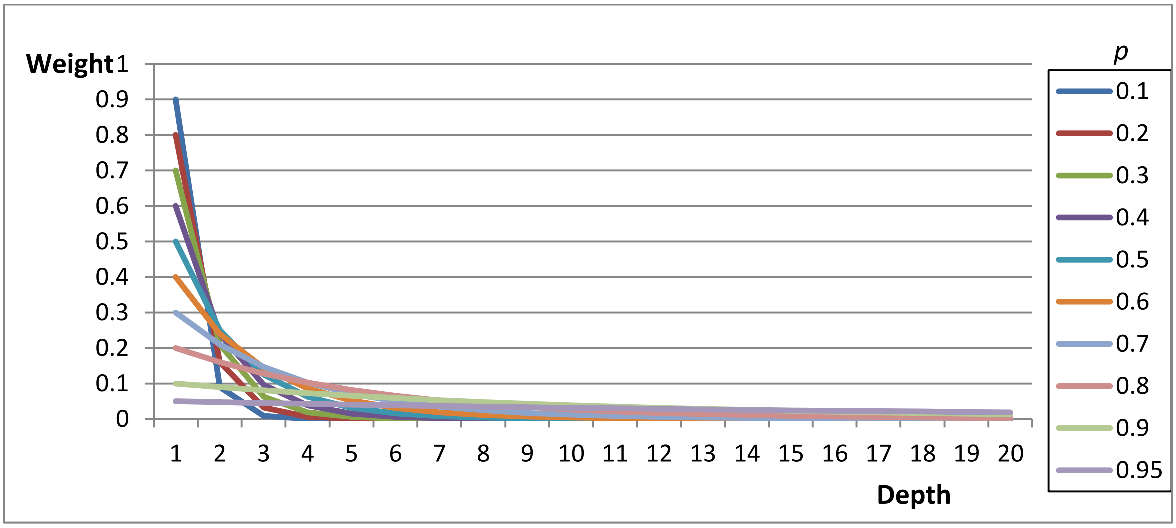


Figure 3-8 RBO Weighting

The RBO measure does assume a large number of variables and it was observed that the sum of weights may not equal 1 if *p* approaches 1 and N is small. This is shown in Figure 3-9 for values of *p* and for N = 10.

Hence the RBO measure is refined to normalise the weights to sum to 1 as shown in equation 3.24.

$$RBO' = RBO * \frac{1}{\sum_{d=1}^{N} w_d} \qquad 3.24$$

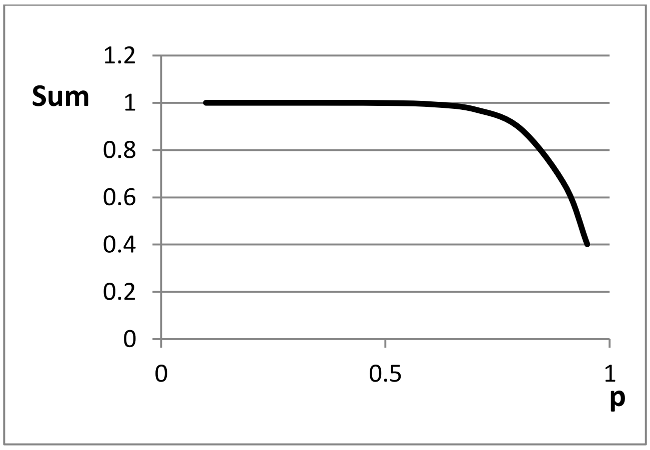


Figure 3-9 Sum of Weights N=10.

Experience using the RBO measure showed that if variables have the same value for a measure, the sort order is undefined and hence RBO may be less than 1, despite the lists of values being identical. In practice, in the case study, this was found to happen only when all the values were 0.0 (specifically, a special case with a set of variables all with a value of 0.0 for Dependency) and the difference from an RBO value of 1 is therefore accounted for and understood in the analysis.

3.6.9 Sensitivity Testing

The ultimate goal of the analysis was to look at the reaction of the system to the opinions of the respondents measured by the location of the variables and how that changes as the number of stakeholders selected changes and if links are removed. However, there is a prior requirement to understand the sensitivity of the system to the parameters which control the analysis: the analysis depth, the depth weighting and the stakeholder aggregation mechanism, and evaluate how the stability and difference measure react to these variables. Once this has been described, then the primary analysis, of the uncertainty in the system, may proceed.

Parameter Sensitivity

The sensitivity analysis to evaluate the effect of controlling parameters in the calculation of the stability indices was conducted in two stages. First, by calculating the stability indices for different values of depth, weighting and aggregation method. Second, by selecting a small number of reference points and calculating the differences for each configuration from these points. In this stage of sensitivity analysis, all of the stakeholders were included.

Note that Vester (2012) does not include any such analysis. In his version of the Cross Impact Matrix Method, the analysis of the system is restricted to a depth of 1. Godet (2011) extends the method to include indirect causality and advises that a depth of 4 -5 is *"about right"* with no weighting by depth applied and no suggestion that any rigorous analysis has been carried out. The assumption must be that this is based solely on empirical observation. Neither of these two proponents of the Cross Impact Matrix Method classify causality by stakeholder, they both aggregate stakeholder opinions through workshops prior to analysis. Therefore, the number of parameters for sensitivity analysis from these two researchers is strictly limited.

If model run times are long or if the number of parameter combinations is large, then sampling techniques are used to ensure the parameter space is adequately covered (See the discussion of sensitivity analysis in Section 2.2.4). However in the research reported here, the goal will be to understand the system reaction to these parameters and to find suitable values for use in the subsequent analysis, it is not intended to search the parameter space for any optimal solution, therefore sensitivity analysis will use a simple “One At a Time” (OAT) (Saltelli et al., 2008) methodology.

The bespoke project software was specified to include the capability to run the calculations multiple times with a range of the analysis depth, depth weighting, aggregation mechanism parameter values as well as a “pick N from M” capability to select the number of stakeholders. While in the case study used in this, research, there was no computer run time induced requirement for sampling methods to reduce the number of experiments this is not guaranteed in other case studies and hence the bespoke software was specified to be capable of restricting the number of experiments required to examine parameter space to reduce run times for sensitivity analysis.

The results from the sensitivity analysis produced by the bespoke project software were stored in a spreadsheet with one worksheet for every configuration giving the list of variables and their influence, dependency and stability indices. A summary sheet was also included with the details of every configuration; the values of the control variables and combination options and the stakeholders used in the analysis, as well as the stability measures of the configuration and its difference measures from a reference point in stability space. This allowed the sensitivity analysis outputs to be readily charted and analysed further using standard office tools.

3.7 Methodology: Uncertainty Analysis Stage

The uncertainty analysis stage was the end goal of the integrated method. This is when the variables that are the most influential, most dependent and, as a combination of these two measures, contributing most to the uncertainty in the system are identified. However, there was more that could be revealed than just the identity of those variables. The variables were labelled by category and examination of these groups was used to identify which category is most influential, dependent, or leading to uncertainty. The differences between stakeholders could also be examined to show how their opinions reinforced or contradicted each other. The relative importance of links can be quantified by their “*potency”* (see the discussion on link “*potency*” in Section 3.6.5) and links between variables could be broken to observe how the system reacts and hence identify those links which give significant variables their positions in the Influence-Dependency space.

Ultimately this analysis could enable a project owner to identify ways of reducing uncertainty by, for example; breaking specific links by acting to remove an influence, or to identify and act on the concerns of one or more stakeholders whose contribution to the causalities is shown to be a source of uncertainty. In short the method described here offers the opportunity not only to identify the variables that are the drivers of uncertainty, but to identify why they have this status and how it may be altered.

The actions in the uncertainty analysis stage were therefore focussed around all three classes of object in the Cross Impact Matrix Method:

- **Variables:** The key variables were identified and the movement of specific variables in the Influence Dependency space examined according to the stakeholder's views of them.
- **Stakeholders:** The effect specific stakeholders and clusters of similar stakeholders have on the system was studied.
- **Links:** The key links were identified and the effect of breaking them examined.

3.7.1 Variables

The variables analysis task plotted the Influence Dependency graph for all variables, and for variables by category. For each of the most influential and dependent variables the analysis examined which links were the most relevant and, by referring back to the initial elicitation interviews, commented on why this variable had its status in influence and dependency.

3.7.2 Stakeholders

The stakeholder analysis task plotted the Influence-Dependency graph for each individual stakeholder and, in conjunction with the interview notes and the analysis of the variables, identified the key passages in the conversations that could be used to determine the stakeholder's more significant views. The quantitative questions were also analysed to quantify the stakeholder's levels of calibration and discrepancy. Correlation between the divergence of their views from other stakeholders (the Discrepancy measure) their uncertainty about the quantified variables (the Calibration measure) and the relative stability of their Influence-Dependency graph was investigated.

Cluster analysis based on the intersection of sets of variables identified by each stakeholder (where a high degree of commonality indicates close association) was used to identify which stakeholders have discussed similar subjects. Pairs of similar stakeholders were then combined to investigate if their merged opinions systematically led to more stable or less stable system, in effect the question was: Do those stakeholders with similar issues reinforce each other's view and make a more stable system or do they add to the instability of the system?

3.7.3 Links

The goal of the links analysis task was to examine the changes to the system when a link was broken and to look for critical links that could be used to change the dynamics of the system. To undertake the analysis, each link was individually removed from the system and the influence and dependencies re-computed. The measures to be examined were:

- The correlation between the strength of influence in each link and the changes in the stability of the system and changes from the reference set when that link was removed.
- The quantified effect of removing the strongest links.

The preliminary analysis stages used a batch run mode of the bespoke project software which removed each link in turn and re-computed the influences and dependencies to find the level of change caused by removing each individual link. This was followed by a qualitative analysis to investigate the changes brought about by removing those links which the batch run identified as having the greatest effect. This stage specifically examined how variables moved in the Influence Dependency space as a link was removed and how the narrative which described the system changed. For a project owner the question that could be answered would be: Would the critical issues in the system be changed if that causality was to be reduced or removed?

Prior to this analysis, and automated by the bespoke project software:

- Links with zero strength of influence were removed. These are links created by a stakeholder who was subsequently omitted from the analysis, specifically in this case study, the researcher.

- Duplicated links to variables that had been merged in the rationalisation process (see section 3.5.2) were reduced to one link. These were the links where a composite variable has links from one external variable to multiple of its internal variables.

3.8 Summary

In Chapter 2, the concept of uncertainty in transport planning was described in the scope of the entire transport planning exercise, from inception and assessment, through modelling, decision making, to the construction risks inherent in implementation. In this chapter, the scope was reduced to the assessment and decision stages, and techniques to manage uncertainty in those areas researched in more detail. The outcome is an integrated methodology which starts with a description of the project concept and ends with a list of elements of the project which are the most influential in its realisation and also a list of those which are deemed to be the most likely to be the roots of the uncertainty in the project. The method can also show which links and stakeholders are most influential in the system and quantify the effects of breaking those links or working with stakeholders to understand their view of the project.

The positioning of the methodology with respect to related work can be described in four areas: working with stakeholders; scenario planning; modelling; and finally in comparison with methods developed in transport planning and other areas.

In working with stakeholders, there is a spectrum of engagement ranging from multi-stakeholder workshops to individual consultation. Scolobig and Lilliestam (2016) discuss the problems of pluralistic approaches in contested projects with multiple stakeholder views and comment that if a dominant stakeholder emerges, then one view may prevail, but if all stakeholders contribute, then a less effective solution will emerge. Scolobig and Lilliestam (2016) however, are focussed on the issues of finding a solution for a proposal whereas in this research, the goal is not to identify the solution, it is to identify the problems hindering the solution. It is therefore possible to take the benefits of a plural approach to individual stakeholders while avoiding the problems of arriving at a sub-optimal solution. Therefore in designing this methodology, the approach adopted for stakeholder engagement has been to consult individually, to recognise that uncertainty lies in their differences, and to preserve those differences in analysis.

In scenario planning (Section 2.4.1), there is a spectrum of uncertainty ranging from a scenario being a simple label for a defined set of options, a scenario being one of a set of plausible futures, and on to a scenario being a future goal, but with an uncertain path to it. Dreborg (1996) and Robinson (2003) refer to this latter type of scenario analysis as backcasting; a scenario study which goes beyond what is possible when forecasting from the present. Courtney (2001) similarly describes backcasting as a method for managing a high level of uncertainty and Khisty (2000) refers to backcasting as a technique to deal with intractable “Wicked Problems”(Rittel and Webber, 1973). On the spectrum of “uncertainty analysis”, backcasting emerges as the dominant method in cases of high uncertainty and in the methodology designed here, the form of backcasting which uses a single normative scenario was adopted to provide stakeholders, who would be consulted individually, with the same scenario rather than add to the complexity of the analysis by consulting with them over multiple future scenarios with different sets of variables and relationships.

In modelling, the observations from the literature review (Section 2.2) were that incompleteness of traffic models forms a major part of the uncertainty in transport assessment and that in reaction to that uncertainty, models are developing in two directions, (a) to model in more detail using agent based activity models and (b) to widen the scope of modelling, including policy and economic macro effects, using a systems dynamics model. The literature concerning both showed that concerns over completeness in the model structures still remain. In this research therefore, a simple model which assumes nothing about transport planning has been adopted. A structural dynamic model (Section 2.4.4) has no algorithms related to the transport domain and issues of completeness are therefore held in the data only, not in the model. Furthermore, using this type of model, which has not previously been applied to transport planning, frees the methodology designed here from the constraints of using pre-existing models and facilitates a wider search for the causes of uncertainty. This contrasts with frameworks described in Section 2.5 which, although they acknowledge the presence of uncertainty, focus on assessment of proposed developments under uncertain conditions and not on assessing the nature of the uncertainty itself.

The core of the integrated methodology is the Cross Impact Matrix Method, and this has been extended from its prior uses to now include causalities from multiple stakeholders rather than the consolidated causalities derived from a focus group where the opinions of individuals are lost. Capability has been designed into the Cross Impact Matrix Method tools, developed for this research to investigate its own stability as the parameters which control the analysis are varied. This stage is considered essential if the method is to be used to investigate uncertainty in the development under study, the analyst must be confident that the findings are due to the uncertainty in the project, not the parameter sensitivity of the method adopted.

Bespoke software was required for the research reported here based on the Cross Impact Matrix Method algorithms devised by Godet (2011) with extensions described in this chapter. The requirements analysis and the production of this software is described in the next chapter.

Chapter 4 Cross Impact Matrix Method Software

The methodology described in Chapter 3 uses a Cross Impact Matrix Method supplemented with some additional requirements for this research; specifically to label individual dependencies and variables by the stakeholders who identified them in the elicitation interviews, and to allow analysis of the system using different combinations of stakeholders. Also there is a requirement to study the sensitivity of the system to changes in the parameters which control the Cross Impact Matrix Method analysis and examine the differences in the results due to the depth of causality and depth weighting to establish if the results can be considered stable as these parameters are changed. There is also a requirement to examine the changes to the results when the decision system (as opposed to the decision analysis) is changed, i.e. by removing stakeholders from the cohort under consideration or by breaking causality links between variables. The need to undertake this sensitivity analysis of the parameters and system analysis of the variables, links, and stakeholders leads to a further requirement, namely to automate the process of changing analysis parameters, changing the set of stakeholders analysed, and breaking causality links; all with the ability to save the results of multiple configurations for subsequent examination.

Two products were found which undertake the Cross-Impact Matrix Method analysis. The first is freely available from Lipsor (Godet, 2011) but this does not support the analysis of the contributions of the individual stakeholders to the overall system and is oriented towards producing large written reports. The second is from Pentaho and is mentioned in a conference paper (Castellanos-Nieves et al., 2011). This forms part of a much larger business analytics suite and is not extensible to include the research described here. Neither of these two products is open source or extensible and neither of them capable of supporting the extensions to the Cross Impact Matrix Method planned in this project. Consequently, new bespoke software was written to deliver this research and more specifically, to include the planned enhancements to the analysis.

4.1 Requirements

A detailed review of the requirements specific to this research was undertaken to inform the design and implementation of the bespoke software.

The requirements were classified as:

- **Research Requirements:** These were the requirements which described the top level goals of the system. They were expressed in terms of the problem and not in terms of the proposed solution. In a commercial environment they are often referred to in software design as “Business Requirements”.
- **User Requirements:** These were the requirements which identified the activities that users undertake to address a research requirement. They represent the interests of the user and are solution independent.
- **System Requirements:** These were the requirements that refer to how the proposed solution operated and how the user requirements were satisfied.
- **Functional Specification**: These were the descriptions of each of the components of the solution and refer to the technology platform, the internal constraints required to implement it, and how the system requirements are satisfied.

While this appears on the surface to be a classic waterfall design process where a hierarchy of requirements is developed linearly with each set controlled by the preceding set and controlling the subsequent set, in practice, in software development, an evolutionary approach is commonly used to provide incremental development of the system and requirements in parallel and this approach was adopted in this research. The discipline of documenting a hierarchy of requirements was however a useful tool to ensure that all the higher level requirements were addressed and ensured that the lower level requirements had a user led purpose, rather than becoming self-serving technology artefacts.

The hierarchy of research, user and system requirements are listed in the tables below

- Research Requirements: See Table 2.
- User Requirements: See Table 3.
- System Requirements – Input: See Table 4.
- System Requirements –Single Scenario Analysis: See Table 5.
- System Requirements – Difference Analysis: See Table 6.

Note that while the application of the methodology in this project carried out interviews with human “stakeholders” to source the data, analysis was not necessarily restricted to this class of input and other sources of data were considered, i.e. reports, journal papers.

Therefore sources were referred to with a generic term “originators” rather than a specific term (stakeholders) implying a sole class of input source.

The function of this bespoke software in the analysis is to undertake the Cross Impact Matrix Method calculations. Its inputs are therefore the list of variables elicited in the stakeholder interviews and coded using the NVivo software (QSR, 2014) and the causality links between those variables. Its outputs are the Influence – Dependency (I-D) diagrams in graphical form and in tabular form along with summary measures describing the system in terms of its stability and its changes from a reference scenario.

Ref	Name	Description of the Research Requirement	Priority	Satisfies
R1	Analysis	Assist in identifying the drivers of uncertainty in a transport development.	High	---
R2	Originators	Combine inputs from multiple originators in the analysis.	High	---
R3	Interactivity	Be usable in workshop situations to generate rapid feedback in investigative analysis.	Medium	---
R4	Interoperability	Allow ad-hoc external analysis of results.	Medium	---
R5	Stability	Produce measure(s) of stability for each combination of input parameters and originators.	High	---
R6	Difference Analysis	Report on the difference between one configuration and another.	High	---

Table 2 Software Specification: Research Requirements

Ref	Name	Description of the User Requirement	Priority	Satisfies Research Req
U1	Analysis Algorithm	Use the Cross-Impact Matrix Method algorithms.	High	R1
U2	Originators Identity	Include the ability to identify the source of the dependencies and variables.	High	R1,R2
U3	Multiple originators	Provide the ability to combine the dependencies and variables attributed to selected originators.	High	R1,R2
U4	Functional groups	Categorise variables by function and select which function groups are used in the analysis (NB only variables are categorised).	Medium	R2
U5	Influence plot	Display the I-D graph of variables as described in the Cross Impact Matrix Method and update it as the selection of variables, links, originators and parameters are adjusted.	High	R1,R2,R3
U6	Graph plot	Produce a linked graph of variables and update it as the selection of variables, links, originators and parameters are adjusted.	Medium	R1,R2,R3
U7	Organisation	Allow the user to organise the data, (variables, influences and categorisations) to aid understanding in the analysis.	Medium	R3
U7.1	Variable Clusters	Enable the user to merge variables into a single variable, consolidating links to the constituent variables into the consolidated variable.	High	R1
U8	Graph Plot Interaction	Assist the user in visualising and analysing the links in graphical form.	Medium	R3
U9	Dependency strength	Lines showing the links between variables in the graph view shall indicate the relative importance of the link measured by link potency (See Equation 3.6)	Medium	R3
U10	Reporting	Export the current state of the variables, dependencies and the results from analysis in a form that can be used in further processing.	Medium	R4
U11	Import	Import variables and dependencies from external sources.	Low	R4
U11	File handling	Save and restore the model.	High	R1
U12	Stability	Compute measures of stability for each scenario.	High	R5
U13	Reference configuration	Save a reference configuration for comparison with other configurations.	High	R6
U14	Batch Run	Automate the process of running scenarios with ranges of input parameters and originator configurations.	High	R6
U15	Difference analysis	Record differences between a scenario and the base scenario.	High	R6
U16	Link Analysis	Make temporary changes to links to enable sensitivity analysis.	Medium	R6

Table 3 Software: User Requirements

Ref	Name	Description of the System Requirement	Priority	Satisfies User Reqs
S1.1	Variables Input	Implement a dialog to edit a list of variables with the following attributes: • Name • Description • Functional group • List of originators.	High	U1, U2, U4
S1.1.1	Variables Grouping (Input)	Allow the user to group variables by function in the list of variables.	Medium	U7
S1.1.2	Variables Grouping (Output)	Allow a set of variables to be treated as one by nominating one as master and linking others to it such that in the analysis, all links to the master or its subsidiaries are taken as links to the master.	High	U7, U7.1
S1.1.4	Variables Ordering	Allow users to –re-order variables in the list in their display window.	Low	U7
S1.2	Function Groups	Implement a dialog box to edit a list of function groups (Create, Edit, Destroy, Order).	High	U4
S1.3	Originators	Provide a means of editing a list of originators (Create, Edit, Destroy, Order).	High	U3
S1.4	Influence Matrix	Allow the user to create influence links of different strengths (Low Medium High) between variables, with links identified by originator.	High	U1,U3
S1.5	Models	Read and write model files using normally accepted GUI based methods.	High	U11
S1.5.1	File operations	Open models, save models, and create new models.	High	U11

Table 4 Software: System Requirements: Input

Ref	Name	Description of System Requirement	Priority	Satisfies User Reqs
S2.1.1	Algorithm	Implement the Cross Impact Matrix Methods algorithm as extended by work in LIPSOR to include multiple depths of influence.	High	U1
S2.1.2	Algorithm extension	Extend the algorithm to handle variables and links specified by multiple originators.	High	U2,U3
S2.1.3	Display	Present the results as a static I-D graph with values fixed by the analysis and also as a dynamic graph showing links and with the ability to interact with the graph	High	U5, U6, U7
S2.2	Analysis Control	React to changes in the control parameters and data inputs dynamically so a change in input is immediately reflected in the output.	High	U5,U6
S2.2.1	Select Originators	Allow the user to select one or more originators from a list and include only the links identified in the analysis by those originators.	High	U3
S2.2.2	Merge stakeholders	Provide algorithms for merging originator link counts as described in Equations 3.4 and 3.5.	High	U3
S2.2.4	Depth	Allow the user to change the analysis depth. See Equation 3.3	High	U1
S2.2.5	Depth weight	Make the strength of a link variable with increasing depth of analysis – i.e. a strength of 1.0 at depth 1 may be different from a strength of 1 at depth 5. See Equation 3.7.	High	U1
S2.2.6	Strength	Enable the user to configure the low, medium, high, link strengths.	Medium	U1
S2.3	Diagnosis	Allow the user to diagnose the responses of the system to changes by providing the means to drill down into why the change has occurred.	Medium	U5, U7, U10
S2.4.1	Layout Presentation	The layout graph should initially position the variables by position in the Influence graph. It then allows the user to select and move variables. The layout graph will also allow the user to pan and zoom the display	High	U5, U6, U8, U9
S2.4.3	Layout colour	Use colour to identify a variable's status. Use colour to identify a variable's group. Use colour and width to display link potency.	Medium	U6, U9
S2.4.5	Variable Selection	Allow the user to select a variable and restrict the view to that variable and to those immediately connected to it (depth=1).	Medium	U5, U6
S2.4.6	Variable Selection	Enable the user to select which variables to display by variable class.	Medium	U4

Table 5 Software: System Requirements: Single Scenario Analysis

Ref	Name	Description of System Requirement	Priority	Satisfies User Reqs
S3.1.1	Stability	Evaluate measure(s) of instability for each variable See section 3.6.6. • The Inverse Distance Metric: (1 - the distance from point (1,1)). • A City Block Distance: (I+D) • The MS metric: (I*D) Produce an overall measure of stability using the mean of the measure for the active variables. See section 3.6.7	High	U12
S3.1.2	Stability	Annotate the I-D graph with the average of the three measures of stability across the variables.	Medium	U12
S3.2.1	Reference	Provide an option to save the current scenario as a reference scenario for difference analysis.	High	U13
S3.3.1	Batch Run	Select parameters for the Batch Run option: • A range of analysis depths • A range of weighting factors • The combination algorithm (S2.2.2) • Pick N from M originators. • For all links, run with that link removed.	High	U14
S3.3.2	Batch Run	Output each scenario tested in a batch run to a spreadsheet worksheet and summarise it and its differences with the Reference Scenario in a summary worksheet.	Medium	U13 U14 U15
S3.3.3	Batch Run	Allow the user to restrict number of combinations of originators, a sample (Every Nth) due to the potentially large number of combinations.	Medium	U13 U14
S3.4.1	Differences: Variables	The differences between variables are to be computed using: • The sum of squares of distances between variables in I-D space. See Equation 3.14. • The number of variables that change sector where a sector is a 3x3 division of I-D space with "small change" overlap definable See Equation 3.15. • The changes in ordering based on variable measures I,D, and the 3 stability measures using the RBO comparator which weights the comparison at the head of the list. See Equation 3.23	High	U15
S3.4.2	Differences: Links	Compute the differences between links using: • The sum of squares of potency differences (See Equation 3.16 • The number of links differing in being present or not present. See Equation 3.17	High	U15

Table 6 Software: System Requirements: Difference Analysis

4.2 Implementation

Open source software is now commonly used in research and there is a large community of software engineers producing sophisticated and complex applications, many of which are extensible using an open API (Application Programming Interface). Producing software from a zero base for a specific research project may well be unproductive when the majority of the required system is already available. Therefore, before implementation began, two open source products were evaluated to examine if it would be more productive to extend an existing tool, or to produce a new bespoke tool for use in this research. The two open source products considered were Gephi (Bastian et al., 2009) and Gnu Octave (GNU, 2015). The third direct implementation option was to use Microsoft Visual Studio (Microsoft, 2010) and write code from a zero base using the basic libraries supplied in the Visual Studio development environment.

The merits of each approach were considered and a summary is presented in Table 7.

Gephi	Gephi is an interactive visualisation and data exploration platform used to examine networks and complex systems, dynamic and hierarchical graphs. Gephi presents the relationships between objects in graphical formats with compelling visual involvement from the user. Gephi has an API which allows it to be extended and implementing the Cross Impact Matrix Method analysis would have been feasible. However, initial work with Gephi showed that, as with many complex applications, the existing infrastructure is large and significant investment is required to understand the relationships between the many object classes in the software. Also, it was (subjectively) felt that Gephi placed a very high emphasis on visual presentation and the researcher's prior experience has shown this can be very time consuming with the law of reducing benefits soon applying in a technical development project.
GNU Octave	GNU Octave is a high-level interpreted language, normally used through a command line interface although a GUI may be provided. It is primarily intended for numerical computations such as linear and nonlinear problems and it also provides extensive graphics capabilities for data visualisation and manipulation. GNU Octave is very similar to the commercial product Matlab. However experimentation with Gnu Octave showed that there was little saving over implementing the software using more conventional software production tools.
Direct Programming	The direct implementation option is to write the analysis software using a readily available programming language (C#) and use libraries supplied in the programming development environment to provide the basic functions such as graphics, file handling and object management or to use open source libraries for the same functions. The advantage of direct implementation is complete control of the software design and function but at the expense of potentially greater initial investment in writing it.

Table 7 Review of implementation options

As the researcher has decades of experience of software implementation and use of software development tools coupled with the decision to emphasis in the project the development of new methods of analysing the causes of uncertainty rather than produce an elegant user focussed tool as would have been the route if guided by Gephi; the decision was taken to use the direct implementation route and write the software anew rather than use pre-existing tools that do not fully satisfy the needs of the research.

The software was implemented using Microsoft Visual Studio using the C# language. The embedded libraries in the development environment were used to provide:

- File saving and retrieval using XML format
- 2D plot of variables
- The Influence Dependency graph

- Dependency between data and graphical updates.

4.3 Software Interface documentation

The bespoke software was designed to have a main window to show the variables and allow interaction with them, and an I-D graph output to show the I-D space with the variable positions fixed as a result of the analysis. Inputs and controls were facilitated with a set of data entry and parameter dialogs.

4.3.1 Main Graphics Window.

This window holds the menus to map the dialogs and also shows an interactive graph of positions of the variables and the strength of the links between them. The positions of the variables may be adjusted in two ways:

- By manually by selecting a variable and moving it with the mouse.
- By selecting an option to move the variables to the I-D positions.

Also, the graph may be adjusted by selecting a single variable which removes from the view all but those variables directly connected to it in the dependency calculations. An example of the main window is shown in Figure 4-1 below with five variables coloured by group and links coloured by their potency.

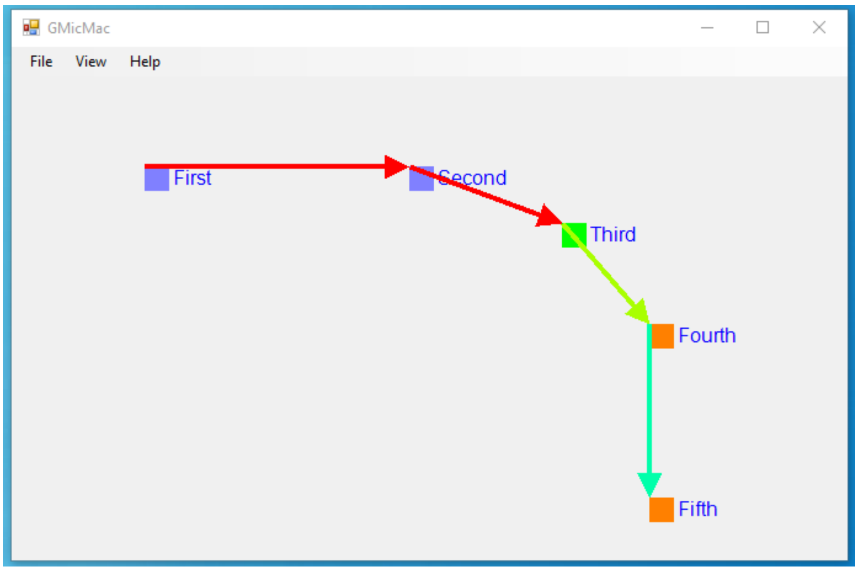


Figure 4-1 Sample Main Window

Main Window Menus

The actions in the main window “File” menu are:

- *New, Open, Save, Save As:* File operations to create a new model, open an existing model and save changes.
- *ID-Graph:* Show the static I-D space graph.
- *Write Cluster Distances:* An option to undertake the analysis of variable similarity as described in Section 3.5.2. This provides a measure of similarity between variables based on the number of links they have in common. The results of the analysis are written to a spreadsheet <modelfilename>ClustDist.xlsx ;where <modelfilename> is the file name for the current model.
- *Remedy Duplicated Links:* An option to clean the model of duplicated links. This should be run after an editing session and before a links analysis.
- *Batch Run:* Select and configure the batch run mode as described in the “Automated Analysis” subsection to section 4.3.3.

The actions in the main window “View” menus are to open the input and control dialogs as documented in section 4.3.3.

4.3.2 I-D Chart:

The I-D Chart Window shows the positions of the variables in the normalised I-D space derived from the dependency calculations. It also shows the stability measures for that configuration and the difference measures from the current reference configuration.

This window has no interactive actions, a sample is shown in Figure 4-2.

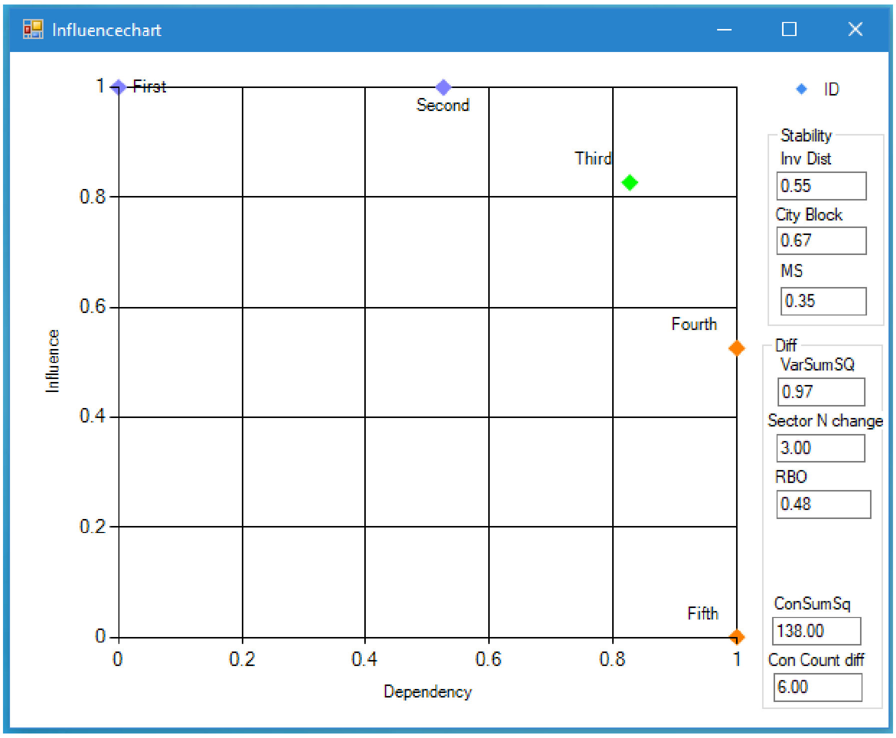


Figure 4-2 Sample ID plot

4.3.3 User Interface Dialogs

The user interface dialogs identified in the "View" menu provide a GUI to the data input and analysis control options.

Variables List and Variable Editor

The variables list contains details of the variables in the system as shown in Figure 4-3.

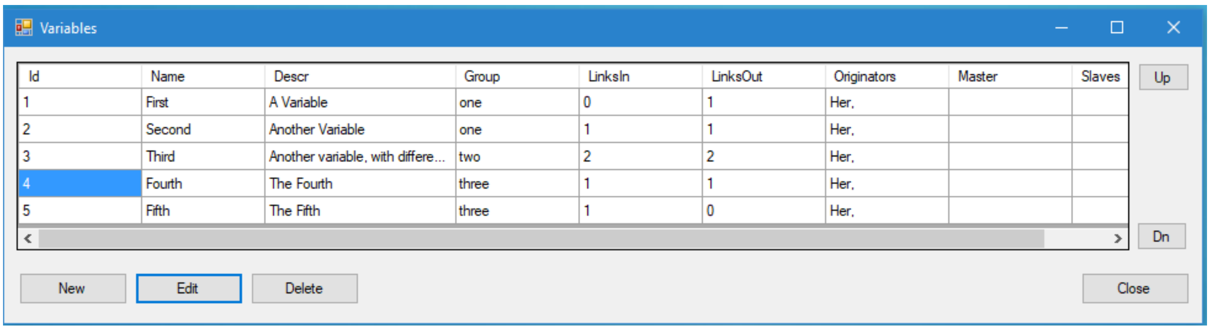


Figure 4-3 Variables Window

The variables may be created, deleted, and edited from this window. They may be moved up and down the list to group them by function or by name. Variables have the following attributes

- A numeric ID used internally.
- A name to identify them to the user.
- A text description.
- An optional group to cluster them by function.
- A list of the originators which identified this variable in the elicitation exercise.
- If a variable is a part of a group where one variable is nominated as master, the slave variables then list their master variable and the master variable shows its list of one or more slaves.

The Variable Editor edits the name and description of a variable and also allocates it to a functional group and a set of originators. If the variable is marked as a slave, the name of the master variable is required. Here, variable “Fourth” is a slave to “Third” and all interactions with “Fourth” will be now be treated as interactions with “Third” in the Influence-Dependency calculations.

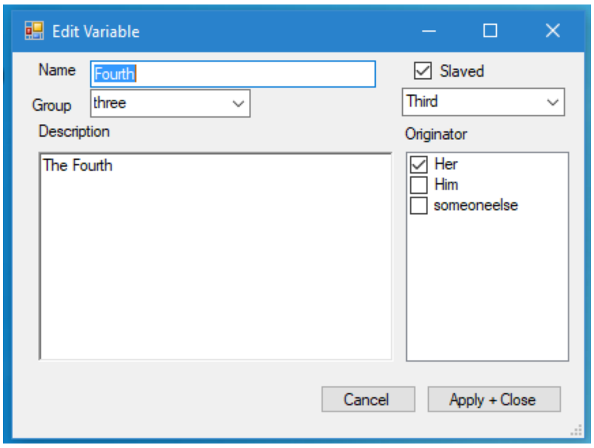


Figure 4-4 Variable Edit Window

The difference to the system analysis when this grouping is used is shown in Figure 4-5. Note that the change in position of variable “T*hird*” is controlled by its combined Influence and Dependency and is not a spatial interpolation of its original position and the position of the variable “*Fourth*” that has been included in it.

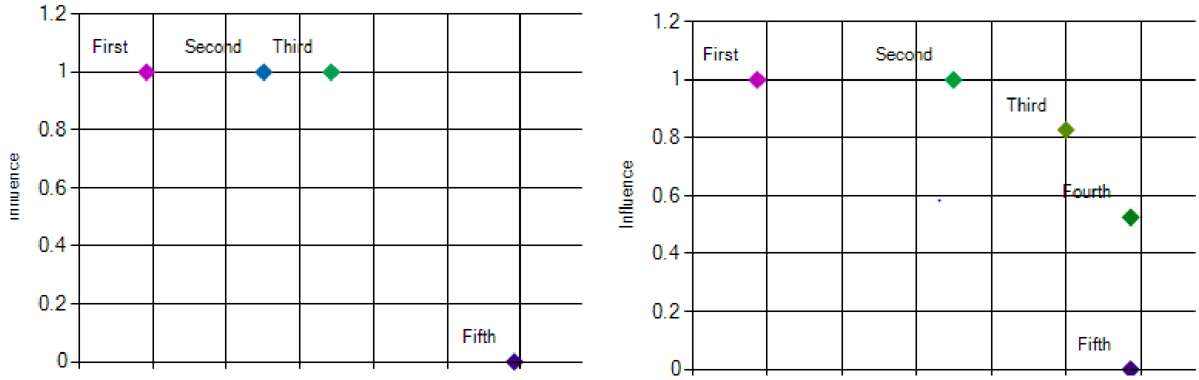


Figure 4-5 Effect of Grouping

Groups and Originators Dialogs

The lists of Groups and Originators are edited by the Groups and Originator dialogs respectively. The Groups list editor is shown in Figure 4-6. Groups are simply labels for variables and may be assigned a colour used in display.

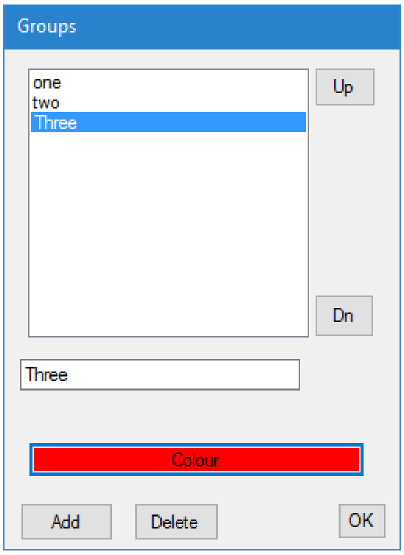


Figure 4-6 Groups list

Originators are labels for variables and links and the Originators Dialog also provides summary information about the number of variables, grouped variables and links owned by each originator.

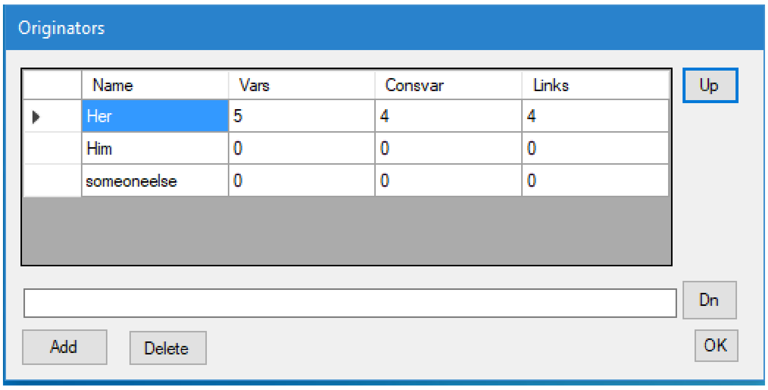


Figure 4-7 Originators Dialog

Links Matrix Dialog

The Links Matrix Dialog, Figure 4-8, is used to edit the links in a 2D matrix. The originator is selected and set as the owner of these links. By double clicking in a matrix cell the link is set to low (yellow), double clicking again sets it to medium (blue) and a third time to high (red). A further double click sets the link back to "none". The links matrix is independent of grouping of variables in the analysis. Note that the cells in the matrix diagonal may not be linked.

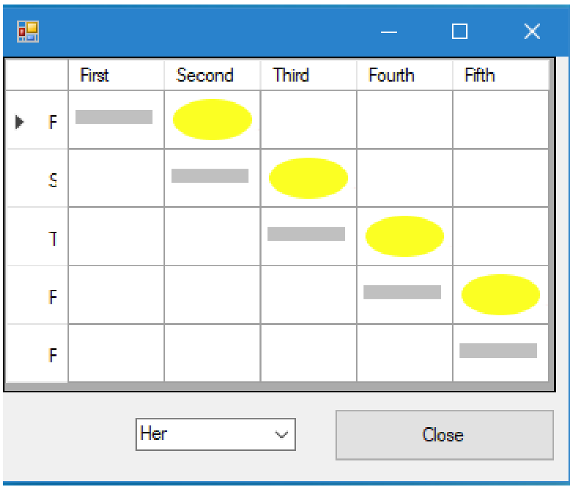


Figure 4-8 Links Matrix Dialog

Controls Dialog

The controls dialog is used to specify the analysis. The options are:

- Select the originators used in this analysis.
- Specify the depth of analysis and the weighting attached to the link potency at each depth with the option to adjust it individually or to set it with a single parameter.

- Select the Summation method which controls how the links are aggregated when multiple originators make the same link.
    - **Sum**: The link strengths are summed. N originators for example allocating weight value 1 will result in a value of N allocated to the link. See Equation 3.4.
    - **Set:** The maximum link strength allocated by any originator to the link will be used. The total number of originators identifying this link is not used in the calculations.
    - **Pow:** The sum value raised to a set power (*p*) is used. If $p < 1$ the strength rises slower than the linear sum option as the number of originators increases, if $p > 1$, the strength rises faster. See Equation 3.5.
- Set the weighting values for the low, medium and high link strengths.
- Set the current configuration as a new reference set.
- An option to pause calculation as parameters are adjusted. As the calculation can take significant time (minutes), it is advisable to pause it if multiple adjustments are made and un-pause it to then make a single calculation with all changes included.
- Set the boundaries and the movement threshold for the zone differences computation as described in Equation 3.15.
- Set the stability measure used to evaluate the rank based ordering difference and the ordering parameters as in equation 3.23.
    - decay factor *p*
    - depth limit *N* where -1 implies no limit
- Move the variables in the main window to their Influence and Dependency positions.

In the sample shown in Figure 4-9, the analysis is to be done with the links from two of the three originators, to depth d=3 using N^p aggregation where p=0.7.

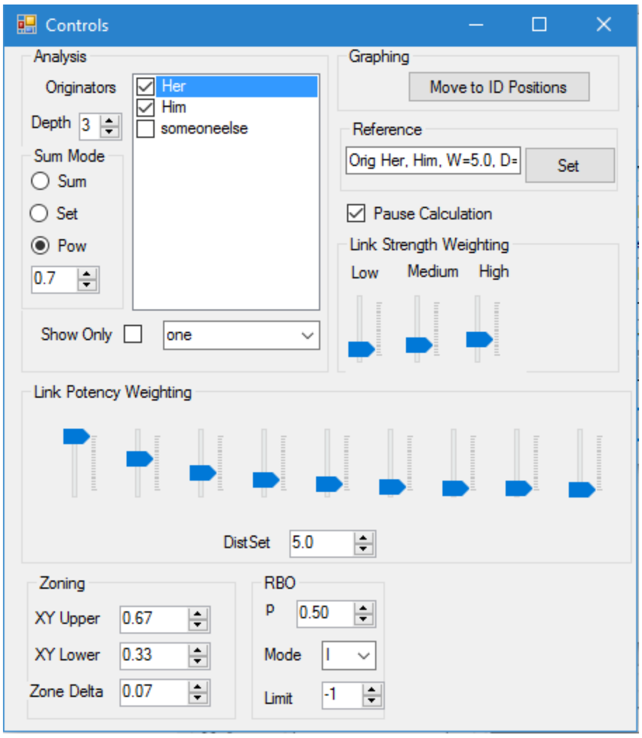


Figure 4-9 Controls Dialog

Automated Analysis Dialog: Batch Run Mode

This is controlled by the Batch Run Dialog shown in Figure 4-10 which sequentially runs the analysis for different combinations of parameters. The controls are:

- The depth of the analysis: An inclusive list of depths. The example shows values 1 through to 9.
- The number of originators: All possible different selections of N from M where N is selected and M is the number of originators in the system. The number of analyses to be carried out peaks when N = M/2. As this is potentially a large number, the analysis may be set to only run every Kth combination. For example specifying 6 originators from 12 yields (12!)/(6! * (12-6)!)) = 924 combinations. If 10 from 20 originators were used there would be 184,756 combinations hence a method of reducing this number is required. Note that the value of K should not be a multiple of the number of originators (M), otherwise a systematic bias in sampling will occur. For example if K=M*3, the selection algorithm will systematically select combinations which always include originator number 3.
- An option to eliminate specified originators from the selection.

- The depth weighting used. In the example shown in Figure 4-10, the analysis will start with 1.0, then increment to 9.0 in 8 intermediate steps. The step length may be varied by adjusting the number of steps.
- The summation mode selected for this set of batch runs. The value of *p,* the summation power will be the value currently set in the control dialog.
- The reference data set used in calculating differences. The reference set is selected in the control dialog by calculating a configuration using the current parameters and marking this as the reference.

The output is saved in the specified excel spreadsheet file for further analysis with one worksheet per run and a summary sheet reviewing the worksheets.

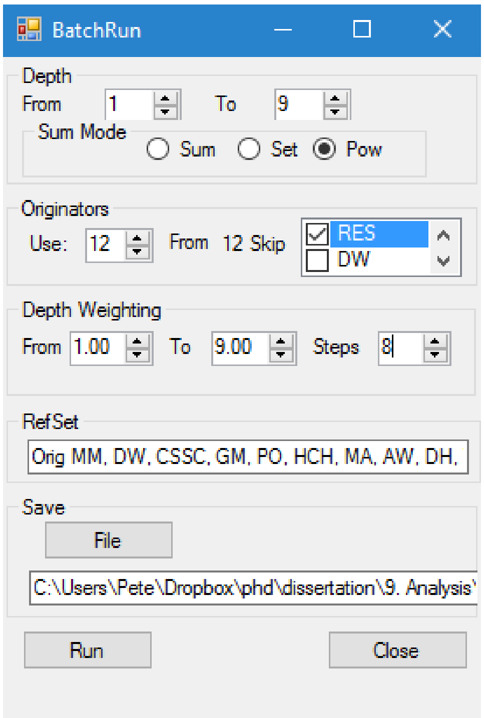


Figure 4-10 Batch Run Dialog

The results in the spreadsheet from this batch run are shown in Figure 4-11:

In the reference worksheet derived from this example shown in Figure 4-11, 81 worksheets , 1 for each configuration of parameters are created and 81 corresponding rows (9 values of weight * 9 values of depth) are output in the reference sheet. The columns in the reference sheet are:

- SheetID: Referencing the worksheet with the variables for this run.
- Depth, Weight: The run parameters.
- Stab_ID, Stab_CB, Stab_MS: The three stability indices.
- VarSumSqDiff, ZoneDiff, ConnSumSqDiff, ConnCountDiff, RBO:I, RBO:ID, RBO:MS, RBO:CB, RBO:ID: The differences indices.
- Sum/Set/Pow: The aggregation method, using the current value of p for power.
- Originators: The subsequent columns contain the list of originators used in this run.

A1 | SheetID

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	SheetID	Depth	Weight	Stab_ID	Stab_CB	Stab_MS	VarSumSq	ZoneDiff	ConnSum	ConnCour	RBO:I	RBO:ID	RBO:MS	RBO:CB	RBO:ID	Sum|Set|	Originator	RES	DW	CSSC	GM
2	1	1	1	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
3	2	1	2	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
4	3	1	3	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
5	4	1	4	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
6	5	1	5	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
7	6	1	6	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
8	7	1	7	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
9	8	1	8	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
10	9	1	9	0.155097	0.169177	0.033527	9.402444	12	12957645	0	0.815352	0.89477	0.631493	0.763802	0.627009	Sum			X	X	X
11	10	2	1	0.166338	0.179464	0.042092	6.463568	29	10745064	0	0.874115	0.971224	0.704601	0.725455	0.660991	Sum			X	X	X
12	11	2	2	0.165982	0.179016	0.041886	6.513008	29	10745064	0	0.874115	0.971224	0.704601	0.725455	0.669123	Sum			X	X	X
13	12	2	3	0.165603	0.178545	0.041667	6.566422	29	10745064	0	0.878531	0.981007	0.704601	0.717323	0.669123	Sum			X	X	X

Figure 4-11 Reference worksheet

The detailed output for each set of parameter and originator combinations is given in the worksheet for each individual run. The variables are listed with their respective measures and gaps are left where either a variable is a slave to a master variable, or the variable is not referred to by the originators specified for this case.

	A	B	C	D	E	F	G	H
1	Variable	Influence	Depender	AND	MS	QS	CB	InvDist
2	Ageing Po	0.020833	0	0.020833	0	65535	0.010417	0.010362
3								
4								
5								
6	Benefit in	0.166667	0.010753	0.155914	0.001792	15.5	0.08871	0.085381
7								
8	NE Private	0.3125	0.010753	0.301747	0.00336	29.0625	0.161626	0.148159
9								
10								
11	Car Use	0.104167	0.569892	0.465726	0.059364	0.182783	0.33703	0.297323
12								
13	PT Passen	0.75	0.247312	0.502688	0.185484	3.032609	0.498656	0.439179
14	Road Netv	0.229167	0.021505	0.207661	0.004928	10.65625	0.125336	0.119195

Figure 4-12 Sample output

Appearance Dialog

This dialog controls how the graph in the main window is presented. The options for the appearance of the variables are:

- Colour by:
    - *By Group*: The variable's group colour is used. This will demonstrate which groups of variables are active in each area of the Impact Matrix. This attribute is also carried through to the ID graph as well as the main window.
    - *By Measure*. The colour for each variable is interpolated between two colours according to either value of the Inverse Distance, City Block, or MS measure.
- Size: The size of the variables.
- Shape: The shape of the variables.
- Font: Brings up a font selection dialog to change the labelling of the variables.

Blocking Links

This dialog, shown in Figure 4-13, allows the analyst to see the relative strength of a link between two variables, normalised to 100, and to select one link, remove it from the system (marked in red) and re-evaluate the system without it. A strength value of 0, rather than an empty cell indicates a link has been made, but in the current configuration, with the specified selection of originators, the link is not used and therefore, while it exists, it is not operative and therefore has zero strength. The "Run Analysis" option systematically goes through all links with a strength value greater than 0, removes that one link and re-calculates the Influence and dependency measures . The outputs are written to a spreadsheet in a similar format to that shown in Figure 4-11 and Figure 4-12.

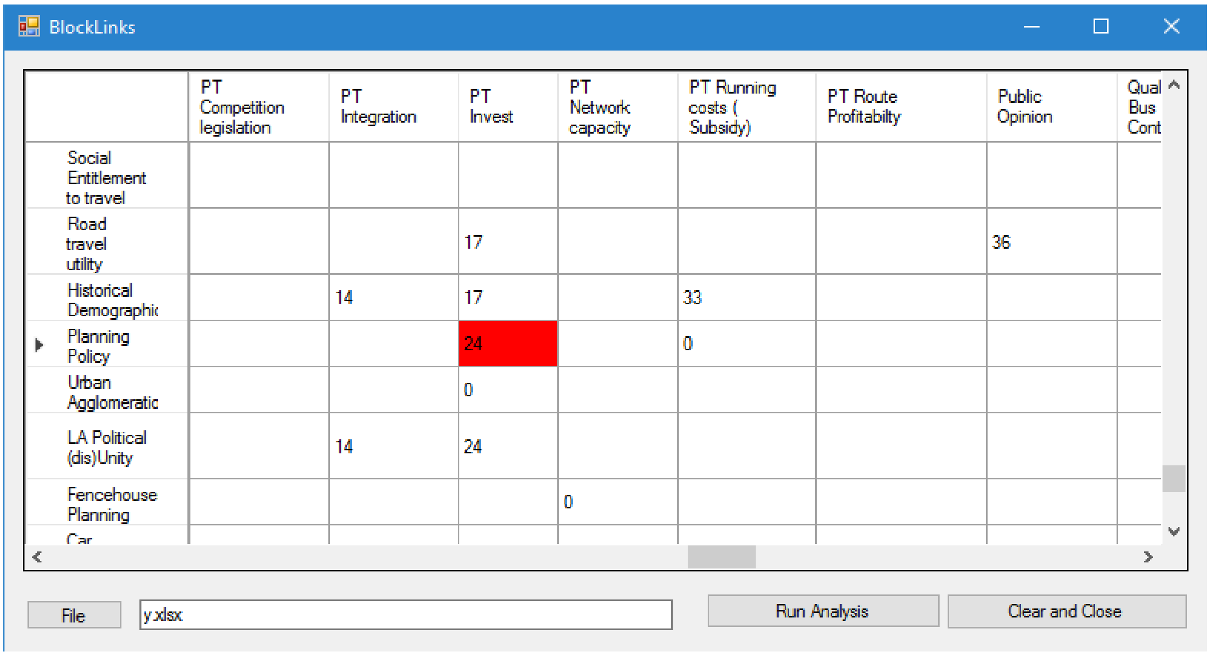
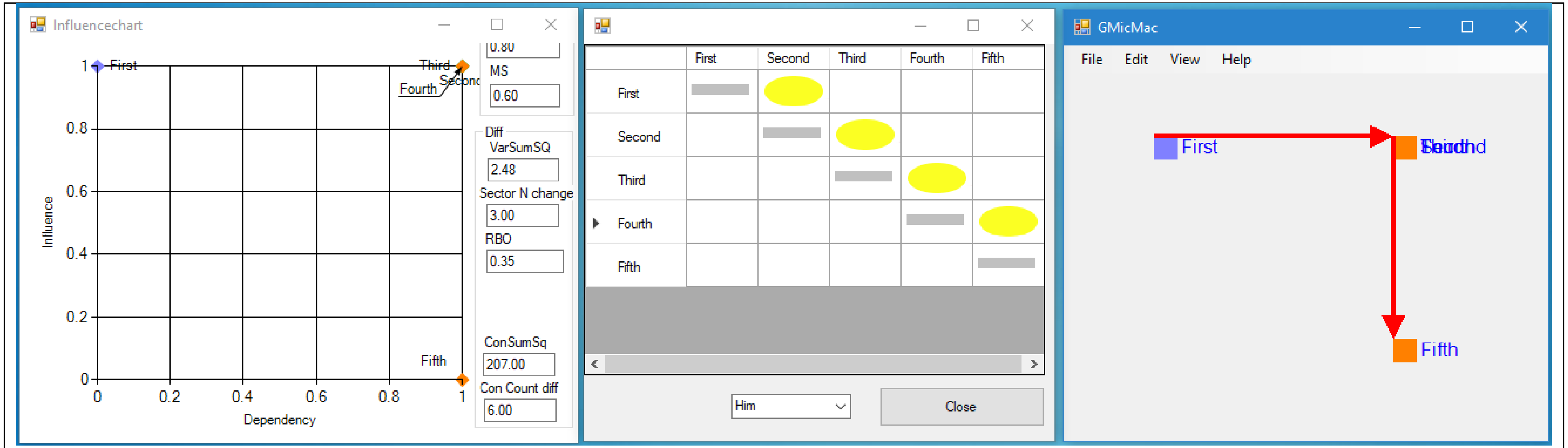


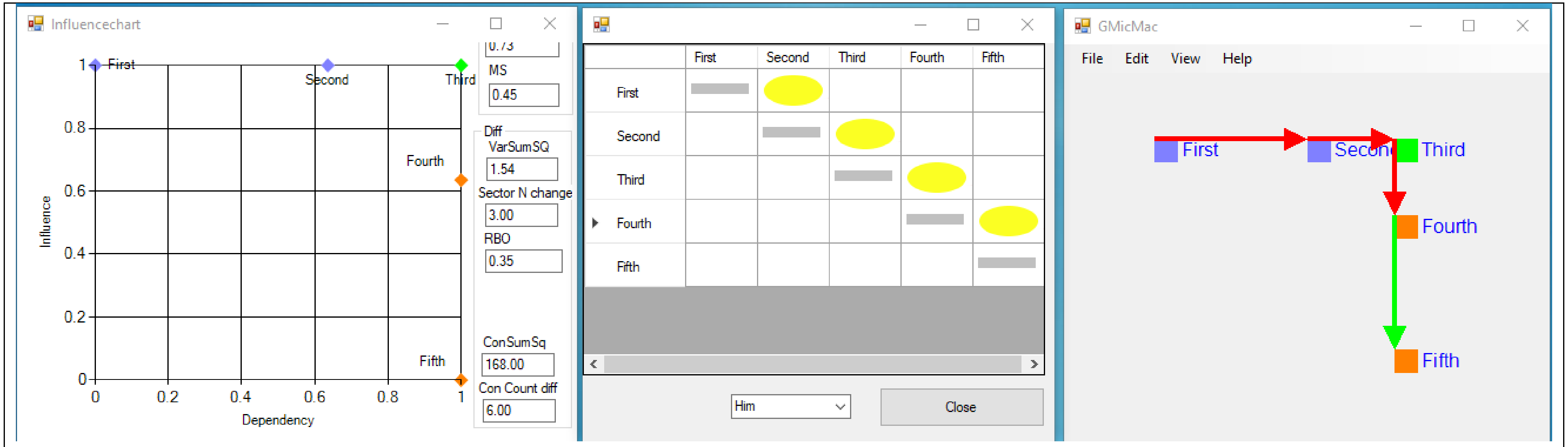
Figure 4-13 Block Links Dialog

4.4 Examples

Some examples of the software in use with a synthetic data set are presented here with a brief explanation.

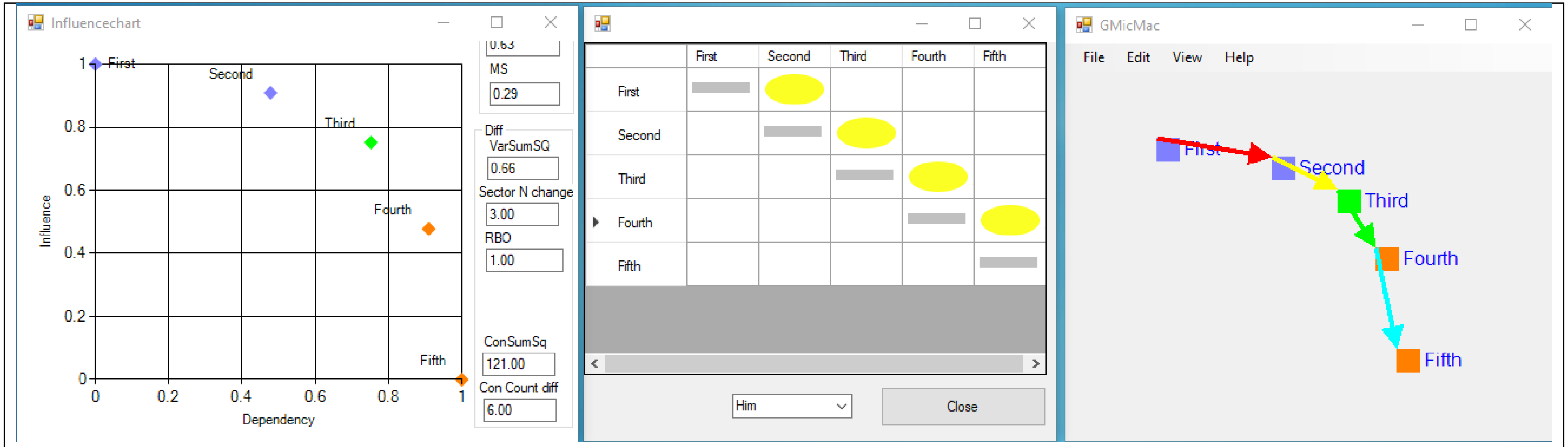


The links selected belong to originator “Him” and are simply directed 1->2->3->4->5. The ID diagram for an analysis at depth d=1 shows 2,3,4 are all equally influenced and dependent while 1 is influential only and 5 is dependent only.

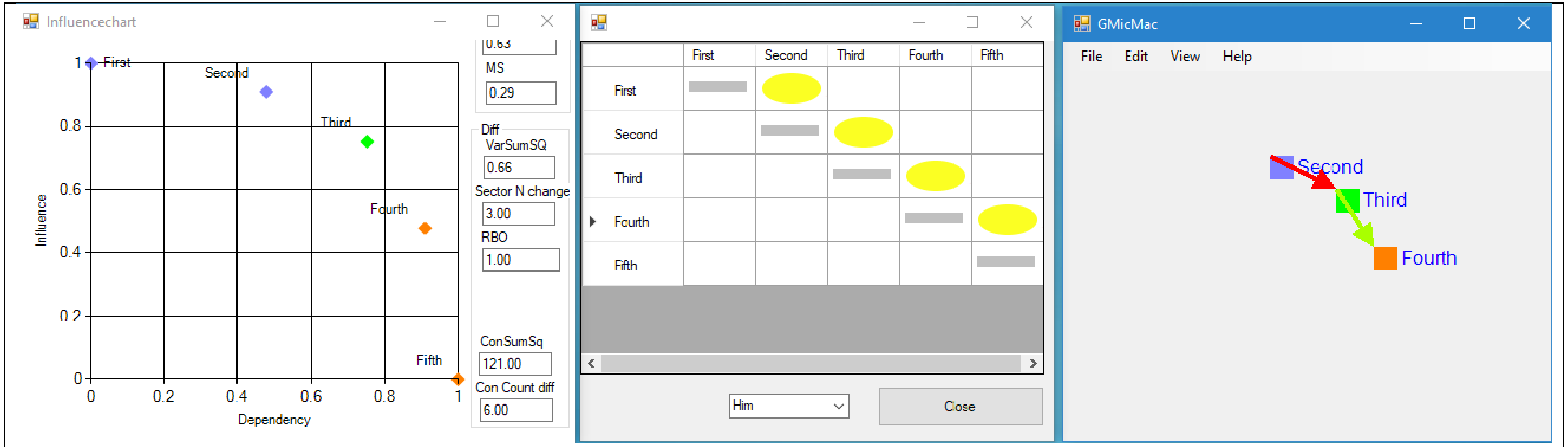


The same data, but the analysis now uses depth d=2 and with a weighting factor of 5 set in the control dialog, the relative weights of the links are 1.0, 0.67.

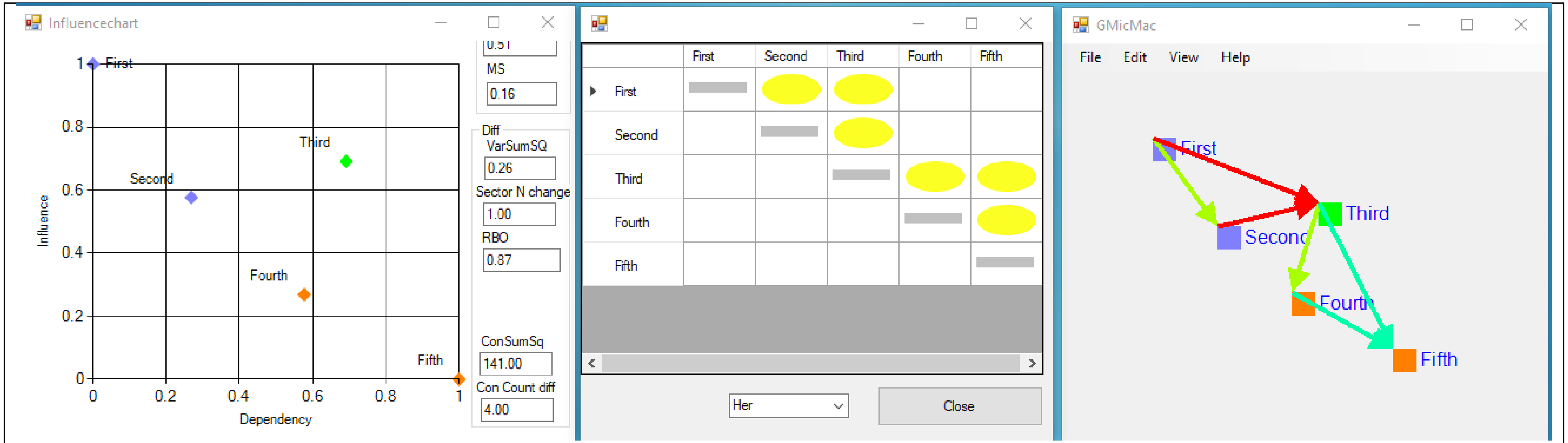
This analysis shows variables 1,2,3 are now all equally influential but differently dependent, Variable 1 directly influences variable 2 and indirectly influences variable 3. Variable 2 directly influences variable 3 and indirectly influences variable 4 and Variable 3 directly influences variable 4 and indirectly influences variable 5. This gives them all the same overall level of influence which is normalised to 1. Variable 4 however only influences variable 5 and hence has lower weighted influence than variables 1,2,3.



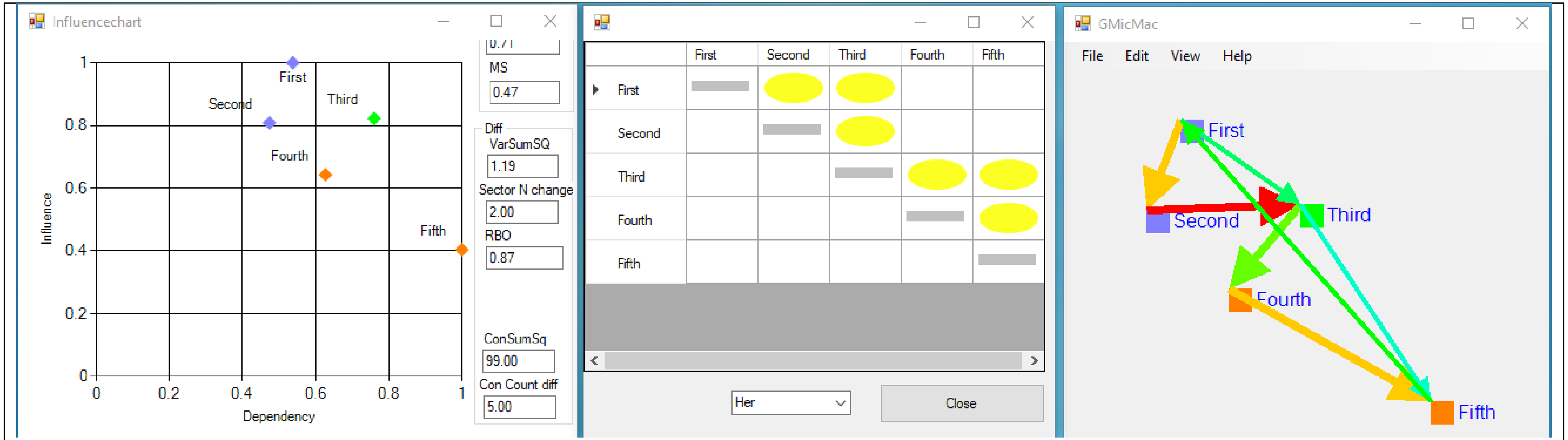
The same data, now analysed at depth d=4 shows that as Influence and Dependency have been extended to greater depth, variables 1, 2 have increased their influence compared to variable 3. Variables 4,5 have similarly increased their dependency. The graph is then normalised to 0-1 on each axis. Note that the potency of each link, a measure of the cumulative causality flowing through it, is shown by link colour and is highest for the link between variables 1 and 2.



The same data at depth d=4, but in the main window, variable 3 has been selected and only those variables directly linked to it are shown allowing the analyst to focus on the role of that variable in the system.



Another originator with a different set of links is used, here shown with an analysis depth d=2. Here variable 5 has zero influence and variable 1 zero dependency Variable 3 however is highly connected.



Finally combining the opinions of both originators at depth d=3 produces a composite analysis. Note that the potency of each link is indicated by colour and the strongest causality now passes through the link from variable 2 to variable 3.

4.5 Summary

In this chapter, the research requirements of the augmented Cross Impact Matrix Method have been analysed and converted to system requirements which can be implemented in bespoke software. The implementation path was considered and the software written using conventional programming methods rather than extending an open source product or adopting a specialised maths programming language.

The software function has been documented in this chapter and its use in the case study will be described in Chapters 8 and 9. In Chapter 8, the batch run mode of the software is used to determine the sensitivity of the outputs to the parameters controlling the analysis and to identify a set of parameters to use in subsequent analysis of the case study. In Chapter 9, the software is used to analyse the case study and to identify the variables in it that contribute most to uncertainty.

Chapter 5 Case Study Selection

This chapter discusses the reasons for the selection of the Leamside Line as a case study to investigate uncertainty in transport planning. The Local Transport Plans of four Local Transport Authorities in the North East of England (Northumberland, Tyne and Wear, County Durham, and Tees Valley) were studied in the context of the Self Conserving Urban Environment (SECURE) project (Bell, 2013) funded by EPSRC. As a result of that review, and of examination of associated consultancy reports, the Leamside Line was identified as a suitable case study for this research project.

5.1 Local Travel Plans

The UK Transport Act 2000 required each Local Transport Authority (LTA) to write a Local Transport Plan (LTP) to describe its transport strategy for the following five years and to update that document every five years. The LTP is intended to describe how the LTA will act to meet a set of five transport related goals, the actions and policies that will be implemented to meet those goals, and the review process and evaluation criteria to ensure that they are met. Further guidance on the requirements of the LTP documents was issued in 2008 (DfT, 2009), and in this directive, the UK Department for Transport (DfT) reduced its own central assessment and monitoring role while giving the LTAs a considerable amount of flexibility in how they interpreted and met their goals. LTAs were encouraged to refine, and augment the original goals to take local needs into account in accordance with their own Local Area Development Frameworks. This increase in local accountability, accompanied by a requirement to collaborate more closely with the local planning framework, implied that while national goals and challenges would underpin the requirements of the transport plans, they would be evaluated locally in the context of the local framework rather than being evaluated in a national context by the DfT. The LTP documents for each area would therefore be expected to diverge in strategy and actions as each LTA responded to the needs of its own area.

The report for the SECURE project reviewed the Local Transport Plans of the four neighbouring authorities in the North East of England; Northumberland (Northumberland County Council, 2011), Tyne and Wear (Tyne and Wear Integrated Travel Authority, 2011), County Durham (Durham CC, 2010), and Tees Valley (Stockton on Tees Borough Council, 2011). The documents all related to the transport plans for 2011-2016, usually referred to as LTP3, the third time these documents had been updated.

Each LTP described a progression from the stated goals to a prioritisation of actions or a check list of how each action satisfied one of the goals. In practice, each LTA went on a different strategic journey to derive from a list of high level goals, a set of actions to be performed to achieve those goals. On this journey, each LTA presented a complex view of a set of actions alternately classified by strategic goal, by geographic area, by action area, and by desired outcome. Several administrative or political emphases may be imposed on any action which implies different LTAs may have multiple different reasons for the same action. While the strategic processes differ, in general there is a common, but loose, hierarchy of strategic thinking in the LTPs: the DfT's five goals are set against a set of prioritisation criteria; action areas are identified and a set of policy statements derived for each area, and actions are described to fit within the policies and priorities. The quantity of information supplied by the LTA for each of these stages varies.

5.1.1 Supporting Documents

The DfT guidance for LTPs advises that the document must be written with due consideration to other strategic goals set out by each LTA; in each of the local authorities within the LTA, and in its neighbouring LTAs. The close links between spatial planning and transport policy require the LTP is written in concert with the Local Development Framework (LDF) and the Sustainable Communities Strategy (SCS).

EU legislation (EU Directive 2001/42/EC on the assessment and effects of certain plans and programmes on the environment) requires that each LTP is accompanied by a Strategic Environmental Assessment (SEA) to ensure the impact of transport proposals on the environment is systematically addressed as part of the planning process. The Habitat Regulation Assessment (HRA) complements the SEA by adding an inventory of the locally significant areas and assessing the effect of LTA policy and of specific transport developments on those sites. The SEA also includes a Health Impact Assessment (HIA) to similarly ensure that human health is considered in transport proposals and to build an evidence base for the effect of transport on health. An Equality Impact Assessment (EQIA) is also required to ensure transport proposals do not either directly or indirectly impact on different groups of people distinguished by race, gender, disability, age, religion/belief, or sexual orientation.

The underlying goal in requiring the additional documents is to promote transparency in formulating and assessing policy effects on health and the environment. However, while each LTP must adhere to a set of DfT and EU requirements, the LTAs are given considerable flexibility to interpret and modify these requirements. The differences between LTAs have developed over time as the emergent behaviour in a large organisation results from a process of incremental change as each initiative settles into a local policy ecosystem (Lindblom, 1979; Lindblom, 1959). This tangle of interaction amongst sometimes contradictory requirements emphasises the complexity of transport policy formation and the effect of the embedded prior beliefs in each LTA which then manifests itself in the diversity of actions and evaluation criteria visible in the LTP documents they produce.

5.1.2 Variation across LTAs

The difference in each LTA's interpretation of the LTP requirements is made evident in their stated prioritisation of the DfT's strategic goals and the evaluation criteria used to measure their performance against those goals.

Goals

The LTPs each identify a set of strategic goals initially derived from the DfT's suggested five goals, which are:

1. Support Economic Growth
2. Reduce Carbon Emissions
3. Promote Equality of Opportunity
4. Contribute to Better Safety, Security, and Health
5. Improve Quality of Life and a Healthy Natural Environment

However, these are suggested goals and the LTAs are able to interpret them as they see fit. Table 8 provides a brief summary of the different prioritisations within each LTA.

County Durham	Co. Durham took the DfT goals but added a new goal as their second priority; to maintain the transport assets. They also removed any prioritisation from the DfT's third, fourth and fifth goals treating them as equal. Their revised list was therefore: • Stronger economy through regeneration • Maintain the transport asset • Reduction of Carbon output • Accessible safer travel • Improving quality of life • Healthy natural environment Co. Durham expands upon these goals in a ten page table with a mixture of specific actions such as "*Deliver Transit 15 and major transport infrastructure improvements.3*", less well prescribed actions "*Promote County Durham as an attractive economic location for investment*", and more aspirational statements "*Embed a 'Whole-Town' approach*".
Tees Valley	Tees Valley described the five DfT goals and quickly highlighted those it perceived to be of highest importance in National Government thinking: • Supporting growth by improving the links that move goods and people around our economy. • Tackling climate change through policies which deliver technology and behaviour that will decarbonise mobility. These were then restated as three challenges: • Improve the journey experience of transport users of urban, regional and local networks, including interfaces with national and international networks. • Improve the connectivity and access to labour markets of key business centres. • Deliver quantified reductions in greenhouse gas emissions within cities and regional networks, taking account of cross-network policy measures. These challenges were then dealt with under three classes of actions at LTA level and further, quite specific, actions were then identified at local authority level[4]. The LTP then went on to reclassify those actions in terms of the non-transport based regional policies and the other regional strategic documents, where other transport policies emerge.
.. Continued	

[3] Transit 15 is an investment in public transport reliability see http://www.durham.gov.uk/Pages/Service.aspx?ServiceId=5867

[4] Note that whereas others are unitary authorities, Tees Valley is sub divided into five local authority areas.

<table>
<tr><td>Tyne and Wear</td><td>The Tyne and Wear LTA rationalised the DfT goals into strategic areas of action, by focussing them towards three major prioritised goals then deriving three classes of prioritised intervention measures to meet these goals. They stated their prioritisation of interventions was to place the lowest cost class of action highest on the priority list.
<table>
<tr><td>Strategic Goals
• Supporting economic development and regeneration.
• Addressing climate change.
• Supporting safe and sustainable communities.</td><td>Interventions
• Managing the demand for travel.
• Management and further integration of existing networks.
• Targeted new investment on regeneration and on inadequate capacity.</td></tr>
</table>
Three chapters in their LTP cover the strategic goals while seven cover the intervention categories.</td></tr>
<tr><td>Northumberland</td><td>In a chapter entitled “Vision, Goals & Objectives” the Northumberland LTP discussed the DfT goals and following a spending review classified its actions into three delivery packages:
• Manage and maintain network
• Influence demand
• Improve capacity
Over the next five chapters, the LTP discussed detailed actions under the five DfT priorities employing a SWOT analysis to describe the strategic nature of transport provision in the region under each heading. This analysis was detailed, identifying specific locations (i.e. road junctions) where action was necessary or where problems originated.</td></tr>
</table>

Table 8 Differences in LTA prioritisation of DfT Criteria

The difference in the ordering of classes of interventions between Northumberland and neighbouring Tyne and Wear demonstrated the freedom for each LTA to set its own goals. In Northumberland, the stated priorities were: 1) Manage and maintain network, 2) Influence demand, 3) Improve capacity. In Tyne and Wear they were: 1) Managing the demand for travel, 2) Management and further integration of existing networks, and 3) Targeted investment on regeneration and capacity. In effect Northumberland appears to have prioritised supply over demand while Tyne and Wear prioritised demand over supply.

Electric vehicles were treated differently by each LTA. They were seen as an economic development action in Tyne and Wear and in Co. Durham; the presence of the Nissan car manufacturing plant may well have influenced this choice of categorisation. Northumberland and Tyne and Wear also viewed electric vehicles as a means to reduce carbon emissions but in Northumberland they were also listed under the heading of influencing demand as, in this

LTP, influencing demand is held to include modal shift to different forms of transport and electric vehicles are classified as a separate mode from fossil fuelled vehicles.

Road traffic noise was treated differently across the LTAs. It does not appear in the Tees Valley LTP, it is briefly mentioned in the Northumberland LTP in the context of environmental assessment of new developments and it is extensively discussed in the Tyne and Wear and Co. Durham LTPs with actions to manage traffic to mitigate noise nuisance; to design quiet roads (through road surface and noise barriers); and to favour acquisition of electric vehicles in the LTA fleet.

The LTAs identify the need for better relations with the bus operators to improve services. Specifically, Co. Durham, and Tyne and Wear identify a desire in the operators to focus on more profitable urban routes in what is a predominantly rural area which is contrary to the requirements of the LTA to improve travel in all areas. In Tees Valley the problem is more oriented towards the different requirements of the constituent local authorities and the lack of co-ordination in public transport provision between them. The political reasons for many of these issues lie in the different motives of the LTA and the bus operators; and, in Tees Valley, the fragmentation of the relationships between the different bus operators and the smaller local authorities.

Northumberland and Co. Durham showed different reactions to the economic dominance of Tyne and Wear, especially the City of Newcastle, in provision of local employment and hence its role in attracting commuter trips. Co. Durham emphasised the need to further develop commuter links to promote regional growth while Northumberland identified provision of more employment within the county as an emerging challenge. However, while these differing strategies were prominent in the respective LTPs, both regions also employed the alternate strategy too. Co. Durham made reference to provision of employment in deprived areas and the barrier that extensive commuting (over 1hr journey time) presented to placing people in employment while Northumberland also sought to improve links to its main commuter destinations in Tyne and Wear.

It may be that in taking the LTP documents at face value, without engaging the LTA stakeholders to determine the real level of prioritisation, we are liable to be guilty of over-interpretation. However, the variation in how each LTA interprets its transport goals and the relevant actions means it is difficult to find a consistent approach to the derivation and implementation of policy and transport provision and emphasises the autonomy of each LTA to create its own strategy for transport in its area.

Evaluation

As with the derivation of LTP polices, each LTA had flexibility in how it chose to evaluate the effectiveness of each of its actions. The DfT listed ten criteria to guide LTAs (Table 9) but allows each LTA to add to the list. Northumberland expanded these criteria directly related to transport in the LTP with 30 additional criteria derived from the SEA report. Tyne and Wear had 36 transport related criteria and another 36 derived from the SEA report while Co. Durham had 36 and 40 respectively although some of the criteria did appear in both sections. Tees Valley had 19 transport related criteria and 25 SEA related criteria although in two cases the SEA criteria simply referred to the DfT list of related criteria.

NI 47	People killed or seriously injured in road traffic accidents
NI 48	Children killed or seriously injured in road traffic accidents
NI 167	Congestion – average journey time per mile during the morning peak
NI 168	Principal roads where maintenance should be considered
NI 169	Non-principal classified roads where maintenance should be considered
NI 175	Access to services and facilities by public transport, walking and cycling
NI 176	Working age people with access to employment by public transport (and other specified modes)
NI 177	Local bus and light rail passenger journeys originating in the authority area
NI 178	Bus services running on time
NI 198	Children travelling to school – mode of transport usually used

Table 9 National Transport Indicators

Some interesting anomalies arise: whilst road traffic noise does not appear in any of the Tees Valley goals or actions, it does appear as one of the evaluation criteria at local authority level. It can be assumed from the context of the evaluation that the relevant unstated actions were those concerning the control of HGV movements through residential areas although this was not clear and it was not the only mitigation action.

Classification also varied between LTAs: National indicators NI175 and NI176 refer to accessibility to services and to employment by public transport or by walking and cycling. In Northumberland these were classified as supporting economic growth (NI176) and improving access (NI175). In Tyne and Wear they were both labelled “accessibility” In Tees

Valley they were referred to as DfT core accessibility criteria but relegated to the Environmental Assessment rather than the core LTP criteria. Co. Durham includes "accessibility"[5] to employment in six of its urban areas when evaluating support of the goal of economic regeneration and in improving access. Under this heading, rather than listing indicators NI175 and NI176, Co. Durham instead lists six individual measures including for example the number of buses tracked in real-time for the county information service.

Once again we have a picture of local variation in response to national guidelines and consequently, difficulty in finding consistent behaviour across LTA boundaries.

5.2 The Leamside Line

5.2.1 Railway History

The brief history of rail transport in the UK is one of chaotic development in the 1800s with frequently multiple links between cities, multiple (often failing) companies running the railway services, and little national co-ordination. In the post war years, as car transport grew, the railways were in decline resulting in their nationalisation in 1948 and in 1963, the Beeching report (Beeching, 1963) recommended wholesale closure of unprofitable lines, many of which only ran the statutory services mandated in 1844 in the Railways Regulation Act (one affordable "workers" train per day). In the 1960s, these services were often redundant as industry had evolved and were poorly supported with few passengers.

Against this backdrop, many railway lines in the UK were closed as the network was reduced in size with emphasis on the profitable long distance routes where the train still competed with the motor car.

5.2.2 The Leamside Line

One transport initiative that was identified in the review of the LTPs as demonstrating the variation in the way each LTA approached the projects was the potential re-opening of the Leamside Line.

The Leamside line is a disused railway line between Newcastle and Durham. It was opened in 1839 and was part of the North East Railway Company trunk route until 1872 when it was bypassed by what is now the current East Coast Main Line (ECML). It was closed to passenger transport in 1964 although by then the only services were a "newspaper" train

[5] Defined as the percentage of employees with a commute of under 1 hr. to arrive by 8:30AM

and a weekly worker's return train between Newcastle and Washington. Thereafter its main traffic was coal and other freight but after the Durham coal mining industry went into decline in the 1980s, the route was closed in 1991 and the line mothballed. In this state, it remains an operational railway in law and capable of being re-opened without the need for the legal processes required by a new rail line although the physical state of the line renders it unusable.

In some areas the track is reduced to single line, in other areas track has been stolen, and one embankment has collapsed. However, the route remains largely whole and much of the major structural engineering works, including the Victoria Viaduct, remain intact. Figure 5-1 shows the route of the line from the junction with the existing main line near Tursdale, four miles SSE of Durham to Pelaw, where it joins the Sunderland line and links to the centre of Newcastle.

Figure 5-1 Leamside Line

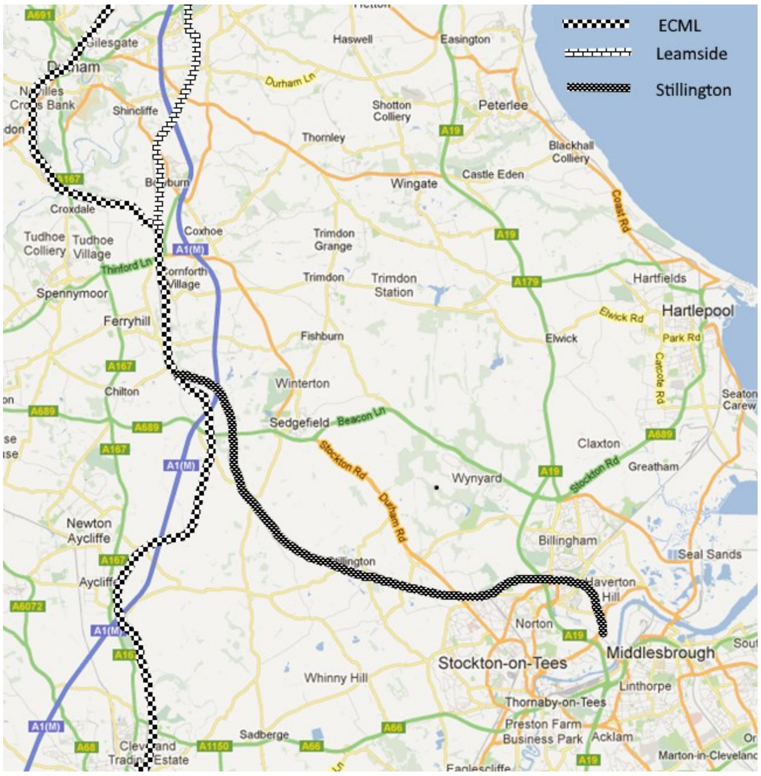


Figure 5-2 Stillington Line

5.2.3 The Stillington Line

The Stillington Line is also often mentioned in the context of re-opening the Leamside line. At present the Stillington Line carries freight only from Teesport at Stockton in the East to a junction with the East Coast Main Line at Ferryhill at its western extent. This line is presently in use but for low speed freight only and would require renovation of the existing track and new stations built if it was to be used for commuter transport. Figure 5-2 shows the route of this line between Tees Port and the East Coast Main Line. Note that the short section of the East Coast Main Line between the two junctions with the Stillington Line and the Leamside Line has four tracks; further north and south of this location, it reduces to two.

5.3 Leamside Line Consulting Reports

The apparent difference in treatment of the Leamside Line became apparent in reviewing the four LTPs for the North East of England and further reports were sought. These are summarised in this section to contrast the differing attitudes of the relevant LTAs as well national bodies with an interest in the line.

The Leamside Line is discussed in two of the regional LTP documents (Tyne and Wear Integrated Travel Authority, 2011; Durham CC, 2010) and the associated Stillington Line mentioned in another (Stockton on Tees Borough Council, 2011). There are five relevant consulting reports on the Leamside Line (AECom, 2010; Network Rail, 2010; AECom, 2007; Network Rail, 2007; AECom, 2006) and a further report which discusses rail projects in the UK (ATOC, 2009).

5.3.1 Tyne and Wear LTP

The Tyne and Wear LTP (Tyne and Wear Integrated Travel Authority, 2011), includes the Leamside Line in its boundaries, and extensive reference is made to it. The main contexts for these references are;

- Improvements to the rail network:
    - Use of the Leamside Line for freight, local passenger and/or Metro services in the Pelaw, Washington and south to the Fencehouses area.
    - In conjunction with the Stillington Line, the Leamside Line offers a significant opportunity to provide a faster link to the Tees Valley City Region and to attract car-borne travellers away from the A1 and A19 trunk road corridors.
- The options available for its re-opening:
    - Access for freight shipments to and from the Nissan car plant.
    - A strategic Park and Ride adjacent to the A1 at Durham Belmont, and improved links onward to the Tees Valley City Region.
    - A diversionary route for main line rail services.
    - The northern section could in principle be used solely or jointly by Metro-type services including:
        a) extension of services formerly terminating at Pelaw, and,
        b) part of a 'Wearside loop' linking Pelaw, Washington, South Hylton and central Sunderland with less distinction between heavy and light rail.
- Environmental assessment:
    - Significant HRA effects at Thrislington SAC., where in the absence of mitigation, there could be potential for significant effects from pollution during any works to re-open the Leamside Line.

5.3.2 Tees Valley LTP

The Tees Valley LTP (Stockton on Tees Borough Council, 2011) makes a single mention of the Stillington Line expressing pessimism at the prospect of funding being made available to upgrade it for passenger use. The Leamside Line is not within the Tees Valley boundaries and the LTP therefore makes no mention of it. This is despite the Leamside Line being the subject of a study (The Tees Tyne Connectivity Study, see section 5.3.4) which focusses on the Leamside Line as a significant component of a transport network that forms an "Urban Agglomeration" of the NE cities of Newcastle and Middlesbrough, and the Tyne and Wear and Tees Valley areas.

5.3.3 Co. Durham LTP

The Co. Durham LTP (Durham CC, 2010) also includes the Leamside Line in its boundary and has plans to make use of it in the context of:

- Transport connectivity
    - Great potential to change entrenched travel patterns. A new station at Belmont could provide access from the existing Park and Ride site with potential connectivity northwards to Washington and Newcastle.
    - Opportunity for relieving pressure on the A1(M) as well as creating the potential to improve internal and external connectivity.
    - Highways England looking at it as one component for mitigating the heavy congestion experienced on the A1(M) and the A1 Western Bypass.
    - A reopened line could take freight and/or passenger services off the ECML which is approaching full capacity in the county and could add resilience to the rail network by providing an alternative route.
    - Park and ride at Durham City.
- A "daughter" policy on freight:
    - The Leamside Line as a parallel route to relieve congestion on the ECML.
    - Associated with the Leamside Line, but not dependent upon it would be the development of a rail based freight facility at a site at the junction of the ECML and the Leamside Line close to Junction 61 of the A1(M) at Tursdale.

5.3.4 Tees Tyne Connectivity Study

This study (AECom, 2006) jointly commissioned by North East Regional Assembly, Nexus, Durham County Council, and Tees Valley Joint Strategy Unit examines options to improve public transport or to promote mode shift between Middlesbrough and Newcastle. The policy goal is described in the "Northern Way Strategy" and is aimed at improving social and economic conditions in the North East of England by creating a wider area economic conurbation to bring more people into employment and widening the skills base available to employers. It identifies the option of re-instatement of the Leamside Line as part of a package to also upgrade the Stillington Line. This report tests seven development options:

1. Improving the Durham Coast line between Newcastle and Middlesbrough.
2. Adding passenger services from Middlesbrough using the Stillington Line to join the East Coast Main Line at Ferryhill.
3. As option 2 but using the Leamside Line to reach Newcastle rather than the East Coast Main Line.
4. Reintroduce a previously discontinued service using the Tees Valley Line via Darlington to join the ECML.
5. Express bus services from Middlesbrough to Newcastle, Durham, Stockton and Sedgefield are improved.
6. Increase car park charges with no change to public transport services.
7. Improve feeder services to express bus interchanges.

In this report, the cost of the combined Leamside and Stillington Line upgrade (Option 3) is estimated to be £112m. Operating costs are estimated at £4.4m pa and revenue from the existing stations assuming an estimated 50,000 journeys annually is £0.3m pa. This option is judged to be the worst of all seven in financial terms. It is notable that when considering option 3, the primary figures used are those concerning the inter-urban journey and the patronage is low. If new stations are built and local services included in the assessment, then the report states that the patronage and revenues will change significantly to 400,000 journeys and £1.5m annually.

The “Tyne Tees Mode Shift Model” was used in this report to predict the movement between road, rail, and bus. This is stated to be an incremental model to predict change in mode choice as provision changes rather than a fundamental model to derive mode choice from basic travel needs. Extensive detail is given about the tangible values entered in the model (fares, distances, and journey times) but no reference is made to the values of time, price elasticity, or the model’s sensitivity to these less tangible values. However the results from the modelling are not claimed to represent the changes in patronage due to a step change in provision, such as re-opening a railway line, neither does it reflect changes in land use induced by changes to the transport network. It only claims to model incremental changes in provision (i.e. timetable or capacity changes) and in effect the report notes the uncertainty inherent in the model due to this incompleteness.

When discussing future demand forecasts in the context of the Regional Planning Assessment (RPA), this report observes that the RPA assumes a steady state in demand structure and a long-term historic trend, whereas new services can lead to step changes in demand. Also more recent trends are for stronger growth despite lack of investment. The Tees Tyne Connectivity Study authors were tasked with creating that step change and hence discounted the RPA low growth figures of 6 – 14% over 20 years observing that across the region rail use has grown by 27% in the 3 years between 2002 – 2005 and in that time doubled at some stations (Thornaby, Seaton Carew, and Chester le Street). However, the figures used in the revenue assessments in the report when projected forwards to 2015 from the base year of 2005 did not take this into account and instead used the same mode choice ratios as observed in 2005 with standard growth assumed as derived from the UK National Trip End Model with TEMPRO (DfT, 2017b).

5.3.5 Leamside Final Report

In 2007 a report was commissioned by Nexus[6] to investigate options to re-open the Leamside Line (AECom, 2007). This report discussed the many options to run local and national rail passenger and freight services. It included the upgrade to the Stillington Line in the list of options as did the Tees Tyne Connectivity study but here, the focus was on the rail line, and considered no other options such as those based on bus transport or the ECML. The report concluded that a weak business case existed for re-opening the Leamside Line albeit with significant financial risk inherent in the re-instatement costs. A stronger case could be made if societal impact was included in the appraisal derived from the economic benefits of the Tyne Tees conurbation operating as an integrated whole rather than as a set of separate cities in the region. The political and economic cases were made strongly in this report while the environmental case was mentioned but did not appear to be included in the quantified assessment.

Three options were identified, the Leamside Line alone, the Leamside with the Stillington Line, and finally, the Leamside and Stillington Lines plus improved merging with the ECML.

[6] Nexus is the Tyne and Wear Passenger Transport Executive and manages transport in that LTA.

Each of these has a high and low cost option depending on the amount of current infrastructure remaining in place

One management option that emerged was for the Leamside Line to be run through a social enterprise model, in effect community owned and operated as a not for profit initiative. The changes in the financial model were slightly obfuscated by simultaneous changes in the operating regime under this business model but the effect on the Benefit Cost Ratio (BCR) is to increase it from 0.96 for the Leamside Line alone with full infrastructure costs to 1.45 for the same option. The report does not give the BCR for the low infrastructure cost, social enterprise management option, therefore it is difficult to comment further.

In predicting demand, the report used the Passenger Demand Forecast Handbook (PDFH) model with parameters derived from a study in Yorkshire:

$$V = k.\ f(P,D,T)$$

Where: V is the number of rail trips between origin and destination on an average autumn weekday.

k is a constant

f(P,D,T) is a function where:

P is a set of population measures at the origin station.
D is a set of destination workplace measures at the destination station.
T is a set of travel times as an absolute measure and as a cost ratio compared with bus or car.

In this exercise, the model was calibrated using local data from Hexham and Sunderland rail services into Newcastle. The value of *k* was found to be under half the value used in the model's original calibration derived from data in Yorkshire indicating lower demand would be expected locally than in previous experience in another part of the UK. No explanation was given for this difference and hence this modelling exercise also demonstrates a class of parameter uncertainty where fitting data from two areas give different calibrated values for parameters; heightening awareness of the importance of basic assumptions, in this case that model calibration parameters are readily transferable.

5.3.6 East Coast Main Line 2016 Capacity Review

The ECML capacity review (Network Rail, 2010) described both freight and passenger operations and focussed on capacity restrictions on the ECML from London to Edinburgh. In discussion of the Leamside Line, this review emphasised its potential role in providing extra freight capacity to relieve the congestion on the section of the ECML immediately south of Newcastle making new Long Distance High Speed (LDHS) services possible by segregating passenger and freight traffic. The authors of this document regard addition of passenger services on the Leamside Line as detrimental to its perceived function if it is re-opened.

This report found the economic case for re-opening was not convincing, as there was, at that time, sufficient capacity on the ECML assuming a high degree of *"flighting"* of services which clusters passenger traffic and freight traffic to cater for their speed differentials. The report stated this assumption may not hold if extra services were required.

The report identified six scenarios for the ECML these are summarised in Table 10 .

	Scenario overview	**Leamside Line an option?**
A	Short-term outcome with freight growth	No
B	Optimised to provide the maximum number of LDHS services along the route.	Yes
C	Optimised to provide an increased number of LDHS services along the route with reduced level of service for other passenger and freight operators.	Yes
D	A likely short-term outcome, i.e. the cheapest	No
E	Optimised to provide maximum number of freight services along the route. Not recommended for further development.	Yes
F	A likely medium-term outcome, the one most effective at revenue generation	Yes

Table 10 ECML Capacity Scenarios

5.3.7 Connecting Communities

This was a national study commissioned by the Association of Train Operating Companies reviewing new rail requirements for the UK (ATOC, 2009). As it reviewed 35 schemes nationally, its discussion of any one of them was necessarily limited, no utilisation figures were given, just a capital cost and a BCR. The Leamside Line was reviewed in the context of adding mainline connectivity to Washington (including diverting the Newcastle – Manchester airport Trans-Pennine service). The capital cost was estimated at £86m, the BCR was 1.4 and re-opening the Leamside Line ranked 10th out of the 35 schemes with a positive BCR assessed nationally. This assessment excluded many of the local services on which the case made in the LTPs rely, although the report comments that if an extensive local service was provided, other stations would be required and further assessment needed.

5.3.8 Tyne & Wear Freight Strategy

The Tyne and Wear Freight Partnership Rail Freight Assessment Report (AECom, 2009) identified issues in rail freight in the Tyne area and discussed the current initiatives to improve rail freight transit in the area. This included the Boldon Curve, a short chord link near Sunderland, re-opened in 2011, the Ashington line in Northumberland and the Leamside Line. The main observations made with regards to the different contexts of the Leamside Line were:

- Freight:
  - Enable the distribution of [Nissan] cars, not only to the rest of the country on the existing rail infrastructure, but also to the Port of Tyne for export.
  - Trade corridor to the industrial estates in Washington and Follingsby for Nissan. This has the potential to reduce the HGV kilometres travelled and reduce the number of HGVs on the A19 and A1 with consequent impacts on congestion and emissions.
  - Address capacity and diversionary issues for passenger services on the ECML with consequential benefits to freight traffic.
- Passenger transport
  - Opening up a small number of stations for a local train service would benefit road users by reducing congestion and also provide a consequent improvement in air quality.
  - Provides connectivity for passengers to Newcastle and Durham through Houghton le Spring and Washington.
- Financial benefit
  - The ECML Route Utilisation Strategy (RUS) recognised that the provision of robust freight paths through the region would involve a major capital expenditure which was very unlikely to be justified with network flexibility benefits alone and other benefits should be sought.

- The Network Rail Freight RUS stated that the projected increase in traffic did not currently give a sufficiently strong case for reinstatement of the Leamside Line.
- The North East rail freight strategy documents, however, state that taking into account:
  - wider economic benefits,
  - forecasted increase in coal and container traffic from the Port of Tyne,
  - possible freight mode shift by industries in Washington,
  - forecast increase in passenger traffic,
  - use of the line as an ECML diversionary route,

  …then the business case improved significantly.

5.3.9 Discussion

The two LTP documents that refer to the Leamside Line both make reference to passenger transport and freight but the emphasis in each LTP is very different. Tyne and Wear place their focus on both passenger traffic and freight in the LTP and heavily on freight in the separate rail freight review. The Co. Durham LTP is much more oriented to passenger transport, in accordance with their strategy of creating better commuter links to the adjacent regions with better employment.

Table 11 compares the summary data from four of the assessment reports where it is available for the assessment scenario, the revenue generation, the costs and the passenger and freight demand. All assume different service patterns and different patronage models but where possible comparable figures are used. For example, the patronage and revenue figures for the Tees Tyne Connectivity Report and the Nexus Leamside Final Report both refer to the Leamside and Stillington option including induced local traffic. However, there is a 75% difference in the predicted number of journeys per year with lower operating costs despite the increased passenger numbers.

The independent study from ATOC is interesting as it describes the Leamside Line in the national context as part of a Trans-Pennine service; a use not suggested by either LTA. The modelling referred to in that report gives a positive Benefit Cost Ratio (BCR) of 1.4 to the reopening of the line with a station at Washington only. The Tees Tyne connectivity report commissioned by the local authorities includes local traffic in its evaluation and while it does not give a BCR, its evaluation suggests the operating costs exceed the revenue by a factor of

3 while the Nexus Leamside Final Report finds this ratio to be closer to 1.5. However, this evaluation does not include induced traffic nor does it include environmental benefits of reduced road traffic. It is also conducted independently of associated measures in the related options such as improving feeder links to the route or managing car parking while these interventions are already proposed by Tyne and Wear and Tees Valley LTAs.

The Leamside Final Report is predicated on the existence of a case to reopen the line and seeks to identify that case and make it as strongly as possible. It finds there is a weak financial case based on revenues and travel time savings but this becomes stronger, though less tangible, when based on building a larger economic conurbation with improved public transport.

The modelling in all these reports is interesting in that the models used are noted to be either poor at handling large step changes in provision or that the calibration of the model using data from the Newcastle area and data from Yorkshire gives a large variation in the value of the key calibration constant. Notwithstanding these caveats, their results in predicting likely usage and financial benefits are confidently presented in the reports and form the basis of their recommendations.

Where the details of the model are known, there appears to be significant question about the confidence we can place in the results and the convergence of the BCR in two reports on a value of 1.4 is interesting. This figure indicates the ratio of the value of travel time savings to the costs of opening and running the Leamside Line. A BCR greater than 1.0 indicates the project generates a nett benefit and for a rail scheme, a value of 1.5 is regarded as the normal value for acceptance to be considered (ATOC, 2009). However the fact that this value is consistently achieved in two very different assessments leads to the suspicion that the modelling has been influenced by factors noted by both Brinkman (2003) and Naess (2013) where a modellers disputed that their forecasts were deliberately manipulated to satisfy the proponents of a project while simultaneously agreeing that forecasts were made to justify projects for which the decision had already been taken. Consistently achieving a value around the threshold of acceptance with such different inputs would merit further investigation.

Report / Topic	ATOC	Tees Tyne Connectivity	Nexus Leamside Final	Network Rail ECML Capacity
Assessment				
Configuration	Single track with loop. Leamside only	Leamside + Stillington. Track configuration not explicitly stated but single track with one or more loops is implied.	Option 2 described here Leamside + Stillington, single track with loops, basic interface to ECML, normal speed option.	Freight only, single track
Stations	Washington	Analysis for six existing stations from M'boro to N'cl. Acknowledges that more local stations may be added.	5 – 7 stations on Leamside line including new Park and Ride. Plus 3 existing stations on Stillington line.	Request for single station at Washington was recorded in consultation with stakeholders
Frequency	Hourly Newcastle - Manchester	Hourly Newcastle - Middlesbrough	1 – 2 local, 1 express, 1 freight per hour.	Seven freight trains per day required to justify cost of re-opening
Revenue ***Leamside + Stillington Including local services***				
Total patronage	Not stated	400,000	693,000	
Total revenue		£1.5m £3.75 - passenger	£2.1m £3.03 - passenger	
Operating costs		£4.4m	£3.3m	

Report / Topic	ATOC	Tees Tyne Connectivity	Nexus Leamside Final	Network Rail ECML Capacity
Costs				
Indicative Cost	£86m Leamside only considered	£90m + £22.1m for the Stillington extension	£83m + £19m for the Stillington extension.	Not given for Leamside Line
Basis of appraisal	Cost benefit analysis based on main line service. Does not assess local services.	Revenue case only.	Cost benefit analysis based on local services. Through services not assessed for the low cost option.	Freight use only
BCR	1.4 Leamside only		0.96(1.46) [7] Leamside 1.14(1.38) Leamside + Stillington 1.06(1.27) Ditto + ECML link	Not given for Leamside Line
Demand Forecasting				
Current	Single statement that there is a large catchment area surrounding Washington with a population of 53400.	Tyne Tees Mode Shift Model to predict incremental mode shift choice.	Forecast using standard PDFH procedures but with lower demand than found in other parts of the UK.	Heavily focussed on freight and the capacity restriction on ECML
Future		Uses TEMPRO figures but maintains same mode choice. Argues that in reality demand will be higher based on local recent growth.	Review of potential benefits to major employment and freight centres on the route for future growth.	Six scenarios reviewed. Four include re-opened Leamside line as a solution option.

Table 11 Leamside Line Report Summary

5.4 Selection of the Leamside Line as a Case Study

Based on the comparative reviews of the LTPS and the subsequent study of the various reports which involved the Leamside Line there appears to be a tentative development which the relevant LTAs in the North East of England will promote but cannot financially

[7] Figures in brackets are the BCR for the Social Enterprise Business Model

justify based on local traffic, for which ATOC (2009) can make a financial case based on what appears to be a lesser case in terms of passenger traffic generation, and for which the Rail Capacity Review (Network Rail, 2010) makes a case based on opening the Leamside Line primarily for freight only. All are very different uses for the same physical transport asset. The strength of the case for re-opening varies too from ATOC claiming it as ranking 10th in England in justification for rail re-opening out of the 35 schemes reviewed to AECom (2006) reporting the Leamside Line to be the least cost effective option of those considered to provide better transport links.

The Leamside line can be seen to present a multi-faceted set of uncertainties including the economic environment it will operate in, the mode of operation, the collaboration of multiple LTAs each with a different vision for the line and the quality of the prediction of its patronage when constructed. The Leamside Line has multiple stakeholders involved in it, each making their own case to re-open it but with no convincing case clearly identified by any one stakeholder. The interaction of policies in the area, with emphasis on freight, on regeneration, and on congestion management coupled with the different evaluation criteria held by the local authorities and by the national rail organisations creates a rich environment of uncertainty which transcends the derivation of the business case through modelling and evaluation and moves into the wider policy ecosystem.

The Leamside line was therefore chosen as a case study for this research and the problem orientation statement developed to take into the start of the analysis was:

> *The Leamside Line is a disused railway line paralleling 18 miles of the East Coast Main Line, South of Newcastle. Re-opening it is considered to be a potential option in the provision of sustainable transport in the North East of England. By what route could a viable business case for development funding be formulated, what associated policies and developments would be linked to that case, and under what conditions would that case succeed?*

Chapter 6 The Normative Scenario

This chapter describes the derivation of the normative scenario used in the backcast elicitation exercise. The normative scenario is the core of this elicitation exercise and is used to present an ideal outcome for the proposed development for discussion with the main body of stakeholders. It is written to describe both the desired goal and the route to achieve it from the current situation. Section 3.4 describes the style of writing which was used in producing the normative scenario. This is in the form of an informal narrative with illustrative vignettes designed to be engaging but not over prescriptive. The aim was to be able to discuss the scenario and provoke discussion in a 1 hour time frame. It was not to be written as a formal consulting report or as a fully referenced academic paper.

6.1 Writing the Scenario

The scenario was written by interviewing four stakeholders with an interest in, or knowledge of, either the Leamside Line or sustainable transport in the North East of England. Stakeholders were identified within Newcastle University and from professional and personal contacts; all had a bias towards opening the line though all had different approaches to identifying the benefits of opening it. The notes and recordings from the interviews were analysed and a three page scenario written with vignettes to illustrate the narrative.

The scenario bounds were set by considering the re-opening of the Leamside Line, however, no limits were set on the direct or indirect consequences of this. Discussion was based around a review of the plans for the Leamside Line, based on a document produced for the SECURE project (Bell, 2013) shown Figure 6-1. This summarised the case for the Leamside Line to be re-opened providing both the problem statement and the initial premise.

6.1.1 Stakeholders and interviews

The stakeholders were:

1. The owner and proprietor of “Chester le Track”, a rail oriented company that owns the rail station in Chester le Street and also sells rail tickets online. #1 has a very strong commercial interest in promoting rail travel in the North East and an

in-depth knowledge of the local issues in the local transport. #1 was interviewed on January 10th 2013 in Newcastle for approximately 1 hour.

2. An activist with the "Rail Futures" national pressure group. #2 is chairman of the North East branch and has an altruistic interest in promoting mode shift towards rail travel to reduce road traffic and congestion and also has a personal preference for rail travel. #2 was interviewed in his home in Durham on February 12th 2013 for approximately 2 hours.
3. A Research Associate in Newcastle University with knowledge of the Leamside Line. #3 has worked on a European Commission FP7 project which developed solutions and processes to enhance the competitiveness of freight transport by rail, in unexploited markets. #3 was interviewed in Newcastle University on April 4th 2013 for approximately 1 hour.
4. #4 is a Professor in Newcastle University with an international reputation for research into sustainable transport. #4 was also the Principal Investigator for the Self Conserving Urban Environment (SECURE) project which researched ways of promoting sustainability in the North East, including the identification of transport inefficiencies. #4 was interviewed in her office in the University on April 4th 2013 for approximately 1 hr 20 minutes.

A selection based sampling scheme was used to identify the stakeholders consulted to write the normative scenario. The goal was to cover passenger rail use, freight rail use, and sustainable transport development. This conformed to the scoping statement which was primarily concerned with re-opening a disused railway.

Notes were taken during the interviews and, where the interviewee was comfortable with the interview being recorded, an audio recording was made using a smartphone App. The discussion was based on the problem orientation statement shown at the end of section 5.4 and on a summary of the consulting reports and LTPs concerning the Leamside Line, based on the conference presentation poster shown in Figure 6-1 but with the numerical information redacted to remove bias in the quantitative questions

After the introduction, the interviewee was encouraged to talk around the subject of why and how it should be re-opened, what it would look like in 2035, and how it would be used? The interviewer took care not to intervene and not to close down any thoughts and opinions from the interviewees.

SElf Conserving URban Environments - *the route to delivering sustainability*

Leamside Line: Case(s) for re-opening

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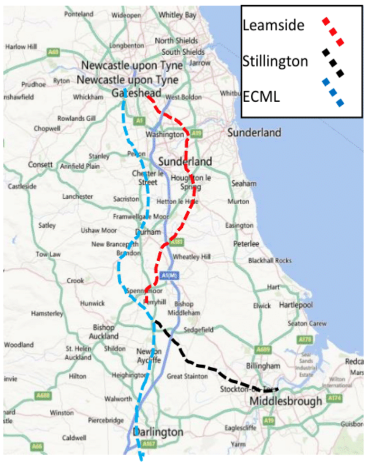
Introduction

The Leamside line is a presently disused railway running parallel to the East Coast Main Line (ECML) from Tursdale to Newcastle. Re-opening it is discussed in the Local Transport Plans by Co Durham as a commuter and by Tyne and Wear as a freight route adding capacity to the ECML. As a commuter route, the Leamside could be linked to the Stillington line providing a new route between Middlesbrough and Newcastle to build an urban agglomeration area to stimulate economic growth. The line has been the subject of several reports with little consistency in their recommendations, largely because no single report takes an integrated view of the case for re-opening.

The Leamside line was closed to passenger trains in 1964 and, with the decline in coal, to freight in 1991, it remains legally an operational railway with the land ownership and access still in place. However, the track and earthworks have deteriorated. The plans to re-open it stem from the capacity constraints on the adjacent section of the ECML. When re-opened, the proposed operations include light rail local services, heavy rail national services, local freight services (Nissan to Tyneport) and to be a part of the national freight network.

In the commuter context, the Leamside in conjunction with the Stillington line (currently open for freight only between Middlesbrough and the ECML) would create a new intra-urban corridor, faster and with higher capacity than the current bus or coastal line services. This could promote the Newcastle – Middlesbrough area as an urban agglomeration area bringing economic benefits of larger urban scale created by better transport and by new communities based around the corridor.

Leamside Documents: Overview	
Local Transport Plans	**Tyne & Wear:** Freight, Heavy rail, Metro extension, P&R. **Co Durham:** P&R, link to Stillington, ECML freight relief. **Tees Valley:** Pessimistic on Stillington investment.
Tyne&Wear Rail Freight Strategy	Trade corridor, reduce road freight, add ECML diversion route, possible passenger traffic too. Financial case weak on flexibility argument, improves if wider economics included.
Tyne Tees Connectivity Study	Re-opening both lines least cost effective of 7 options. Model uses standard TEMPRO growth - lower than observed, ignores land development, inappropriate for step changes .
Nexus Leamside report	Reviews options to open one or both lines. Weak case on transport economics, significant cost risk, case improves with societal considerations, contains uncertain forecasts.
ECML 2016 Capacity Review	Leamside reopened to relieve ECML freight congestion. Leamside is option in 4/6 scenarios, viable 7 trains/day Notes case for opening Washington Station for passengers.
ATOC ^ Connecting Communities	Reviews 35 UK rail re-opening options. Leamside is #10. Only considers long distance services via Washington, acknowledges case improves with local services.



^ *Association of Train Operating Companies*
^^ *Benefit Cost Ratio == cost benefit analysis*

Report Summary: Costs, Services, Income and Demand *				
	ATOC ^	**Tees Tyne Connectivity**	**Nexus Leamside Final**	**ECML 2016 Review**
Indicative Cost	£86m Leamside only	£90m+£ 22.1m Inc. Stillington	£83m + £19m Inc. Stillington	Not Given
Services	Hourly Newcastle - Manchester	Hourly Newcastle - Middlesbrough	2 local, 1 express, 1 freight / hr.	7 freight per day
Stations	Washington only	At least 6 if both lines re-opened	5-7+P&R on L'side 3 on Stillington	None. Request for 1 at Wsh'ton noted
Patronage	Not stated.	400,000	693,000	N/A
Revenue	Just a BCR for	£1.5m £3.75/pass	£2.1m £3.03/pass	Not Given
Operating	Washington service	£4.4m	£3.3m	Not Given
Basis for appraisal	CBA. Mainline service only	Only revenue case noted	CBA on local services only	Freight use only
Future Demand	Not stated	Cautious modelling, but report argues actual demand will be higher.	Reviews freight & employment benefits, implies future growth.	7 trains per day to be viable
BCR ^^	1.4	Not Given	0.96 – 1.46	Not Given

** Only the four principal reports are summarised here.*

Conclusions

The Leamside line has been described as a solution looking for a problem yet the various reports considering its future tend to focus on one aspect of its potential and tend to use cautious figures in estimating demand which belie the observed ~30% increase in local rail use in the last decade. There are many uncertainties in the case for reopening the line(s); there are significant construction cost risks, freight traffic is volatile, passenger forecasts are unreliable, and depend on external influences ranging from land use to national economic conditions. A study into the integrated case for re-opening, including analysis of the uncertainties, is required to build a robust evidence base to inform its future.

Acknowledgements

SECURE is a consortium of 4 universities, Newcastle, Loughborough, Sheffield and Exeter funded by the Engineering and Physical Sciences Research Council (EPSRC) under their Sustainable Urban Environment programme. It is supported by a range of industrial and local authorities' stakeholders.

EPSRC Pioneering research and skills

Figure 6-1 Leamside Line Re-opening: Secure Project Review.

6.1.1 Scenario Structure

The scenario was developed by linking the opinions of the Leamside re-opening expressed by the four interviewees using a mind-map. The final version of the map, laid out hierarchically to highlight the key issues and messages, is shown in Figure 6-2 with notes where vignettes may be written.

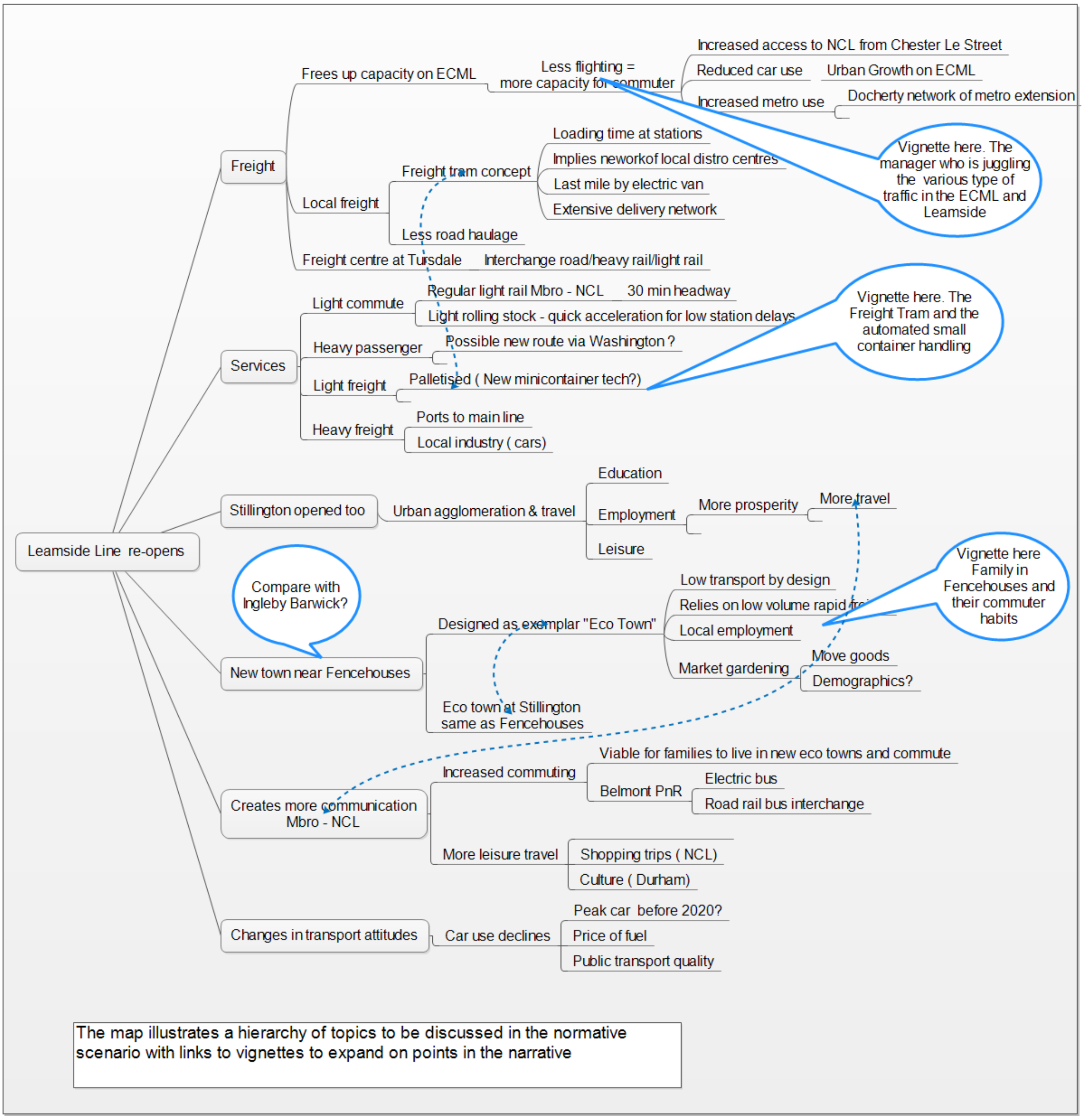


Figure 6-2 Leamside Scenario Mind Map

6.1.2 Normative Scenario

The normative scenario was written based on the recorded interview notes and the mind map. The next stage was that it was peer reviewed within the context of the SECURE project

(Bell, 2013) by presenting the scenario as a route to sustainable transport efficiency in a project workshop meeting attended by multiple researchers from different backgrounds. Advice received at this workshop was to review the work by Lord Andrew Adonis (Adonis et al., 2013) concerning strategies for transport developments in the North East which ranged from extensive metro extensions to far greater provision for car based transport with zero emissions vehicles and an observation that budget constraints as well as the different requirements each would have on urban design meant the scenarios were in some respects exclusive of each other. In the spirit of the proposal in this case study, the scenario in the "Adonis Report" which emphasised rail extension was used to inform the normative scenario developed here.

The final 3 page scenario is presented in Figure 6-3 and a description of how it was used contained in section 7.1.

The Leamside line in 2030

Part of the network

In 2030 the Leamside line is an integral part of the transport network in NE England. The public transport network consists of the Tyne metro, the bus network, the Tees valley metro (recently launched and built from the pre-existing network of suburban rail services) and medium distance rail between Middlesbrough and Newcastle based on the Leamside and Stillington lines which were re-opened in 2025. Coastal train services also run via Sunderland.

The opening of the Leamside line allowed more freight movements south of Newcastle, Rail freight in 2030 also now includes quite short distance lightweight movements within the region as well as the long distance more traditional heavy bulk movements. The freight centre at Tursdale is a key local hub linking the rail and road network.

Public Transport

Public Transport in the NE has been rising since 2000. In the first decade of the century, the rail franchises that were let on the basis of no growth in patronage saw on average a 30% growth in the first 10 years, The NE was starting a slow move back to public transport that was continued through into the 2020s. The Adonis report in 2013 on NE development made choices stark: ring Newcastle with motorways, hope for technology solutions to vehicle emissions and continue to manage congestion; or make the investment in high quality public transport and reduce car use.

The choice fell on the side of public transport development allied to considered congestion mitigation in urban and trunk road hot spots. This strategy worked well with both the EU drive to remove fossil fuelled cars from urban areas by 2050 and the continued problem of range anxiety of electric vehicles which still precluded their use for long distances. The NE public transport network is heavily used both for convenience and because it is also cheaper than running and parking a car.

The commuter service on the Leamside line consists of a light trains running between Middlesbrough and Newcastle. The train stops at Stockton, Thornaby, Stillington New Town, East Durham Parkway (previously known as Belmont Park and Ride), Fencehouses New town, and Washington before arriving in Newcastle Central where it interchanges with the Metro. Journey time is around 1 hour and the ticket is part of the NE England integrated travel card, so for regular commuters, ticket price is not an issue. Stations are well lit, safe places with good connections to the road network and to the local bus services. East Durham Parkway is a good example; the platform, up on the rail embankment, is connected by covered walkways down to the road level where electric buses run a shuttle service into Durham every few minutes (The buses are flash charged at the terminus as they wait for a few minutes before making the return journey). The A1 regional motorway is just 200 yds away from the carpark and there is extensive

Figure 6-3 The Leamside Line Scenario

car parking with electric vehicle recharge points.

New towns

The new rail link was a catalyst for new development at Fencehouses on the Leamside line. The town was designed as an exemplar of low emissions practice with localised food production waste management and employment. The rail link with frequent shuttle buses running round the town was a key part of that design. Walking and Cycling is the main local transport mode with shops, schools and offices integrated within the residential areas rather than set aside on retail or office parks. Many people living in Fencehouses also work there and commuting distances are short. In fact as the cost of travel is low, disposable income is higher and the town is actually quite prosperous. The Leamside line is however a key link to Newcastle and Middlesbrough so using the train for leisure trips as well as commuting to work and to tertiary education is a fact of life in Fencehouses.

Living in Fencehouses

Helen and Stuart and their children are a typical family in Fencehouses. Stuart works in the local utility company office and cycles to work, Helen works in Middlesbro' and takes the train. Depending on the weather she either takes the metro from the station to work or cycles. She prefers to use her own bicycle so leaves one in secure storage at the station although the train carries bikes and "Boris bikes" are available. Their eldest daughter, a student in Newcastle has a very similar commute in the opposite direction. Their son walks to school but his sports activities mean he, and his mates, need transported to rugby and cricket pitches all over the county.

Like most parents, they find transporting children to activities from music lessons to rugby training requires precision timing so, as they use their car, they do appreciate the reduced congestion on the roads compared to what their own parents had to cope with.

Freight

The case to reopen the Leamside line was partly built on redirection of heavy freight trains from the ECML to the Leamside line freeing up ECML capacity in the Durham – Newcastle pinch-point. The main heavy rail traffic is from Tyneport docks onto the national freight network and from the Nissan car plant to the docks. The new freight centre at Tursdale also provides an interface to the road network and onto the local freight operation. The local freight operation is what sets the Leamside line and the rest of the NE rail network apart from the conventional heavy rail freight operation. The key difference is that the distance over which rail is viable has been dramatically reduced. The concept is close to being a "freight tram" with rapid automated handling of pallet sized freight, the use of the suburban rail network and the metro, with small depots serving local areas and electric vans making the "last mile" delivery. The system already complies with the 2011 EU plans to remove fossil fuel powered vehicles from urban centres and has helped boost the concept of urban market gardening pioneered at Fencehouses by making short distance low volume freight commercially and environmentally more viable.

Freight

The nineteenth rail freight depot in Tyne and Wear has just been opened. Its at Benton, close to the metro station and uses the metro lines. Freight cars pull into the siding and automated loading and unloading systems manage micro and nano containers (3 and 1 cubic metres respectively) feeding them straight into waiting vans for local delivery. Containers may be full of market garden produce, from Fencehouses, waste for recycling, or may be full of internet shopping orders about to be delivered over the final mile by a fleet of electric vans

The road to rail

By 2013 there were several reports written on the future of the Leamside line, these discussed local commuter operations, national rail operations and freight only. They had one thing in common; a conclusion that on their relatively narrow individual focus and with economic assessment based predominantly on travel time savings, the re-opening was hard to justify and the Leamside line could be summed up as a solution looking for a problem.

The impetus to re-open came from several sources: the observation that rail passenger numbers were rising beyond what had been forecast causing a re-assessment of the economic case, including the value of emissions savings, including the value of economic growth due to urban agglomeration, and measuring social justice. These all improved the business case as did the drive to find infrastructure investment projects as the UK came out of recession. The fact that the Leamside line was still nominally an operational railway meant the legal process to re-open it was greatly simplified and did not block progress.

The economic case for re-opening the Leamside in tandem with the Stillington line was made on the release of capacity on the East Coast Main line as long distance freight was diverted, on the forecast of mode shift from cars for local commuting between Newcastle, Washington, Durham (East Durham Parkway) and Middlesbrough. There was also support from the HA as part of a programme of congestion management and traffic reduction on the regional roads. The case was made for the 2019 rail control period and construction started in 2022.

The technical barriers to the re-opening, i.e. capacity constraints at Middlesbrough station and management of mixed use freight and light rail were overcome with new rail management systems. More logistical barriers, i.e. duplication of existing Metro, bus and suburban rail services were overcome through collaboration with the bus companies to operate the new local rail service and to complement it with linked bus and metro services with a common ticketing system. The significant engineering problems were expensive (i.e. re-routing past the Victoria viaduct which remains a cycle route) and replacing collapsed embankments; but funding was made available.

The knock on effects of the new rail lines were several. With pressure relieved on the ECML, more commuter trains between Newcastle and Durham were able to stop at Chester le Street promoting more growth in rail use, less cars on the road and playing apart in the growth of Chester le Street as a commuter town. The requirement for more housing in the NE was not able to be met by additional growth in existing towns and Fencehouses was selected as the site for a new town designed as an emissions free community. This, and the need to reduce emissions from delivery vehicles in cities, was the catalyst for lightweight freight on the NE railways and new rail management systems.

Railway Timetabling

John is a rail manager for the NE of England with responsibility for the routes south of Newcastle.

The priorities have changed. In 2010, flighting was necessary in the timetable to batch slow freight and express passenger trains on the line. The number of slower commuter trains stopping at Chester le Street had also been reduced to improve throughput on the line. When the Leamside line re-opened in 2025, some freight was routed on to it to relieve the bottleneck south of Newcastle. More freight could be shifted, and as flighting was no longer necessary, passenger services could be more evenly spaced.

Now in 2030, his problems are back. The Leamside line with its mixture of slow heavy freight and light commuter trains is at capacity. The growth in freight also means the ECML is back at full capacity, the extra commuter services stopping at Chester le Street are heavily used and he is under pressure to find more capacity on the network.

6.2 Quantitative Elicitation

In addition to the normative scenario, six quantitative questions were asked in the interviews which adopted the method of elicitation set out by Cooke (1991) and demonstrated through many examples by Gossens (2008).These questions were initially intended to estimate the design scenarios tested in potential transport models related to this project and to the SECURE project (Bell, 2013) but also served to elicit further causality in the task of re-opening the Leamside Line. Subsequent to this exercise in 2013, similar techniques were described in separate research by Tuominen et al. (2014). These questions were also capable of revealing characteristics of the respondents with regards to their level of agreement with the value derived from all stakeholders (Discrepancy) and their range of values in their answers (Calibration). In this research, however, the primary goal was that in answering the questions, the interviewer was able to gather more data concerning causality as all questions related to the normative scenario, with the exception of the first practice question.

The elicitation method is described in section 2.4.2. It seeks a most likely value for a quantity and a range for that value by combining estimates from expert stakeholders. The method requests respondents to provide a central value and ranges about that value. The quantiles used here were 1% and 25% expressed to the interviewees as:

- -1%: Very surprised if it’s less than… Only a 1% chance it’s less than this value.
- -25%: A bit surprised if it’s less than… A 25% chance it’s less than this value.
- The most likely central value.
- +25%: A bit surprised if it’s greater than… A 25% chance it’s greater than this value.
- +1%: Very surprised if it’s greater than… Only a 1% chance it’s greater than this value.

Note that the quantile of expectation is expressed here and is symmetric at ±25% and ±1%. This does not imply the elicited values are similarly symmetric about the central value.

The following section gives the six questions and the reasons that lead to them.

6.2.1 Questions

Length of the Canal System in Birmingham

The question was “*What is the length of the canal system in Birmingham?”*

This first question had no relevance to the project, but had two goals. The first was to introduce the stakeholder to the method of *range elicitation* so that subsequent responses focussed on the answers, not the method. The second was to calibrate respondents in their estimated use of ranges.

The guidelines for an elicitation exercise recommend that one or more calibration questions are asked so that they can be used to quantify the accuracy of a stakeholder's estimates by calibrating their answers against known quantities (Cooke, 2013; Gossens and Cooke, 2008). With regards to the Leamside Line and Fencehouses, stakeholders have a wide range of levels of local and subject knowledge and hence comparability would be compromised. It is for this reason that a single unrelated question was included and was asked first, introduced to the interviewee as a "practice" question to work with ranges, and this question was suggested as one where many people are aware of anecdotal evidence but would need to rely on "professional guesswork" or "engineering judgement" to quantify the actual length and recognise their estimate contained uncertainty.

Peak Car

The second question was "*In your estimate what will be (or what was) the year of peak car use?"* It was made clear that this was to be answered in the context of the North East of England, rather than global car use. It was intended to elicit the drivers of road travel activity and the behaviour changes that are considered to have occurred.

Fencehouses New Town

The third question was "*Assuming the New Town at Fencehouses is built, what is the likely population?*" If any modelling was to be undertaken of the proposed development, this figure would be required, but in this research, the accompanying question: "*What factors are important in making that estimate?*" was the more important one to investigate the planning and demographic dynamic surrounding the development of the new town and the quantitative question served to focus that.

Leamside Line Patronage, and its Increase

The fourth question was "*What would you estimate the ridership numbers to be in 2025 (year of opening) and in 2030?"* which encouraged the respondent to think about the mode of use. The accompanying questions were: "*What trip types will predominate?*" and "*What frequency of services can be expected?"* This was initially asked as a double question, the first regarding the patronage in 2025 and the second in 2030. However, the question was changed following the first interview as the interviewee simply applied a single growth factor to all range bands. Subsequent interviewees were asked: "*What would you estimate the ridership numbers to be in 2025 (year of opening)?"* and "*What change in ridership would you expect in the first 5 years*?" to elicit a range of growth factors and the reasons for them.

Freight

The final question was "*What is the likely number of freight trains on the Leamside Line per day?"* This was intended to elicit more about the use of the Leamside Line and the planning choices that had been made as plans to reopen it were developed.

The questions that were asked here were designed to elicit more causality by querying the reasons for the quantitative answers that were given and the actual values elicited were not used in this research. However, the values and ranges given by the interviewees were quantified to examine their levels of agreement with each other and their self-precision in estimates. This analysis is described in section 9.2.3.

6.3 Summary

The output from this stage of the integrated methodology is the normative scenario which is used in the elicitation stage described in the next chapter. In the elicitation stage, stakeholders were invited to read the scenario and as they did so, to comment on the plausibility of the events it describes leading to the re-opening of the Leamside line and on the end point of the scenario. The quantitative questions are intended to elicit the same comments on plausibility, but using a different approach.

In developing the scenario, the start point was the Leamside Line and the potential to re-open it based on the review of the LTPs that mentioned the line and the reports concerning its potential future. During the interviews with the four initial stakeholders, the scope of the scenario was extended to include a new sustainable urban development and an innovative local freight handling initiative. Both of these developments used the Leamside Line as an anchor point for their own existence and both contributed to the case for the Leamside Line to be re-opened. The scenario therefore encompassed more than the single act of re-opening a railway line, the scenario included developments that would have synergy with it.

This gave a richer scenario to take forward to the elicitation stage than if it had been generated from the LTPs and consultant’s reports alone.

Chapter 7 The Elicitation Exercise

7.1 Introduction

The elicitation exercise was, in effect, the data gathering and data cleaning stage of the analysis preparatory to the Cross Impact Matrix Method evaluation of uncertainty. The elicitation exercise had six stages:

1. Identify stakeholders.
2. Elicit their views on the normative scenario, supported by the qualitative questions.
3. Identify those variables which control or are controlled in the decision process according to each stakeholder.
4. Identify the causality relationships between those variables from the interviews.
5. After preliminary analysis, review the stakeholder list and identify more stakeholders if necessary.
6. When elicitation was complete, review the variables and consolidate if necessary.

The end point of the elicitation exercise was a list of variables which encapsulate the scenario and the stakeholder's individual interpretations of it. This list was then used to conduct the sensitivity analysis on the Cross Impact Matrix Method itself (Chapter 8) and the uncertainty analysis on the Leamside Line case study (Chapter 9).

In each interview, the stakeholder was given the scenario described in Chapter 6 and asked to comment on it as the interviewer took notes. The interviewer probed the plausibility of the scenario querying why events would happen and why they would not. The interviewer was aware of the issues in elicitation of bias and anchoring as described in section 3.5. The generic coding and the linking methods used to extract data from the interview notes are described in section 3.6. In this chapter the specific elicitation exercise undertaken for the Leamside Line cases study is described using the normative scenario described in Chapter 6.

Six quantitative questions were also asked in the elicitation interviews following the method of elicitation set out by Cooke (1991) and demonstrated through many examples by Gossens (2008). These questions would have provided data to guide any potential transport models related to the project, i.e. in the SECURE project(Bell, 2013) but here they also served to reveal characteristics of the respondents.

Analysis of the numerical values was carried out using Cookes classical method (Cooke, 1991) implemented in the Excalibur (EXpert CALIBration) software from Lighttwist (2016) but as no traditional transport modelling of the Leamside Line was undertaken for this project, the elicited numerical answers were not used in any further analysis. The causality elicited in the process of discussing answers to the quantitative questions was however coded along with the causality elicited from the scenario and included in the Cross Impact Matrix Method analysis.

7.2 Identify Stakeholders

The first batch of stakeholders was identified from the researcher's existing professional and academic network. This network is composed of Transport Planners, Transport Modellers, and Researchers in Newcastle University. Interviews were conducted in late 2013 to early 2014. In June 2015, the research was presented at the final conference and review meeting of the SECURE project (Bell, 2013) held in Newcastle. Approximately fifty attendees were present drawn from the planning, sustainability and transport fields and from commercial, government, academic and activist backgrounds. At that time eight stakeholders had been identified, interviewed and preliminary analysis of the recorded interviews undertaken. After discussion in the conference forum, more stakeholders were identified and three further interviews conducted shortly after.

The final list of stakeholders was:

- **#1:** A Durham City Council Urban Planner with 18 months experience in planning. Interested in the Leamside Line as it is a known potential transport development within the county and will affect the city. #1 was also starting to use the Leamside Line in a study into the optimal location of a freight hub for the North East. Interviewed on 04/10/2013 in Durham City Council for 60 minutes.
- **#2:** A Durham City Council Spatial Policy Team Leader with 18 months experience specifically in transport, but many years in urban planning. Good knowledge of the Leamside Line as it is adjacent to the city boundaries. Interviewed on 04/10/2013 in Durham City Council for 50 minutes.
- **#3:** An Independent Transport Consultant with 30 years of experience, specialising in accessibility studies. No specific knowledge of the Leamside Line but in depth

experience of similar developments and in advising local and national government on accessibility policies. Interviewed on 12/12/2013 in Edinburgh for 100 minutes.

- **#4:** An Independent Strategy Consultant. Previously responsible for a DfT scenario planning project (DfT, 2007) but with no specific knowledge of the Leamside Line. Interviewed on 12/12/2013 in Edinburgh for 110 minutes.
- **#5:** Two: Gateshead Council officials. Both with 7 - 10 years in transport planning and transport policy. Their interest in the Leamside Line is that they represent an adjacent Local Authority. Interviewed on 17/12/2013 in the council offices for 105 minutes.
- **#6:** A Sustainability Projects Manager at Northumberland Council with 30 years of experience in local government. No specific knowledge of the Leamside Line but some experience of similar proposals. Interviewed on 17/12/2013 in the council offices in Morpeth for 100 minutes.
- **#7:** A Strategic Transport Manager with Durham City Council. Knowledge of both the Leamside Line and urban development. Interviewed on 09/01/2014 in the council offices in Durham for 60 minutes.
- **#8:** The Regional Director of a major transport consultancy. A planning consultant with 20 years of experience in advice on planning policy in the North East of England but with no specific involvement in the Leamside Line. Interviewed on 22/01/2014 in Newcastle for 65 minutes
- **#9:** A local campaigner for sustainable transport, a member of the public with no detailed knowledge of the Leamside Line but actively involved in lobbying for better public transport, walking, and cycling provision in the Newcastle area. Interviewed in Newcastle for 60 minutes on 30/07/2015, but with no recording undertaken.
- **#10:** Head of Professional Services at ITS UK with expertise in traffic and transport management. Interviewed in Felton in Northumbria for 60 minutes on 30/07/2015.
- **#11:** Waste Management Transport Manager in Newcastle City. A civil engineer who engaged with this study in his capacity as a transport system user. Interviewed on 30/07/2015 for 85 minutes in the council office in Newcastle.

All stakeholders were identified through professional contacts or from engagement via the SECURE project (Bell, 2013). In effect this was a selection based sampling system where the researcher approached stakeholders based on the researcher's perception of the stakeholder knowledge required. This sampling was reviewed as a part of the methodology intended to augment the stakeholder selection as results emerged from the analysis. Systematic error in stakeholder selection was considered to ensure that stakeholders were not biased to a positive or negative view on re-opening the Leamside Line and that they did not tend towards extreme views, either positive or negative, about the proposal. The stakeholder's characteristics are summarised in Table 12. The salient points that arise are:

- There is good coverage of the types of organisations represented in the sample. Half are from Local Authorities, half are from other relevant organisations, or are independent.
- Planners or planning advisors (i.e. consultants) are prevalent in the stakeholder list although a pressure group representative and a transport user are included.
- All stakeholders either have specific knowledge of the Leamside Line, or relevant knowledge of the services it may provide.
- All stakeholders have a professional interest in the Leamside Line or in similar developments.

Ref	Job Description	Employer Type	Relevant Knowledge
#1	Urban Planner	Local Authority	Leamside Line is within job remit.
#2	Spatial Policy Team Leader	Local Authority	Leamside Line is within job remit.
#3	Accessibility Consultant	Independent	Extensive knowledge of public transport development practice.
#4	Strategy Consultant	Independent	Strategic advice in transport policy development.
#5	Planners	Local Authority	Leamside Line is within job remit.
#6	Sustainability Manager	Local Authority	Relevant knowledge from adjacent Local Authority.
#7	Planner	Local Authority	Leamside Line is within job remit.
#8	Regional Director	Consultant	20 years in transport planning consultancy.
#9	Sustainable Transport Activist	Pressure group	Lobbies for sustainable transport development in the NE.
#10	Consulting Director	National Advisory body	Director of transport technology related professional services.
#11	Transport Manager	Local Authority	Relies on transport for job function.

Table 12 Stakeholder Summary

An alternate sampling technique would have been to use an open system of self-selected respondents garnered from social media or from email groups. This sampling technique was rejected for use here in this research as the methodology relied on open ended interviews to explore the uncertainty in the case study. Using a closed set of questions, or imposing a requirement to form a detailed response to a complex scenario without offering the interviewer the opportunity to probe causality in depth would reduce the depth of inquiry available in the proposed data collection method. Also, allowing respondents to be self-selected removes the control regarding sample bias from the researcher and places it with the respondents.

7.3 Interview Coding

The interviews were recorded using a smart phone App and notes were taken as the conversation continued. The interviews were later coded in the NVivo software using the method described in Section 3.6.3. The interviewer focussed on asking questions on causality between elements of the scenario. Interviews in 2013 and 2014 were transcribed and the text document coded. Given the accumulated experience, interviews in 2015 were coded directly from the audio recording into the NVivo database. The interviewer's notes from all interviews were similarly coded in NVivo yielding 2 coded documents per stakeholder.

Variables were classified according to a small number of classes:

- Economy and Demographics
- Fencehouses
- Leamside
- Politics
- Public Transport
- Road Travel
- Sustainability
- Freight

7.3.1 Number of Variables

Previous research (Miles et al., 2014; Packer, 2011) stated that one measure of completeness of coding is to assess if the number of variables has reached a plateau, i.e. no new variables, or very few new variables are being introduced with each new interview. To assess this, after coding was complete, a search was run using the NVivo "extract" option to count the number of nodes linked to each source. NVivo lists the transcript or audio documents and the interviewer's notes separately hence the maximum number of new variables from each of the two sources for each interviewee was taken. This report was then processed to place the interviewees in the order in which the variables had been coded and the number of variables in the cumulative set found at the end of each coding exercise. Figure 7-1 and Table 13 show how the number of variables rises as coding progresses and the table describes the new variables added by the later coding work. Note the stakeholders are numbered by their interview order which is not the same as the order in which the interviews were coded and the count reported here is the "raw" count, before the variables were rationalised as described in section 7.4.

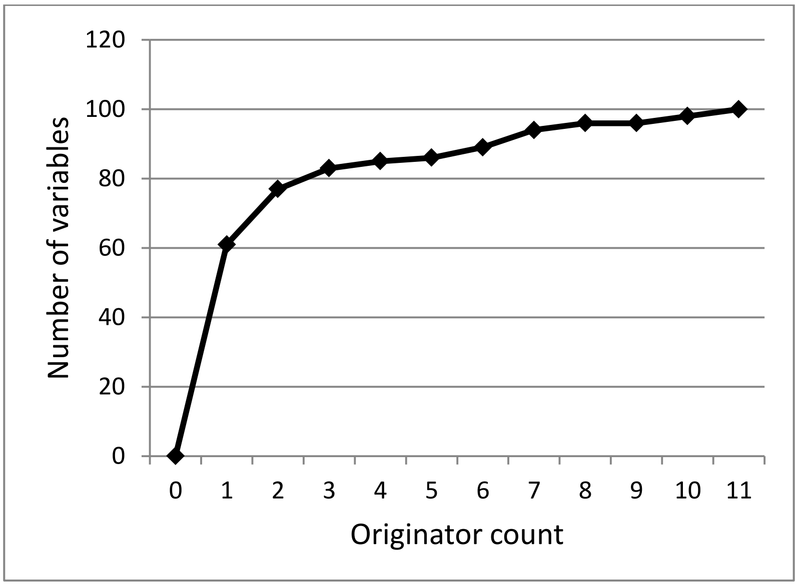


Figure 7-1 Variable Count as Coding Progresses

Seq	Stake-holder	Variable Count	Summary description of variables added.
1	#5	61	Initial coding of variables.
2	#7	77	• In the Behavioural category, a tendency to a longer commute, the historical employment patterns and a rising population but a reluctance to mode shift or move to new areas resulting in the behaviour of commercial developers. • In the Sustainability category, variables centred around electric vehicles and the benefits to the local economy of sustainability policies. • In the transport related categories, integrated freight, public transport running costs and the quality of the road network. In the politics category, the regional planning timescale and the political ambition and foresight in the Local Authorities.
3	#2	83	• In the Economy category, the concept of Durham as a city hub. • In the transport related categories, passenger utility on rail and road, the rail planning timescale and the use of the Leamside line for freight.
4	#6	85	• In the transport related categories, the travel driven lifestyle and the use of car clubs.
5	#8	86	• In the demographics category, a reluctance to start to commute long distances, to contrast with the previously observed habits of commuting long distances in the region.
6	#1	89	• In the road transport category, multiple car ownership households. • In the politics category, the preferred mode of use for the Leamside Line. • In the planning category, the location of Fencehouses.
7	#4	94	• In the politics category, societal justice. • In the economy category, the knowledge economy. • In the Leamside category, rail technology as an enabler of LEP integration to open the rail line. • In sustainability category, the environmental cost
8	#3	96	• In the road transport category, car parking provision. • In politics an institutional bias to spending on road transport.
9	#9	96	None.
10	#11	98	• In the road transport category, a generic variable- the utility of road travel. • In the sustainability category, walk and cycle provision.
11	#10	100	• In the economy category, the heritage and tourism” variable as a generator of travel. • In the politics category, the social entitlement to travel variable.

Table 13 Variable Count as Coding Progresses

7.3.2 Coding Practice

Figure 7-2 illustrates coding in practice. It illustrates units of text identified as variables highlighted in the left side window and the corresponding variable shown on the right, the “modus operandi” for NVivo being to select an area and assign it either to one of the catalogue of variables or to create a new variable Selecting a block, or selecting a variable highlights the corresponding variable or block. In this example, the subject under discussion at that time, which implicitly forms another relevant variable, is coded in the block of note “4” (Top left), where in this case “4” refers to a side note made by the interviewee in the text of the scenario. In other cases the context variable was added as a selected block of space adjacent to the notes.

Figure 7-2 also illustrates how blocks of causal diagram (rather than blocks of text) are coded as variables in the analysis and that the coded areas need not be limited to the simple phrases. Transcripts were similarly coded and Figure 7-3 illustrates a typical example where selected areas of text are coded as variables with the text transcribed from the interview in the left window and the variables in the right.

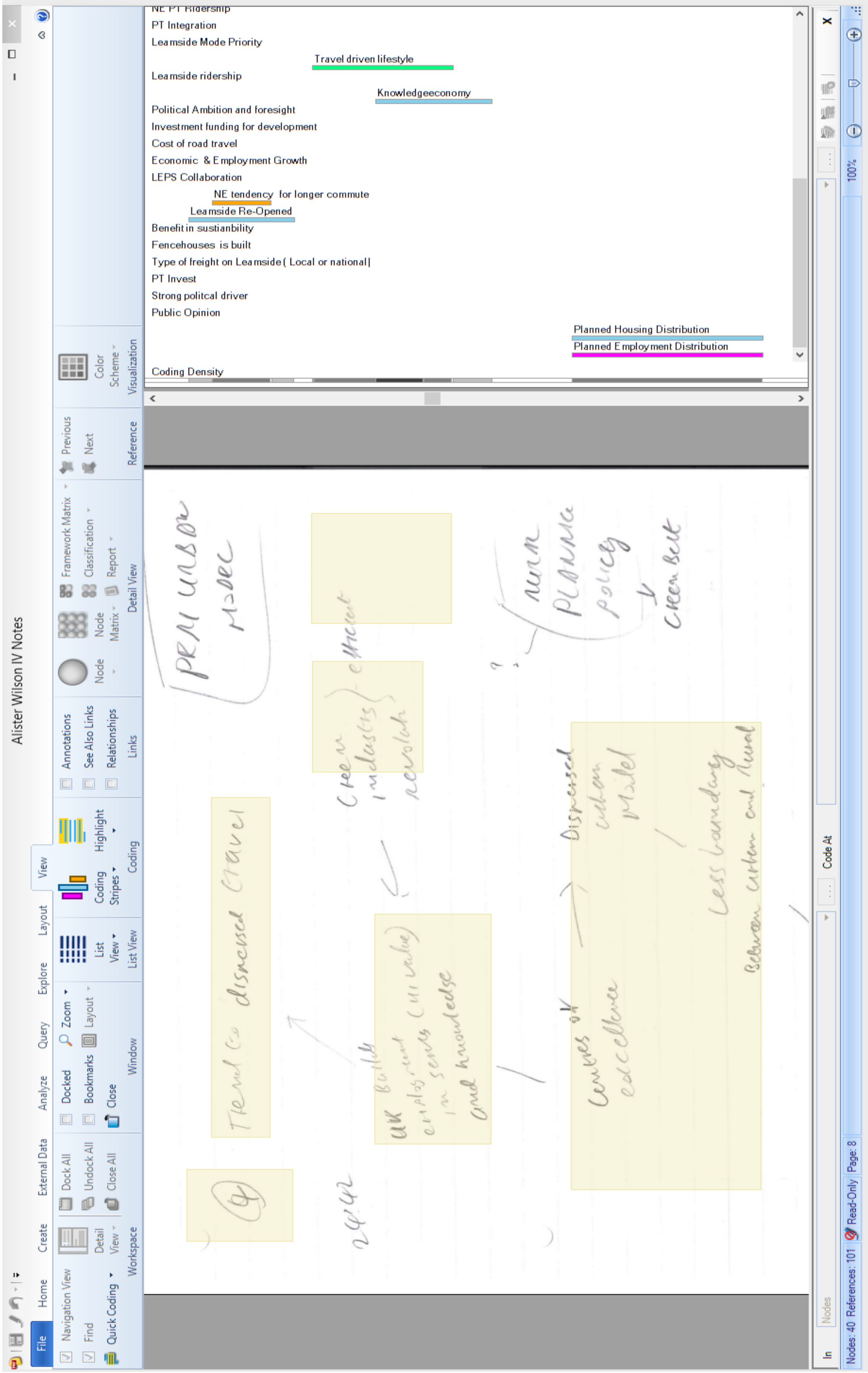


Figure 7-2 Interview Notes Coding

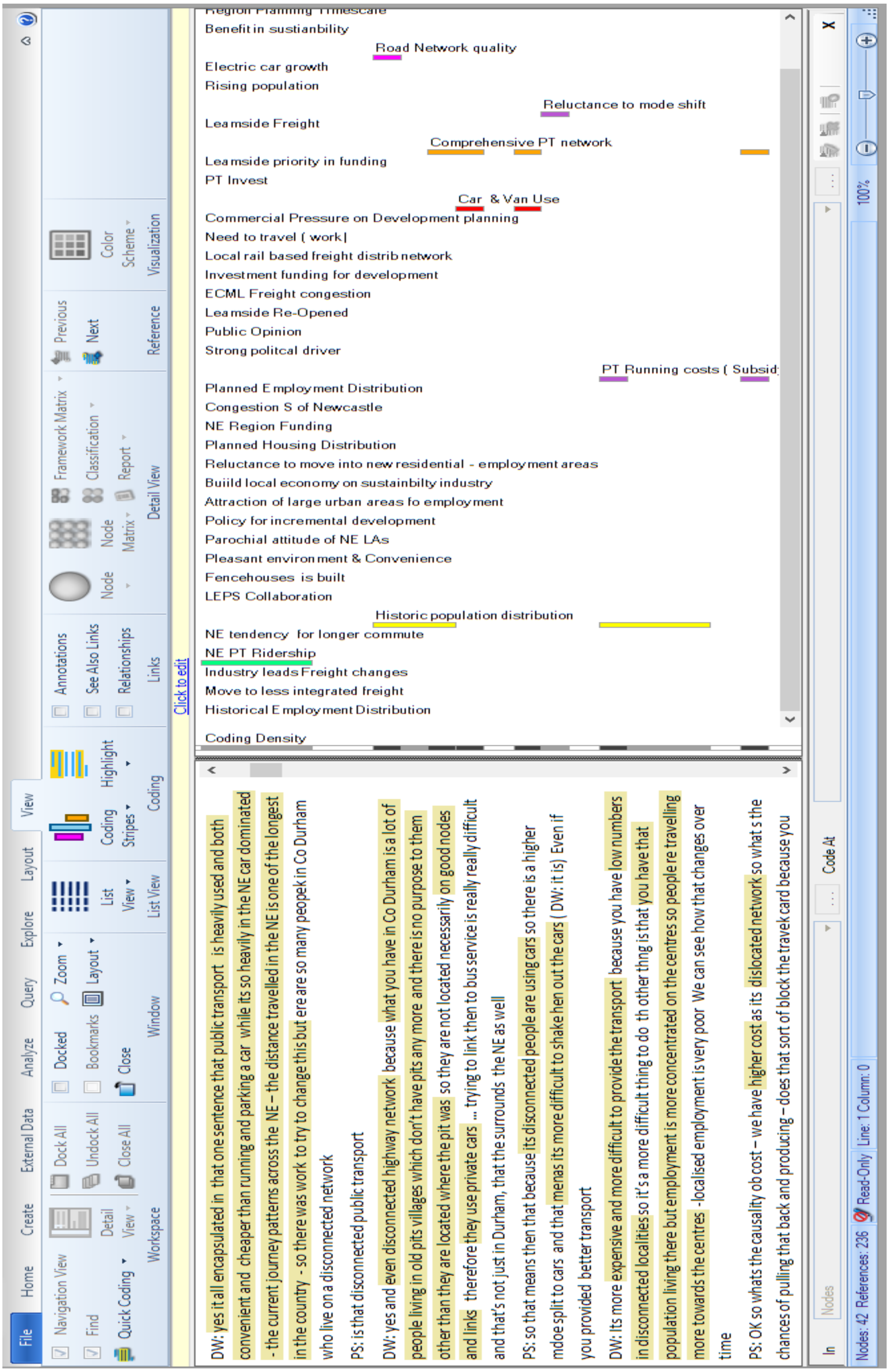


Figure 7-3 Transcript Coding

7.3.3 Linking

Links between variables were formed by searching the transcripts for link words and phrases between adjacent variables and coded as describe in section 3.6.4. The transcript in Figure 7-3 shows typical examples of text that forms the links between variables: "*disconnected highway network*" ***because*** *"… Co Durham villages*" and "*Not located on good nodes and links"* ***therefore*** *"they use private cars*". Similarly links were identified in the causal diagram snippets from the lines drawn by the interviewer between each variable.

These links were interpreted as X influences Y from the context of the discussion or from the stated causality in the transcript and encoded in the analysis software as shown in Figure 7-4. A link matrix was created for every individual stakeholder. Note that in Figure 7-4, no distinction was made about the strength of any of the links, all are coded equally as "low" shown as yellow ovals.

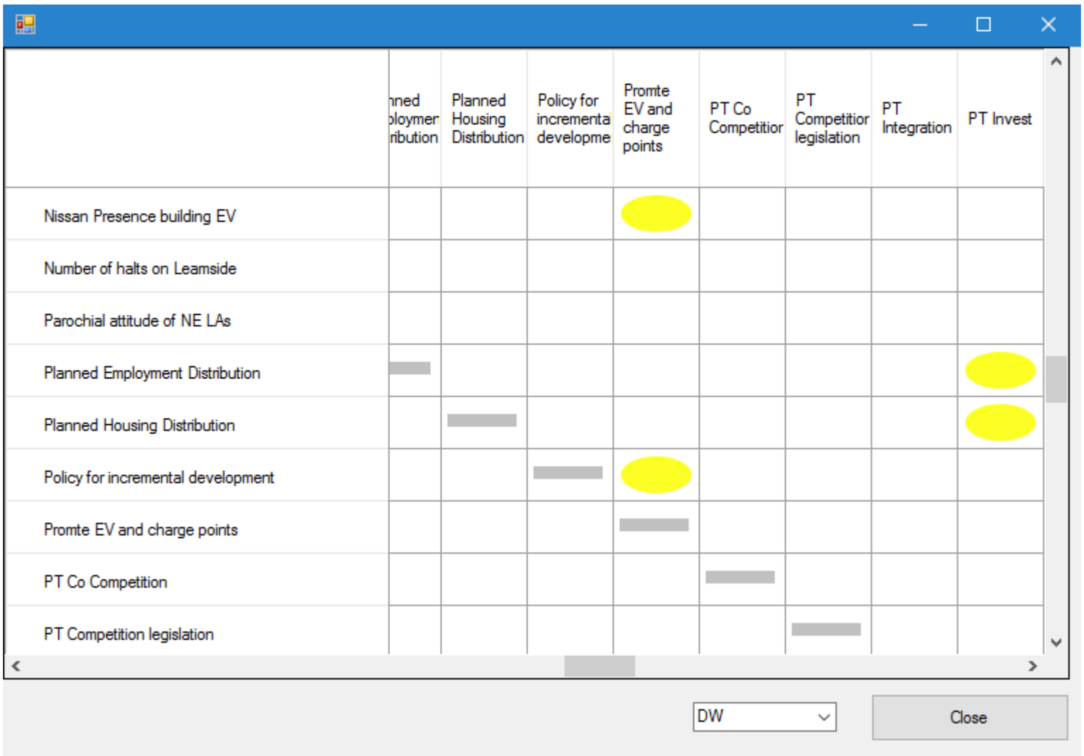


Figure 7-4 Link Coding

7.3.4 Observations

Some generic observations were made during the coding process:

- The scenario suffers the same problem as was observed in a Department for Transport Scenario Planning Exercise attended by the researcher in 2013[8] (Birtchnell et al., 2012; Cook et al., 2012) when efforts to discuss transport network implications of a technology were ignored as the participants discussed the technology. This occurred when the stakeholder did not agree with the concept and departed from looking at the causality between the elements of the scenario and instead challenged the detail of the concept. Their comments then focussed on the shortcomings in the concept and not on how the path to it may either succeed or fail. The interviewer was then drawn into switching from the "what if" questions to the "why not" questions, albeit with the same causality goal.
- The scenario is multi-faceted, which complicated the elicitation. However, if the scenario and interview had been constrained to be too narrow, stakeholders would not have had the opportunity to investigate the causality in the wider context and the analysis would be artificially limited.
- In one interview, when talking about the financial prosperity of Fencehouses, the scenario posits that as people live locally they are better off in terms of disposable income as, with local transport requirements only, and an emphasis on walking and cycling, their personal transport costs are minimal. Several stakeholders agreed but did not go further. Another argued that this is not the case; it is the passenger service that creates connectivity and hence helps create wealth and that saving disposable income through less travel is not a reason for increased prosperity. This illustrated how a point in the scenario, where the causality may be agreed as plausible by several stakeholders, can be refuted and can lead to different causality by another stakeholder.

As coding progressed, some adjustments were made:

[8] In this exercise ~25 transport industry professionals including the researcher were asked to comment on the implications for the UK transport network of developments in 3D printing. i.e. would the freight network in future be used to move a smaller volume of generic 3D print feedstock or the current larger volume of finished parts. In this case, that workshop found that as participants focussed on the (subjectively rather poor) examples of 3D printing technology presented to them, they were consequently slow to move past this to think about the transport implications.

- Coding was subjective. In early coding, a variable was coded as "Congestion South of Newcastle" and another was coded as “Congestion on the Western Bypass". Both refer to the A1 near Newcastle which bypasses the West of Newcastle from North to South. These were trivially amalgamated.
- Initially there were two nodes related to ECML rail utility “Rail Capacity” and “ECML freight congestion”. The two are closely linked in the context of the ECML south of Newcastle where there are passenger capacity constraints primarily due to the volumes of freight traffic and the two variables were paired. The decision was made to merge them as coding progressed and a new variable “ECML Passenger Utility” was created referring to the service offered to rail passengers. Two examples of coding where this merge was made are shown here:

  > **#2:** So the (economic case of the Leamside line*)<Coded as Leamside Business case*> was made on the (basis of capacity) <*Coded as ECML Freight congestion*> - yes so the impetus came from several sources, which is exactly what we are saying at the moment we are looking at freight, suburban rail. And (relieving capacity on the ECML*)<Initially coded as rail capacity*>
  > **#7:** so there is enough congestion< *Coded as Congestion South of Newcastle*> there to turn people on to rail but there (isn’t the capacity to do that) < *Initially coded as Rail Capacity*> so you are right in terms of how you get more (capacity on the East Coast Main line) <*Initially coded as Rail Capacity*> - (get more freight off it) < *Initially coded as ECML Freight Congestion*> so really it’s not carry more freight its carry the freight we have got on the Leamside line

In the latter case, the entire phrase was coded as one variable.

- Four variables were coded related to public transport desirability. These were:
  - Fare cost
  - Comprehensive network
  - Pleasant environment and convenience
  - Service Frequency

  These were merged to one single variable at the linking stage coded as “Public Transport Utility” to reflect the influence of the attractiveness of public transport and its dependence on individual variables coding investment, subsidy and management.

- The variable “Car use” was used for urban congestion. During coding, this was extended to “Car and Van use” when the discussion extended to include last mile delivery by van. This was kept distinct from the congestion variable which explicitly referred to congestion on the A1 and Western Bypass, both on the strategic road network.

7.4 Variable Reviews

At the end of the coding exercise, and after the early analysis, 99 variables were in use[9]. An exercise was carried out to rationalise them using two techniques:

1. Merge those that are similar in their link patterns.
2. Merge those that refer to similar concepts on re-examining the text.

The first is addressed by exporting the links correspondence distance table from the analysis software as described in chapter 4. This table was then used in a hierarchical cluster analysis in Microsoft Excel, extended using software supplied by XLStat (AladdinSoft, 2016). The results of the cluster analysis are shown in the dendrogram in Figure 7-5 using a log scale where a higher value implies greater link similarity.

The second was addressed by manual review by first summarising all variables and by extracting sample text from each. The number of stakeholders referring to each variable and the number of references made to it was also output. Note that as in the coding there were multiple sources for each stakeholder (i.e. scanned notes and transcript), the count from each from the NVivo software was inadequate and was corrected manually to become a count for each stakeholder.

Where, as a result of the review, variables were to be merged; the merging process was undertaken in the analysis software by creating a new variable to act as the master and subsuming others into it as slaves. Appendix A. holds the list of consolidated variables.

The following observations are made, based initially on the variables with high similarity in the clustering dendrogram and subsequently using the text summary from the outputs of NVivo. They are grouped according to the category of the variables.

[9] Table 13 refers to 100 variables. As two have already been amalgamated, 99 are referred to here.

7.4.1 Economy and Demographics

The two variables “Historical Employment Distribution” and “Historical Population Distribution” have a high degree of similarity in the dendrogram. Both refer to the pre-existing demographics of the area.

> *These two variables were merged to a single “Historical Demographics” variable in the “Economy and Demographics” category.*

The two variables “Planned Employment Distribution” and “Planned Housing Distribution” have a high degree of similarity in the dendrogram both refer to current planning policy and both are commonly co-coded in the interview transcripts. Two more variables “Policy for incremental development” and “Regional Planning Timescales” also have a high degree of link similarity; one refers to the style of development and the other to the existence of local structure plans that are infrequently updated as well as the inertia in the planning system. These four all refer to one common concept: Local Authority Planning Policy.

> *These four variables were merged to a single “Planning Policy” variable in the “Economy and Demographics” category.*

The two variables “Attraction of large urban areas for employment” and “NCL MBRO Agglomeration” have a high degree of similarity. The former refers to the effect of a larger pool of employment opportunities the latter to the perceived economic benefits of urban agglomeration and has more links to “political” variables.

> *These two variables were merged to a single “Urban Agglomeration” variable in the “Economy and Demographics” category.*

The three variables “Need to travel to work”, “NE Tendency for a longer commute” and “Travel driven lifestyle” are similarly linked.

> *These three variables were merged into “Travel driven lifestyle”.*

The two variables “Reluctance to commute long distances” and “Reluctance to move to into new residential /employment areas” are closely related in text and in link similarity. Note that the former contradicts the “Tendency to longer commute” and “Need to travel to work” and “Travel Driven Lifestyle” variables but these clusters represent differently held opinions about travel in that the first cluster affects urban planning while the second affects transport planning.

These two variables were merged to a single "Commute Inertia" variable in the "Economy and Demographics" category.

The variables "Rising population" and "Ageing population" both refer to population demographics, but are remote from each other in the dendrogram, the former referring to pressures on housing and transport, the latter to demand placed on public transport by concessionary travel for the elderly.

These two variables were kept distinct.

7.4.2 Fencehouses

While the two planned employment and housing variables already merged into the "Planning Policy" variable are also adjacent to the "Fencehouses is built" variable in the dendrogram, the former two refer to a process, the latter to an action.

The "Fencehouses is Built" variable was maintained as an independent variable despite its similarity in linking to the two planning variables.

The three variables "Fencehouses as a Dormitory Town", "Fencehouses critical mass", "and "Fencehouses link to PT Net" are clustered in the dendrogram and all refer to the size and connectivity of Fencehouses. The variable "Fencehouses is in the right place" refers to the location of the new town rather than explicitly its connectivity but is also co-coded with the "Fencehouses link to the PT net" variable.

These four variables were merged to a single "Fencehouses Planning" variable in the "Fencehouses" category.

The variable "Fencehouses is Built" was revisited in the light of the preceding merge of Fencehouses variables. This variable refers to the actual decision rather than the planning as mentioned in the point above and it is also remote from these planning variables in the cluster dendrogram.

The variable "Fencehouses is Built" was maintained as an independent variable.

The variable “Fencehouses Prosperity” is adjacent to the four Fencehouses planning variables but refers to the post build prosperity rather than the planning action.

This variable was kept distinct.

7.4.3 Leamside Line

The “Leamside Business Case” and the event “Leamside Re-opened” variables are similar in their links but one is the business case made to justify the other and the presence of a strong business case for a transport development does not necessarily imply the decision will be made to fund it.

These two variables were kept distinct.

The “Leamside Journey Time” and the “Number of Halts on the Leamside” variables are related through simple timing but differ in the effect they have on the type of ridership. They are however attractors of passengers to the Leamside Line.

These two variables were merged to a single “Leamside Passenger Utility” variable in the Leamside category.

The “Leamside Freight” variable refers to national freight on the Leamside Line as a diversion route, whereas the “Local rail based freight network” variable refers to the Freight Tram as described in the scenario.

These two variables were maintained as distinct variables, but some recoding was required.

The “Leamside Ridership” and “NE PT Ridership” variables are closely related and share many common links, but one is specific to the case study whereas the other is general to the North East Region.

These two variables were kept distinct.

The “Leamside Business Structure” variable refers to the commercial structure of the business case and has a sole link to the business case.

This variable was merged with the “Leamside Business Case” variable

7.4.4 Politics

The three variables “NE Region Funding”, “LEPS Collaboration” and “Strong Political driver” are clustered in the dendrogram and are also adjacent to “Parochial attitude of NE LAs”.

> *The collaboration and the parochial attitude variable on examination are opposing descriptions of a similar attribute; the tendency of Local Authorities to compete or collaborate; and were combined into a single “LA Political (dis)Unity” variable in the “Politics” category.*
>
> *The regional funding variable refers specifically to the financial variables and hence was kept distinct from the single “LA Political (dis)Unity” variable.*
>
> *The “Strong Political Driver” variable refers to the need for clear leadership for the project to happen. It has similar influence and dependency to LA collaboration, but the act of collaboration does not necessarily imply a leader is found, hence it was kept distinct from those adjacent to it in the dendogram .*

On manual examination, the two variables “Political Ambition and Foresight” and “Strong Political Driver” were seen to both refer to the leadership required to instigate and carry out a transport project. The former tended to be used to refer to institutional leadership, the latter to a project champion for a specific project, but the comments made by the stakeholders were similar.

> *These two variables were merged to one “Political Action Initiated”.*

The variables “Promote EV and Charge Points” and “Electric Car Growth” are similarly linked and refer to the provision of electric vehicles although one is the cause and the other the effect. The variables “Nissan Presence Building EV” and “EV Technology” are also similarly linked and refer to the same concept; the policy in the NE to promote electric vehicles, and its effect.

> *These four EV related variables were merged into one “Electric Vehicle Policy” in the “Politics” category.*

The “Social Entitlement to Travel” variable refers to a need for free travel in poorer areas while “Social Justice” refers to planning for transport availability. Both are related though they do not share many links having only been referenced by 1 and 2 stakeholders respectively. Similarly “Concessionary Travel” refers to a subset of the population (the over 60s) and their existing entitlement to free travel.

> *These three variables were merged to a single “Social Inclusion” variable in the Politics category.*

The variable “Commercial Pressure on Development Funding” refers to urban development and the reality that investors require a return on housing or commercial premises -including freight terminals. The variable “Investment Funding for Development“ refers to public and private transport related development, similarly “NE Region Funding” refers to Government provided funding.

> *These three variables were renamed to “NE Private Investment” and “NE Public Investment” with the variable “Investment funding for development “ recoded to either the public or private investment variable and links adjusted accordingly.*

The variables “Political Ambition and Foresight, “Electioneering” and “Public Opinion” all superficially refer to a political process. The first two are close in the dendrogram, while the public opinion variable is remote. As the text tended to refer to “Electioneering” in a cynical “pre-election” manner while the political ambition is more related to post –election actions they were not merged. The “Public Opinion” variable was remote in the cluster analysis and also refers to the opinions of the public, not the actions of the politicians.

> *These variables were kept separate.*

7.4.5 Public Transport

The variables “Car Use” and “NE PT Ridership” are similarly linked and hence adjacent in the dendrogram, but are coded differently and represent different concepts.

> *These two variables were kept distinct, despite their link similarity.*

The “PT Running Costs (Subsidy)” and “PT Investment” variables are similarly linked, but while one refers to ongoing cost of existing facilities, the other refers to capital investment.

> *These two variables were kept distinct.*

The variables “Belmont Parkway (E Durham)” refers to the presence of an integrated Park and Ride hub close to Durham. In three interviews, the conversation at the time is about the effect on transport and on commerce and tourism at Durham a concept similar to the variable “Durham as a city hub”. In the fourth, the topic is the subsidy required for the connecting shuttle buses to enable this.

These two variables were merged.

The comment leading to the “Gateshead Rail Interchange” variable initially appears to be an example of the parochial nature of local authorities and a candidate to be merged, however, its causality links it to public transport and passenger utility.

The variable was therefore kept separate, but a causality link from “Parochial Nature of LAs” to this variable was created.

The variables “PT Competition legislation” and “Quality Bus Contracts” refer to the control of bus travel by legislation and contract.

These two variables were merged into “PT regulation” in the “Public Transport” category.

7.4.6 Road Travel

The variables “Car Clubs” and “Multi-car households” are similarly linked and share text aspects of the variable “Car ownership”.

These three variables were merged into one “Car Availability” variable in the “Road Travel” category.

The variable “Car Park Provision”, although similarly linked to the “Car Availability” cluster, refers to modifying demand through influencing car transport convenience and although not clustered close to the variable “Road Travel Utility” is similar in meaning.

The “Car Park Provision” variable was included in the “Road Travel Utility” variable.

The variable “Road Network Quality” refers to connectivity and is clustered with planning variables in the dendrogram.

The ”Road Network Quality” variable was renamed “Road Network Connectivity” to avoid confusion with the “Road Travel Utility” variable.

7.4.7 Freight

The "Industry Leading Freight Changes" and "Local Hub Usability" variables share common links and in one instance (of 3 for the latter variable) the two are co-coded.

> *These two variables were merged to a single "Local Freight Requirement" variable in the Freight category.*

The variable "Move to less Integrated Freight" refers to the delivery requirements of consumer and shipper and is co-coded with "Industry leads Freight change".

> *This variable was added to the "Local Freight Requirement" variable.*

The variable "Use of the coastal line for freight" has only one reference and one link to the "Local rail based freight distribution network" variable.

> *These two variables were merged.*

7.4.8 Sustainability

The two variables "Benefit in Sustainability" and "Build Local Economy on Sustainability Industry" refer to different benefits of emissions management/air quality and the economic benefits of new industry and are therefore not closely related. The "Build Local Economy on Sustainability Industry" variable is however similar in intent to the "Planned Employment Distribution" variable.

> *The "Build Local Economy on Sustainability Industry" variable was merged with the "Planning Policy" variable.*

7.4.9 Post-merge Link Checks

Having systematically scrutinised the variables from the clustered dendrogram and by manual inspection, attention turned to the links between variables to re-visit the decisions made, especially where variables had been merged or changed. This exercise resulted in one change.

Examination of the links showed "Rail Management Technology" to be linked to "Political Disunity" and the reasoning behind this apparently incongruous link was queried. The links from "Rail Management Technology" were primarily directed towards to the Leamside business case, passenger utility and freight use of the rail network. The links under question were:

- Stakeholder #4 noted that better transport technology was an enabler of integration – specifically between LEPS.
- Stakeholder #9 noted that LEP collaboration was required to implement rail management technology.

In both cases the technology referred to was in communication technology and use to build collaboration and not in rail management. Collaboration can be understood to imply better communications, and hence integration with technology as an enabler, hence these two links were re-interpreted as collaboration through communication technology and then redirected towards “LEPS Collaboration.

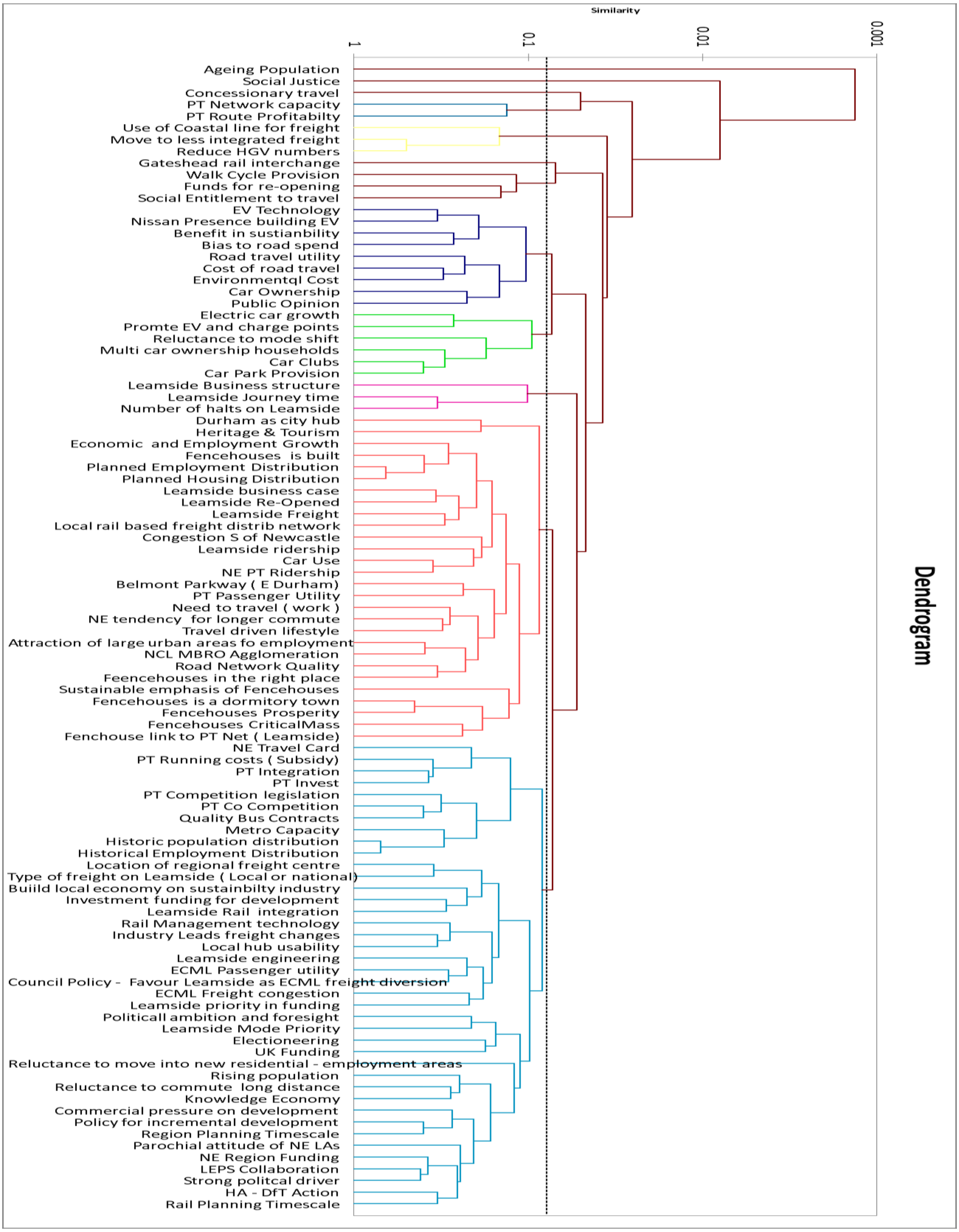


Figure 7-5 Pre Merge Coding Dendrogram

7.5 Summary

The output from the elicitation stage of the research, described in this chapter, is a set of variables which together describe the eleven stakeholder's views of the normative scenario that presents a vision of how the Leamside Line will operate in 2035, with a new community of Fencehouses adjacent to it and a passenger and freight operation. Furthermore these variables also code how that scenario may be achieved. The data coded using NVivo (QSR, 2014) is derived from the interview recordings and transcripts and interviewer's notes. The data transferred to the bespoke software written specifically for this research (Chapter 4) is a copy of those variables before rationalisation and the causalities between them as described by the individual stakeholders in the interviews. The task of merging variables following the review described in section 7.4 is undertaken in the bespoke project software.

The next two stages of analysis will be first to examine the sensitivity of the Cross Impact Matrix Method to the parameters used in its own algorithms (Chapter 8), and second, to examine the causes of uncertainty in the initiatives to re-open the Leamside Line (Chapter 9).

Chapter 8 Sensitivity Analysis

8.1 Introduction

In the taxonomy of uncertainty described in the literature review, one form of modelling uncertainty identified was that due to parameterisation of the algorithms used by the model, specifically the choice of parameter values, and the sensitivity of the model results to those values. If the results derived from a model change significantly as modelling artefacts, i.e. the parameters chosen in analysis, are adjusted then the results of that model cannot be robustly defended. This chapter focusses on the use of the bespoke project software specifically to examine the behaviour of the Cross Impact Matrix Method Algorithms and study the sensitivity of the system to the parameters that aggregate and weight the stakeholder's views on the causality between variables and parameters used to analyse the causality; the analysis depth, and the depth weighting. One of the outputs of this chapter will be an understanding of the dynamic of the method as those parameters change and a recommendation for the values to be used in the subsequent analysis of uncertainty described later in Chapter 9.

Also, although the primary goal of the Cross Impact Matrix Method is to identify the elements of the development scenario that contribute most to the instability of the planning process, there is a complementary goal to look at the reaction of the system to the volume of data used in the analysis, expressed here as the number of stakeholders contributing to the data. If the results vary significantly as an additional stakeholder is included, then once again, the results of that model cannot be robustly defended. The second output of this chapter will be an understanding of how the system reacts as more stakeholders are included.

Therefore, the analysis for this project has been undertaken in three phases; the first two examine the sensitivity of the system to the parameters used in creating the Influence-Dependency graph and the effect of increasing the number of stakeholders. The third, the uncertainty analysis, is described in Chapter 9.

This chapter looks at the first two phases of the application of the Cross Impact Matrix Method:

- **Parameters**: This phase, described in section 8.2, studied how the system reacted to changes in parameterisation of the variables used to control the Influence-Dependency graph generation and how the measures of stability vary in the analysis of the system. The goal was to understand the system reaction to these variables and how to focus the subsequent analysis. As it was not intended to search the parameter space for any optimal solution, this stage could therefore use a simple "One At a Time" (OAT) (Saltelli et al., 2008) methodology.
- **Stakeholders**: This phase, described in section 8.3 studied how the system changed as the number and combination of stakeholders was changed in terms of stability and differences from a reference "complete" set. This stage also looked at the behaviour of the variables as the number of stakeholders changed.

In these first two phases of analysis, the goal was not to analyse the specific aspects of the case study, these phases were intended to observe the general system behaviour.

8.2 Parameter Sensitivity

The parameter sensitivity analysis stage studied the variation in the stability of the system as the methods of combining links were varied; these were the method of stakeholder aggregation, the depth weighting, and the depth of the analysis. The outputs were the stability measures for the configuration with all respondents selected and the difference in the configurations as the parameters were changed.

These parameters are described in Section 3.6.5, and the goal here is to analyse the response of the system measured in stability and in difference. Subsequently the knowledge gained here will be used to guide selection of suitable parameters to use in the analysis of the Influence and Dependency of variables and the effect of the different stakeholders on the stability of the system.

The parameters to be investigated are:

- **Rank Based Ordering:** This was described in Section 3.6.8. The investigation explores the sensitivity of the measure to the depth control parameter "*p*" and hence how the RBO measure may be interpreted.
- **Summation Mode:** This was described in Section 3.6.5 and controls how the strength of link varies according to how many stakeholders made that link. The

investigation examines how number of stakeholders, and the method used to aggregate them affects the results of the analysis.

- **Depth and Weight:** This was also described in Section 3.6.5 and sets the depth of indirect linking and the weight attached to the depths.

The batch run capability coded in the bespoke project software was used to run the analysis with 11 stakeholders at depths ranging from 1 to 9 and weight values from 1 to 9. The runs were using *Sum*, *Set*, and *Power* summation modes with values of p 2.0, 1.5, 0.8, 0.5 for the Power mode.

8.2.1 Rank Based Ordering

Rank order of the variables by their Influence value, their Dependency value or by one of their stability measures informs the analysis of the role of the variable in the decision system. Quantifying their change in order measures how much the system changes as the analysis parameters are adjusted, as the number and selection of stakeholders is varied and as links are broken. The goal of this particular component of the analysis was to evaluate the behaviour of the RBO measure as its control parameter p is adjusted and hence, to understand how to interpret the effect of the parameter and how to interpret the RBO measure in evaluating changes in the order of variables when adjustments are made to the Influence and Dependency calculations.

The RBO p parameter (described in Section 3.6.8 : Equations 3.20 and 3.21) controls the depth weighting of the “agreement overlap” when comparing the order of two sets of the same variables. This parameter weights the changes in order at the start of the set more than those at the end, and in this context means the change in order of those variables with a higher measure becomes more important than those with lower values.

In order to investigate the effect of the value of p in the RBO calculation, the analysis was first undertaken for all stakeholders, at depth d=1 to establish a reference data set. The analysis was repeated with depths d=2-5 to create changes in ordering and the RBO calculation undertaken for the Influence, Dependency and the ID stability measures of the variables for values of p=0.1- 0.99. Note that the value of p has a maximum of 1.0, but a value of 1.0 gives each member of an infinite series a weight approaching 0.0, hence 0.99 was used.

Two assessments of the change in the RBO *p* parameter are shown here. In both cases the Z axis shows the RBO measure where a value of 1 implies that the ordering of the list of variables in the test set and the reference set is identical. The X axis plots the depth, i.e. the change in configuration which determines the actual changes in order and the Y axis plots the *p* parameter which determines the value of the RBO measure reporting that change. In both graphs, the value of the RBO measure is 1 when depth =1 for all values of *p* as this is the comparison with the reference set and the order is therefore the same. At low values of *p,* the RBO measure is weighted to quantifying just the changes in the order of the variables at the head of the list, at higher values of *p*, changes in ordering further down in the list are taken into effect.

This analysis showed two effects in operation in the RBO measure. The Inverse Distance stability variable (See Figure 8-1) showed a step change in the RBO difference measure at depth *d*=3 for low values of *p*. Examination showed this was due to a change in rank order of the two variables at the head of the list which dominated the measure at low values of *p*. Conversely the Influence variable (See Figure 8-2) showed no change in rank order difference with depth at low values of *p* but did show variation at high values of *p* as there was a change in order in variables lower down in the list which was masked by weighting the relevance too much towards those higher up the list at low values of *p*.

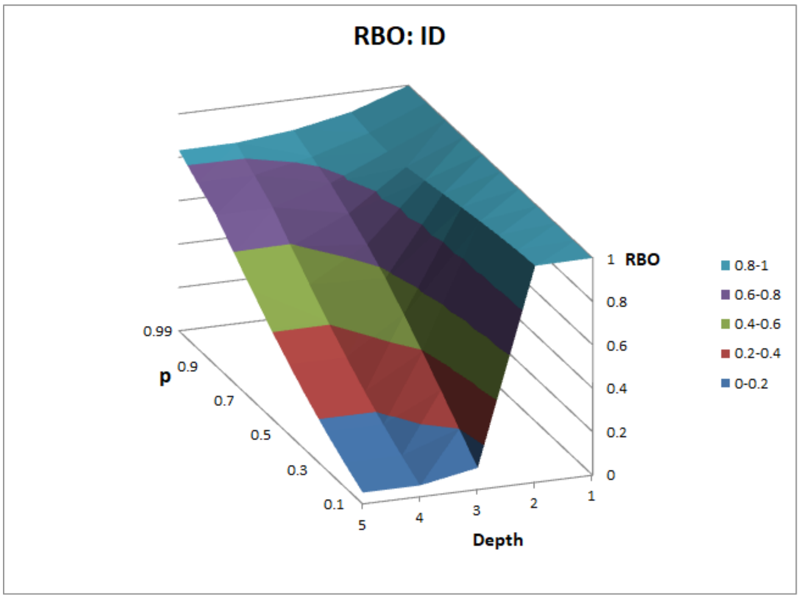


Figure 8-1 RBO Measure for Inverse Distance Variable

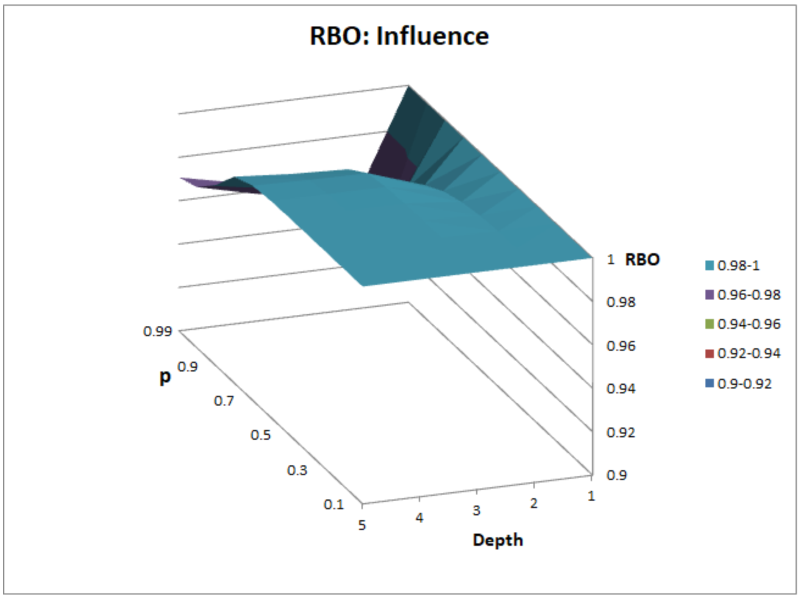


Figure 8-2 RBO Measure for Influence Variable

Recommendation

The requirement of the RBO Measure was to indicate relative changes in rank order and was essentially used as an indicative measure only. This implies that the measure should alert the analyst to changes in order of the more relevant variables while not masking changes in order when just those at the head of the list change. Consequently a value of *p*=0.95 for the RBO weight parameter was used in subsequent analysis to include changes in the body of the list as well as the head but simultaneously, the calculation was limited to the top quartile (15) variables, essentially ignoring changes in those variables deemed to be of lesser importance and which would not be expected to be included in the analyst's narrative of which variables contributed most to understanding uncertainty.

8.2.2 Summation Mode

The goal of this analysis was to examine the effect of the summation mode specifically the value of the *P* parameter in Equation 3.5 which weights the strength of a causality link according to the number of stakeholders who make that link. Note that the *Sum* and *Set* mode are equivalent to *P*=1.0 and *P*→0 respectively as described in section 3.6.5 and hence in the analysis below are placed in that order in the values of *P*.

The stability measures as *P* is varied are shown in Table 14. The change in stability by all three measures is monotonic as the power variable rises. The change in order with respect to the reference set is also higher as the difference in power variable from the reference rises. The changes in rank order of the 12 most Influential and most Dependent variables as the value of *P* changes are charted in Table 15 and Table 16 with their RBO ordering measures calculated from a base of the *Set* option with mid-range values of depth and weight d=5, w=5.

Measure	***P*=2.0**	***P*=1.5**	**Sum**	***P*=0.8**	***P*=0.5**	**Set**
Stability: Inverse Distance	0.25	0.27	0.30	0.31	0.32	0.34
Stability: City Block	0.29	0.31	0.33	0.34	0.35	0.36
Stability: MS	0.07	0.09	0.11	0.12	0.13	0.14

Table 14 Summation Mode

In the tables of the most Influential and Dependent variables, it becomes clear that there are changes in order as the summation power changes and the RBO measures show the changes accumulate as *P* increases from the reference base value. However, there is no systematic flow, variables rise, fall, and both rise and fall in the list. Also, the changes in order are more pronounced in the Influence measure but as with the Dependency measure, variables both rise and fall.

Examination of the effect of the summation mode across the range of different values of the power variable shows that increasing the value of *P* has the effect of emphasising the importance of the more influential variables, while compressing those with lower Influence values into a smaller range. This is shown in Figure 8-3, where the more influential variables are emphasised at higher values of *P* whereas as *P* is reduced, variables are more evenly distributed in Influence measure. However the selection of most Influential and Dependent variables for further analysis is based on their order and not on absolute values and the narrative about which subset are most Influential and Dependent is similar for different values of the summation *P* parameter.

Rank	*P*=2.0	*P*=1.5	Sum	*P*=0.8	*P*=0.5	Set
1	Political Action Initiated	Political Action Initiated	Political Action Initiated	Political Action Initiated	Political Action Initiated	Political Action Initiated
2	LA Political (dis)Unity	LA Political (dis)Unity	LA Political (dis)Unity	LA Political (dis)Unity	LA Political (dis)Unity	Economic and Employment Growth
3	PT Passenger Utility	PT Passenger Utility	PT Passenger Utility	PT Passenger Utility	Economic and Employment Growth	LA Political (dis)Unity
4	NE Public Investment	NE Public Investment	Planning Policy	Economic Employment Growth	Planning Policy	Planning Policy
5	Planning Policy	Planning Policy	NE Public Investment	Planning Policy	PT Passenger Utility	PT Passenger Utility
6	Economic and Employment Growth	Economic and Employment Growth	Economic and Employment Growth	NE Public Investment	NE Public Investment	Historical Demographics
7	Leamside business case	Public Opinion	Leamside Re-Opened	Leamside Re-Opened	Historical Demographics	Travel driven lifestyle
8	Cost of road travel	Leamside Re-Opened	Public Opinion	Public Opinion	Leamside Re-Opened	NE Public Investment
9	Public Opinion	Travel driven lifestyle	Historical Demographics	Historical Demographics	Public Opinion	Public Opinion
10	Travel driven lifestyle	ECML Freight congestion	Travel driven lifestyle	Travel driven lifestyle	Travel driven lifestyle	Leamside Re-Opened
11	Fencehouses Planning	Historical Demographics	ECML Freight congestion	ECML Freight congestion	Knowledge Economy	Knowledge Economy
12	ECML Freight congestion	Cost of road travel	Knowledge Economy	Knowledge Economy	ECML Freight congestion	ECML Freight congestion
13	Leamside Re-Opened	Fencehouses Planning	HA - DfT Action	HA - DfT Action	HA - DfT Action	HA - DfT Action
14	Local Freight Requirements	Leamside business case	Local Freight Requirements	Local Freight Requirements	Congestion S of Newcastle	Congestion S of Newcastle
15	Historical Demographics	Local Freight Requirements	Urban Agglomeration	NE Private Investment	NE Private Investment	Road travel utility

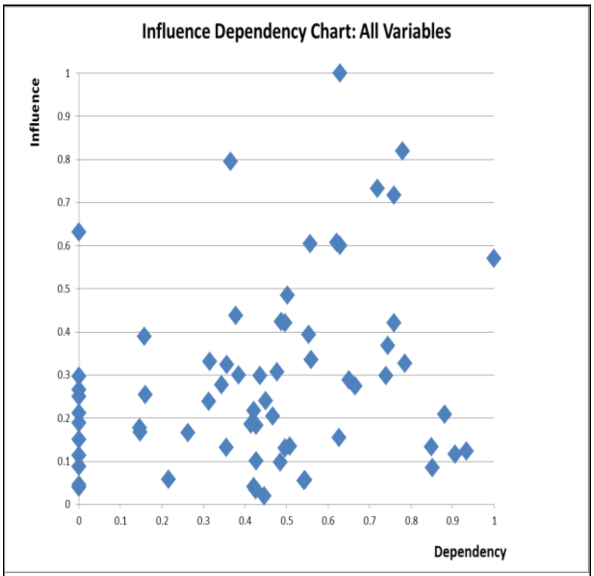
RBO	0.73	0.77	0.82	0.84	0.96	1.0 (Ref)

Table 15 Most Influential Variables

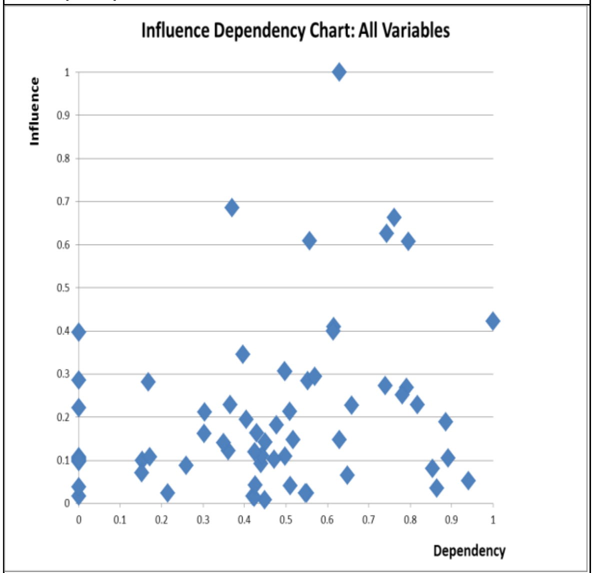
Rank	p=2.0	p=1.5	Sum	p=0.8	p=0.5 (ref)	Set
1	Leamside Re-Opened	Leamside Re-Opened	Leamside Re-Opened	Leamside Re-Opened	Leamside Re-Opened	Leamside Re-Opened
2	NE PT Ridership	NE PT Ridership	NE PT Ridership	NE PT Ridership	NE PT Ridership	NE PT Ridership
3	Car Use	Car Use	Car Use	Leamside business case	Leamside business case	Leamside business case
4	Fencehouses is built	Fencehouses is built	Leamside business case	Car Use	Car Use	Car Use
5	Leamside ridership	Leamside business case	Fencehouses is built	Fencehouses is built	Fencehouses is built	Fencehouses is built
6	Local rail based freight network	Leamside ridership	Leamside ridership	Leamside ridership	Leamside ridership	Leamside ridership
7	Leamside business case	Local rail based freight network	Local rail based freight network	Local rail based freight network	Local rail based freight network	Local rail based freight network
8	Congestion S of Newcastle	Congestion S of Newcastle	Economic and Employment Growth	Economic and Employment Growth	Economic and Employment Growth	Economic and Employment Growth
9	Economic and Employment Growth	Economic and Employment Growth	Congestion S of Newcastle	Congestion S of Newcastle	Congestion S of Newcastle	PT Passenger Utility
10	Leamside Freight	Leamside Freight	Leamside Freight	Leamside Freight	PT Passenger Utility	Congestion S of Newcastle
11	Planning Policy	PT Passenger Utility	PT Passenger Utility	PT Passenger Utility	Leamside Freight	Leamside Freight
12	PT Passenger Utility	Planning Policy	Planning Policy	Planning Policy	Fencehouses Planning	Fencehouses Planning
13	Fencehouses Planning	Fencehouses Planning	Fencehouses Planning	Fencehouses Planning	Planning Policy	Planning Policy
14	Fencehouses Prosperity	Fencehouses Prosperity	PT Invest	PT Invest	PT Invest	PT Invest
15	PT Invest	PT Invest	Fencehouses Prosperity	Fencehouses Prosperity	Leamside Mode Priority	Leamside Mode Priority

RBO	0.89	0.93	0.96	0.99	0.99	1.0 (Ref)

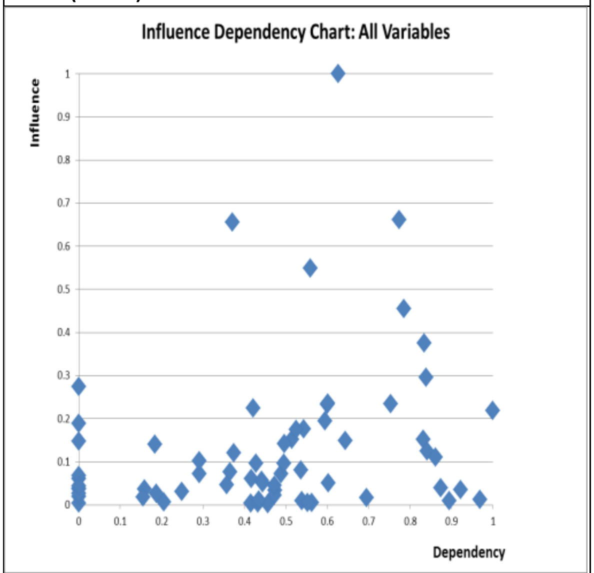
Table 16 Most Dependent Variables



P=0 (Set)



P = 1(Sum)



P = 2

Figure 8-3 Effect of Power Summation Variable P=0.0 – 2.0

Recommendation

In Vester's (2012) methodology, and in Godet's (2011) the only mode available is "*Set*" as there is only one composite stakeholder. Godet does however use a "weak, medium strong" classification with values 1, 2, 3. Therefore there is little in the literature on the current practice to assist in selecting any value of *P* to use in future analysis. The closest approximation to current practice is to mirror a "weak, medium strong" classification with value 1, 2, 3 which with up to 11 stakeholders in the case study, is obtained using the Power mode with value of 0.5.[10] This will therefore be the primary mode used in subsequent analysis.

8.2.3 Depth and Weight

The goal of the study into the weight and depth measures was to examine how the results of the analysis changed as these two related parameters were adjusted. Two questions were to be addressed; the first was to comment on the stability of the results as these parameters changed, especially to detect any discontinuities or rapid changes in results. The second was to find values of the weight and depth parameters that reflected the complexity of the causality chains in the system and could be used in the subsequent uncertainty analysis. The measures used to quantify the results of the analysis were the three stability indices developed in section 3.6.7 and the changes in ordering, quantified by the RBO measure for Influence and Dependency.

Using the Power Mode with *P*=0.5, the stability measures were examined for depths *d* = 0 -9 and weights *w*= 1-9.The stability measures are shown in Figure 8-4 as 3D plots of stability (NB: Z axis, Higher is less stable) as weight and depth vary. All measures show a similar shape showing rising instability with increasing depth and weight but with a less steeply rising instability as the weight parameter increases as causality at deeper depth is reduced in influence. Note that the apparent flat area of the 3D graph between depth=1 and depth=2 was investigated and found to be an artefact of the dataset with all stakeholders included. It was not evident with all combination of stakeholders and no other areas of the graph showed similarly flat areas.

[10] $3 = 11^{0.46}$. Hence to 1 decimal place the value of P selected is 0.5

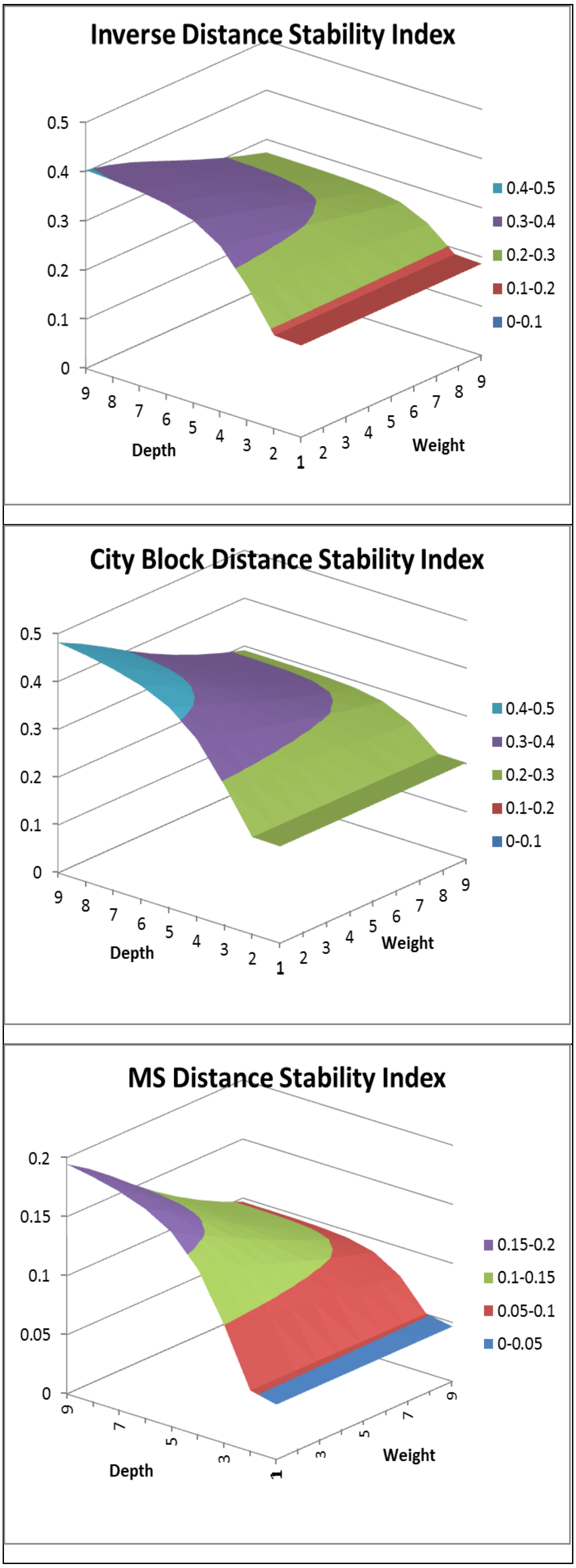


Figure 8-4 Depth and Weight Measures

The status of variables quantified by which zone of the I-D space they were placed in, and their order, as weight and depth were varied, was examined by comparing them with a reference dataset with parameters w=5 and d=5 and for *P*=0.5. Table 17 shows the number of variables that change zone (as described in Section 3.6.8) as depth and weight change. There are no zone changes at any value for weighting above depth 3 with respect to the mid-range reference case of *w*=5 and *d*=5, highlighted in the table indicating no changes in the narrative describing each variable.

	Depth								
Weight	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	4	9	0	0	0	0	0	0	0
2	4	9	0	0	0	0	0	0	0
3	4	9	0	0	0	0	0	0	0
4	4	8	1	0	0	0	0	0	0
5	4	7	1	0	0	0	0	0	0
6	4	7	1	0	0	0	0	0	0
7	4	6	1	0	0	0	0	0	0
8	4	6	1	0	0	0	0	0	0
9	4	6	1	0	0	0	0	0	0

Table 17 Changes in Zone

The difference in ordering for the two base measures, Influence and Dependency is shown in Figure 8-5 and Figure 8-6. Above the reference point of w=5 and d=5, there is little change in the order (Influence RBO=0.99 – 1.00 Dependency RBO=0.95 – 1.00) although at high depths and with a value of w that weights causality links at depth 9 similarly to those at depth 1, the order of variables changes. This change can be observed in Figure 8-7 where the order of the highly variables changes as depth increases but more credibility was attached to the changes in order seen in Figure 8-8 where increasing depth of causality is weighted less.

RBO Influence

D/W	1	2	3	4	5	6	7	8	9
1	0.87	0.96	0.99	1.00	0.99	0.98	0.97	0.97	0.97
2	0.87	0.96	0.99	1.00	0.99	0.98	0.98	0.97	0.97
3	0.87	0.96	0.99	1.00	1.00	0.99	0.98	0.98	0.98
4	0.87	0.96	1.00	1.00	1.00	0.99	0.99	0.99	0.99
5	0.87	0.97	1.00	1.00	1.00	1.00	1.00	0.99	0.99
6	0.87	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	0.87	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	0.87	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	0.87	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00

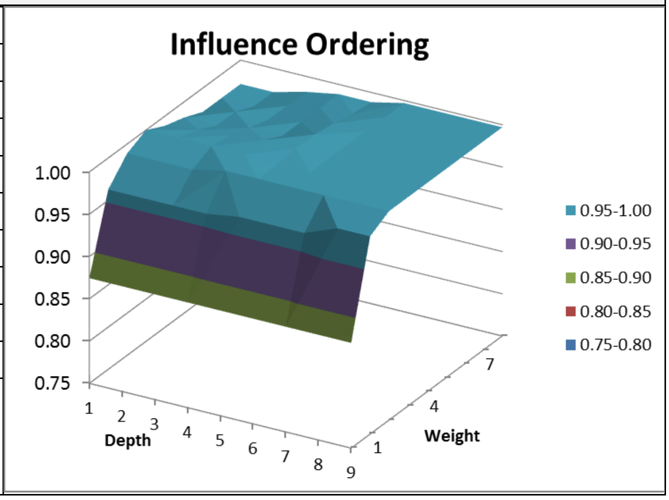


Figure 8-5 Ordering Differences: Influence

RBO Dependency

D/W	1	2	3	4	5	6	7	8	9
1	0.98	0.96	0.96	0.93	0.81	0.71	0.70	0.70	0.86
2	0.98	0.99	0.97	0.96	0.95	0.83	0.81	0.81	0.86
3	0.98	0.99	1.00	0.99	0.99	0.96	0.95	0.95	0.86
4	0.98	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.86
5	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	0.86
6	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00	0.86
7	0.97	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.86
8	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.86
9	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.86

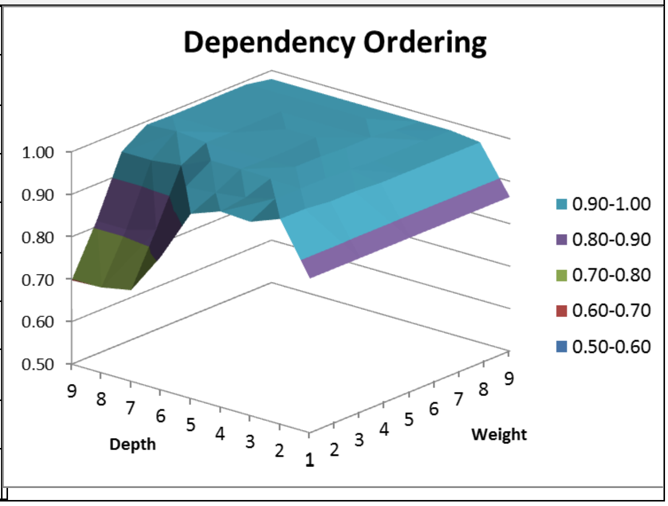


Figure 8-6 Ordering Differences: Dependency

The detailed change in the order of variables as the depth and weight parameters were varied was also studied. For a fixed value of weight, the analysis was run for values of depth from 1 – 9 and the variables were then ranked by their Influence and Dependency measures. Figure 8-7 and Figure 8-8 show the subsequent changes in order of all variables as the depth increases for values of *w*=1 and *w*=5. In both cases, for clarity, only the highest ranked variables are represented in the legend and these are in the order of Influence and Dependency at *d*=1. The change in the number of lines in both the Influence and Dependency graphs is due to the number of variables that have constant dependency of 0 and consequently cluster in the lowest position - the constant bottom line in the

Dependency graph. Also, clusters can be seen when d=1 as variables have the same values of Influence or Dependency which is more probable with one layer of causality.

The observation is that as depth increases, the order of variables changes as more causality is introduced. At higher weight values, the change is reduced as the higher depths are low weighted and hence their contribution to the Influence or Dependency is reduced. However, in the Influence measure, the upper quintile set is constant (up to the 12th variable) and within this set, the changes in order with w=1 are not major, indicating that the set to be studied in depth is the same, regardless of depth and weight. The changes in the Dependency measure are more marked at lower values of w (high weighting at depth) but when w=5, there are few significant changes at values of $d > 5$.

Recommendation

In summary, the most basic analysis, using a causality depth of 1 and no weighting by number of stakeholders, produces an Influence-Dependency chart as shown in Figure 8-9 whereas deeper causality depth (d=5) and stakeholder weighting (w=5)produces an Influence-Dependency chart as shown in Figure 8-10 both have only the most influential variables labelled for clarity.

The interpretation of the difference between Figure 8-9 and Figure 8-10 is that the former gives less differentiation between variables, evidenced by the formation of rows and columns. Also as the depth increases and indirect causality is introduced, the average Dependency increases shown as variables are now more evenly spread on the X axis and variables adopt different roles as described by Vester (2012) and shown in Figure 2-3. Specifically the variable “HW-DfT Action” being the actions of the two controlling authorities moves from being a sluggish indicator of action to an active controlling factor, reflecting their designated role in transport planning.

The informality of the Cross Impact Matrix Method where chains of causality between two variables may be direct in one stakeholder’s view and indirect in another’s lend credibility to Godet’s (2011)form of the method, to include indirect linking. The questions to be resolved become; how long may those chains be and how are the links in the chain weighted by depth? The end point of this exercise was to select a combination of those weight and depth variables that will model the system without over-fitting the analysis by using excessive depth.

Examination of the ordering shows at a depth > 5 with weight w=5, there is no significant change in order of variables on their Influence measure and at depth > 4 no significant change in order of variables on their Dependency measure. Analysis of the dependency on weight and depth shows that at a depth > 4, there is no change in the system with respect to how variables are positioned in an "area of interest" i.e. the zone they are placed in. Comparison of Figure 8-9 and Figure 8-10 show that the differences between the most basic analysis and that which is carried out at greater depth are significant in distribution of variables in the ID space and in the detailed ordering but less so in the clusters of variables that rise to the top of the Influence measures and the Dependency measures. Based on the ordering measures, a depth d=5 is indicated being the higher of the values where order changes cease to be significant for both Influence and Dependency.

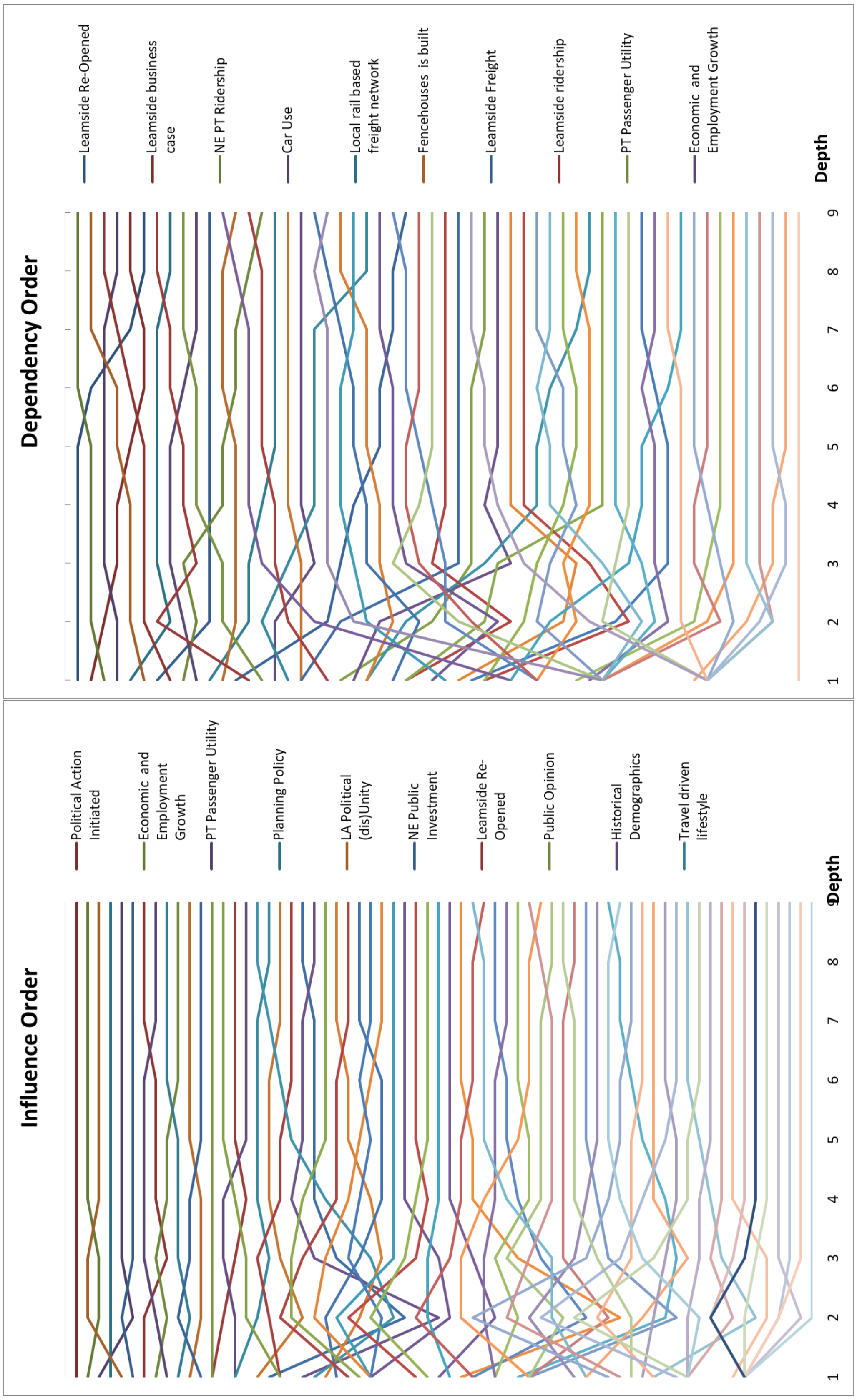


Figure 8-7 Changes in Order by Depth: Weight w=1

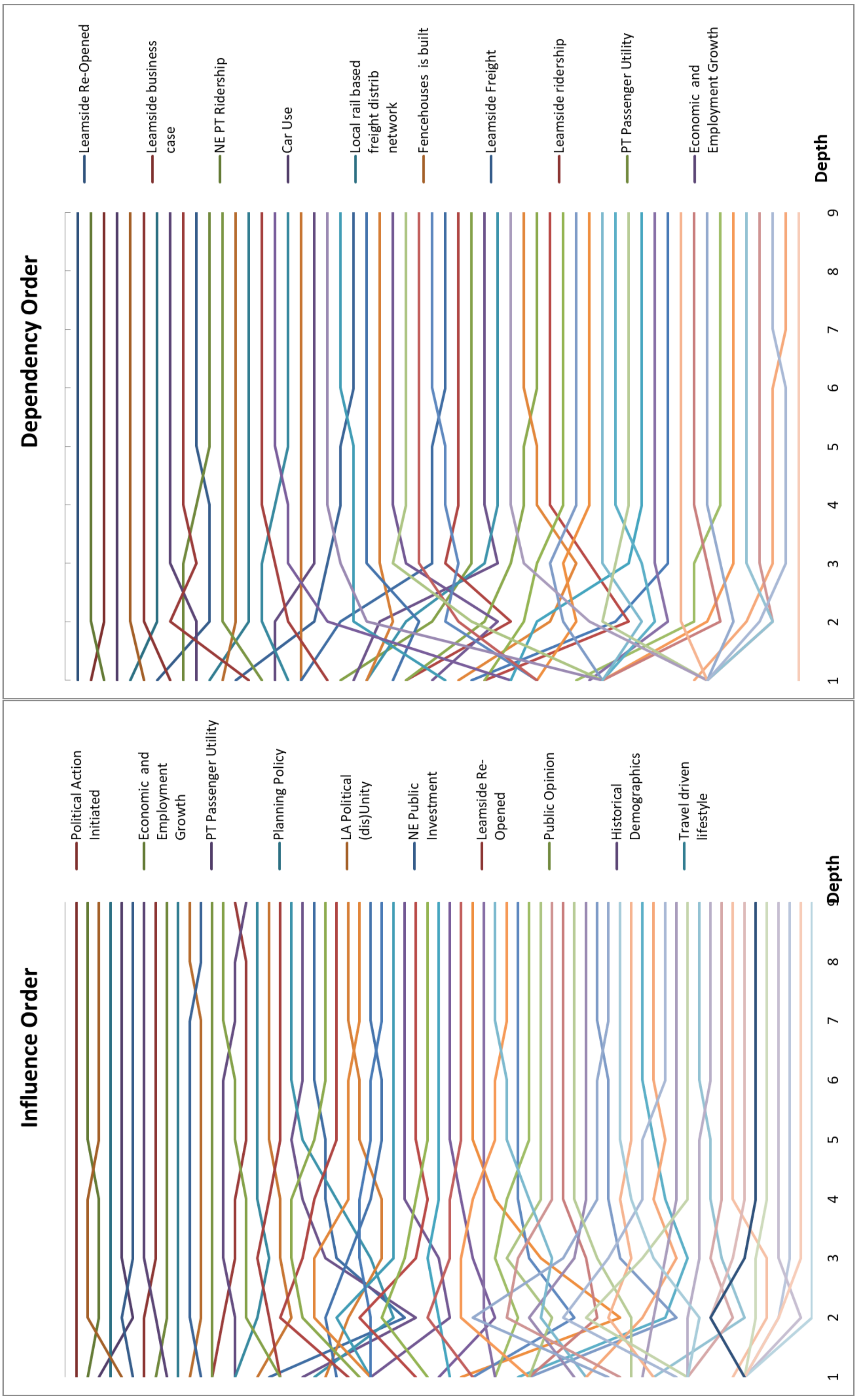


Figure 8-8 Changes in order by Depth: Weight w=5

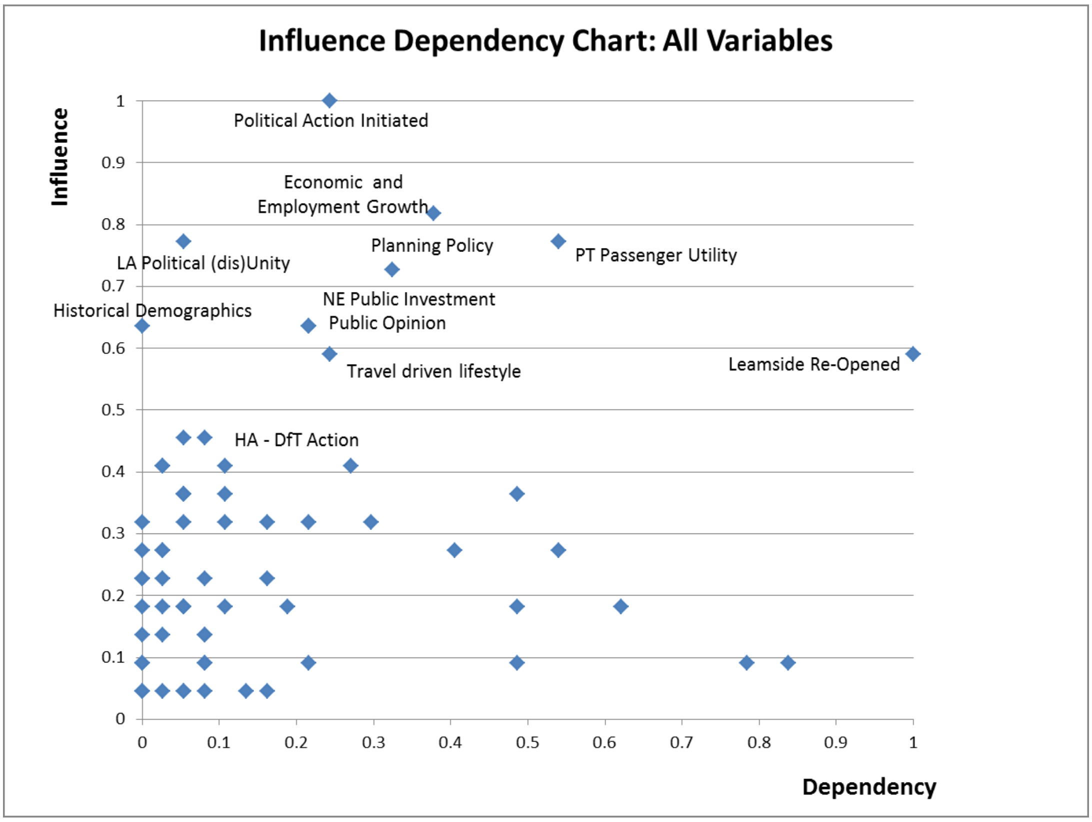


Figure 8-9 ID Chart: Based on Vester (2012)Methodology without depth or weight.

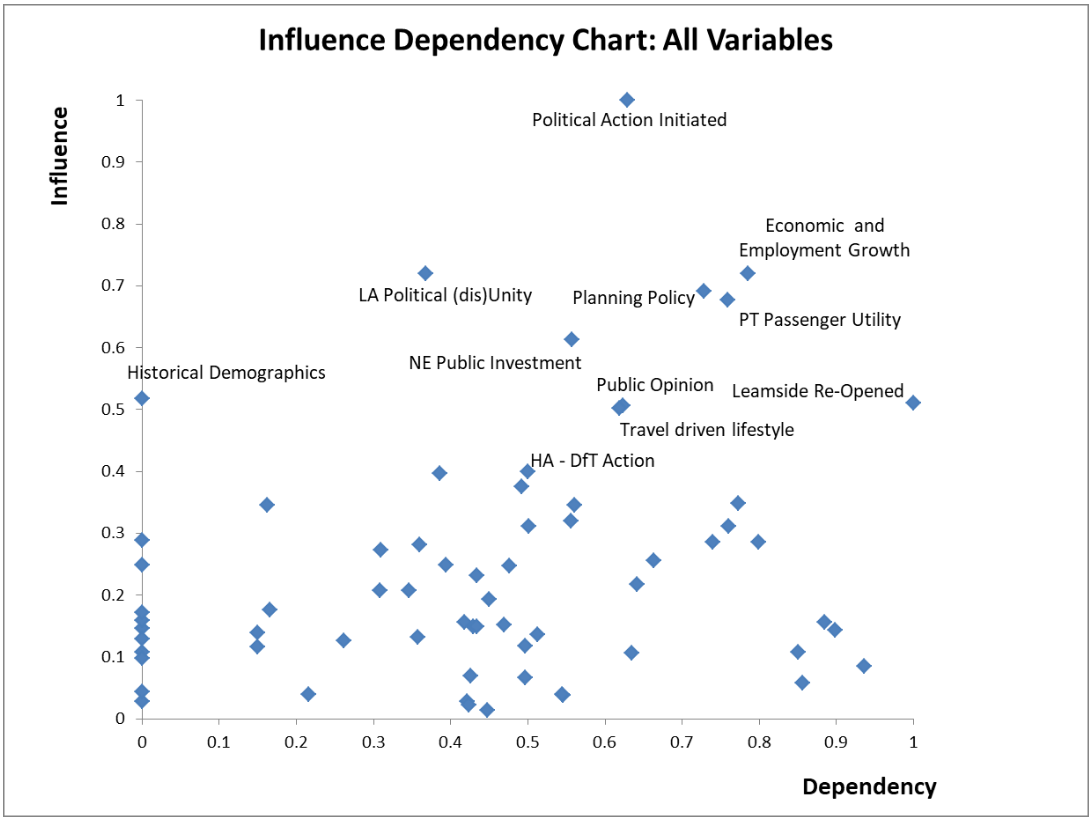


Figure 8-10 ID Chart: Based in this study with depth and weight

Analysis of the stability measures show that as depth increases and as the weight of the deeper connections increases, then instability also increases, but that increase in instability is slow above depth =5 apart from at low weight values (Note: low weight parameters give higher values to deeper depth links). Above depth =5 and weight = 5, the difference analysis shows, the rank ordering changes little and the narrative describing the system would be stable, also the zoning of the variables is constant. Therefore subsequent analysis will be based on:

- Depth = 5
- Weight = 5
- RBO p = 0.95,
- Sum mode = Power, P=0.5

8.3 Stakeholder Sensitivity

Having investigated the relative importance in interdependence between the depth and weighting parameters on the Influence and Dependency calculations, the next step of the research was to explore how the stability measures were affected by the number of stakeholders included in the analysis. Therefore, the goal of the stakeholder sensitivity study was to examine the behaviour of the system, measured in terms of stability and variable ordering, as the number of stakeholders is increased.

8.3.1 Effect of the Number of Stakeholders on the Stability Measures

The batch mode of the bespoke project software was run with depth and weight set to *d*=5 *w*=5 and selecting all combinations of N stakeholders from the set of 11 for all values of N from 1 – 11 resulting in 11, 55, 165, 330, 462, 462, 330, 165, 55, 11, 1 combinations[11]. The results for each of the three system-wide measures of instability (ID, CB and MS, refer to Section 3.6.7) are shown in Figure 8-11, which charts the instability measure on the Y axis vs the number of stakeholders on the X axis. Each marker represents the value of the instability measure for one combination of stakeholders, the mean of the measure for all combinations for each value of N is also shown.

[11] The combination formula is M!/N!(M-N)! where M is the number of objects and N are selected. Here, M=11.

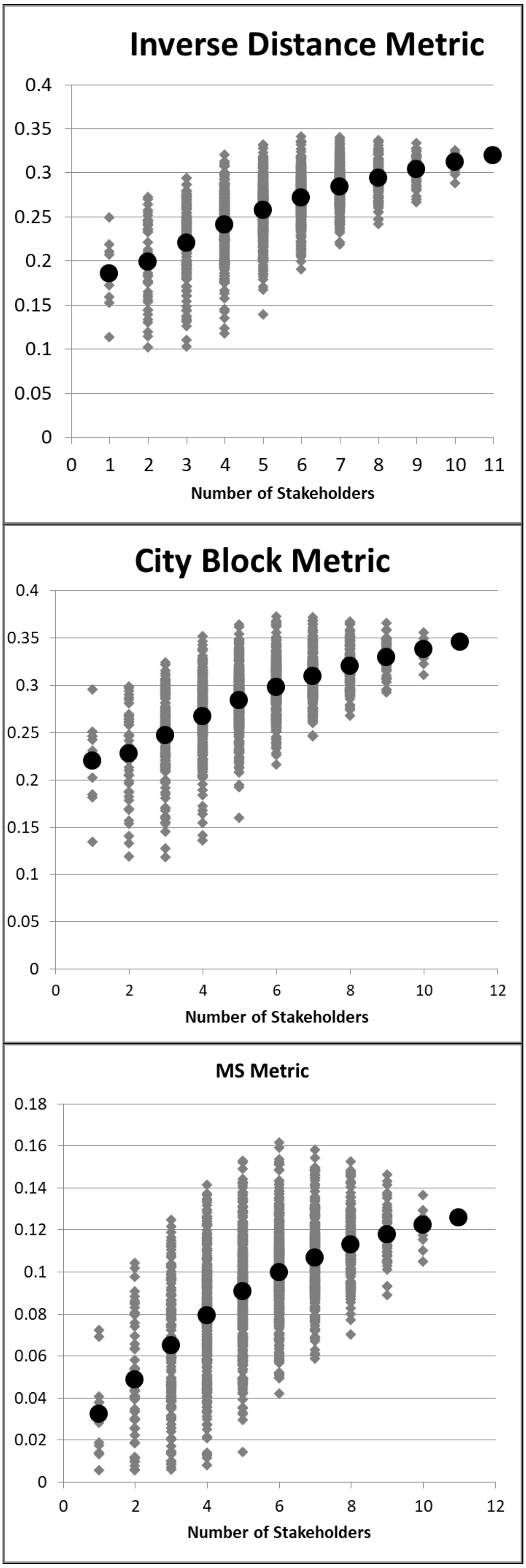


Figure 8-11 Stability Measures vs Number of Stakeholders.

The first observation from the shapes of the graphs is that the same conclusion can be drawn despite which measure of instability is used. The range of the measures differs, but their trend, in mean and in spread, as the number of stakeholders rises is the same.

The second observation is that the average level of instability increases with the number of stakeholders indicating that each individual in isolation tends to understand the system as relatively more stable than the view that emerges when multiple stakeholders are involved. This is generally true when many stakeholders are considered (> 3) but the finding can change when a small number is considered. When 2 or 3 stakeholders are combined, their combined system can be more stable (with a lower value of the stability measure) than their individual systems indicated by the lower minimum values of instability for N=2, 3 than for N=1. As the number of stakeholders rises above 6, the spread of instability decreases indicating a convergence on a similar system as stakeholders are added to the list.

8.3.2 Effect of the Number of Stakeholders on the Position of the Variables

Similar analysis was undertaken to look at how the position of each of the variables changed as the number of stakeholders used in plotting their positions was increased by selecting N from 11 for N = 1 to 11. The movement of the average position for each variable is shown in Figure 8-12. In most cases, variables move from lower dependency to higher dependency and lower influence to higher influence as N goes from 1 to 11.

However, as N increases from 1 to 2 there are many cases visible in Figure 8-12 where Influence or Dependency drops before assuming the normal increasing trend. This was examined and attributed to the large variable movements seen when small numbers of stakeholders are merged and, as some variables rise rapidly in Influence, the effects of normalisation to a scale 0–1.0 on those with a smaller increase in absolute Influence is that they show a decrease in normalised Influence. This effect is reduced as with more stakeholders, the relative movement between variables is reduced.

Analysis of the correlation between the movement of the variable and their initial position in the I-D space shows there is no significant correlation between the gradient of the variable movement and Influence or Dependency (correlation 0.36 for Influence, 0.14 for Dependency).

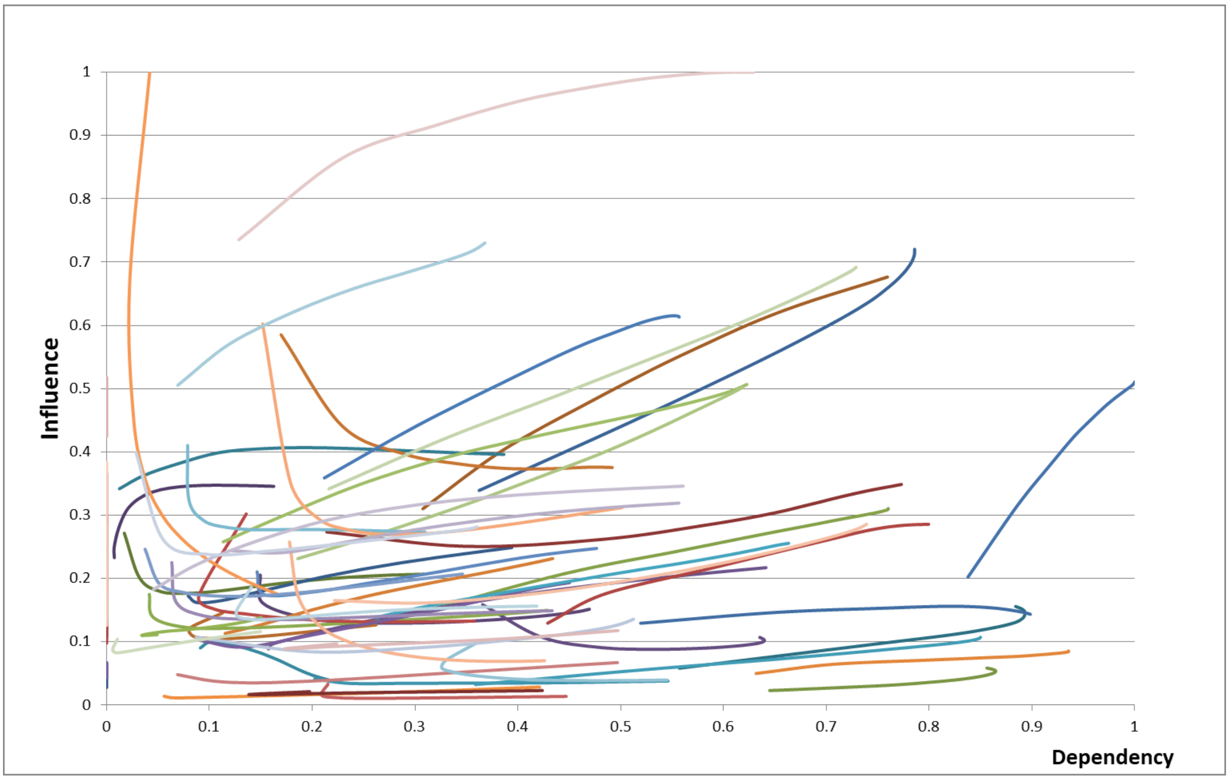


Figure 8-12 Variable Movement in I-D Space as Number of Stakeholders Changes.

The main conclusion drawn from this analysis is that in general, Influence and Dependency increases as the number of stakeholders increases, and Dependency increases at a faster rate than Influence, but there are some anomalies and outliers. These are described below, each with a figure showing the position of the variable for each combination of N stakeholders selected from the full set of eleven stakeholders for values of N from 1 to 11. The mean position and the variance of the Influence and Dependency measures are also shown to summarise the eleven I-D graphs.

- The line that starts at (0.05,1) and moves with steep negative slope to finish at (0.17, 0.0.17): This is Co Durham's view that the Leamside Line is to be prioritised as a freight diversion route and is shown in Figure 8-13. This is the most important (i.e. Influential) driver to one of the stakeholders from Co Durham with just one point when N=1, with high Influence and low Dependency indicating its status in that stakeholder’s view as a pre-determined, and strong policy. However, as more stakeholders are included, its Influence drops significantly until, in the overall decision it becomes much less relevant.
- The line that starts (0.08, 0.51) and moves with positive slope to (0.37,0.73): This is the “Political (Dis)unity” variable and is shown in detail in Figure 8-14. This variable

has a wide spread of influence indicating that while some stakeholders saw it as very influential, others thought it was less so. The variable becomes more influential and dependent as including more stakeholders bring different causalities and hence raise the Influence and Dependency measures.

- The line that starts from (0.1, 0.74) and moves to (0.60, 1.0). This is the “Political Action Initiated” variable and is shown in Figure 8-15. This variable shows a similar behaviour to the “Local Authority (Dis) Unity” variable in that as more stakeholder opinions are combined, it becomes more influential and more dependent. It also shows a distinct cluster in the dependency measure as two stakeholders attribute a larger set of dependencies to this variable and clusters form with, and without, these two stakeholders included.
- The line isolated line from (0.83,0.2) to (1,0.5) is the “Leamside Re-opened” variable shown in Figure 8-16. This variable’s Influence measure rises steeply as the number of indirect influences increase with the number of stakeholders. Only 2 of the 11 stakeholders referring to this variable discussed it as solely dependent, i.e. not influencing any other aspect of the decision. The steep rise in Influence measure as stakeholder opinions are joined shows that multiple influences were identified, reinforcing each other as they are combined.

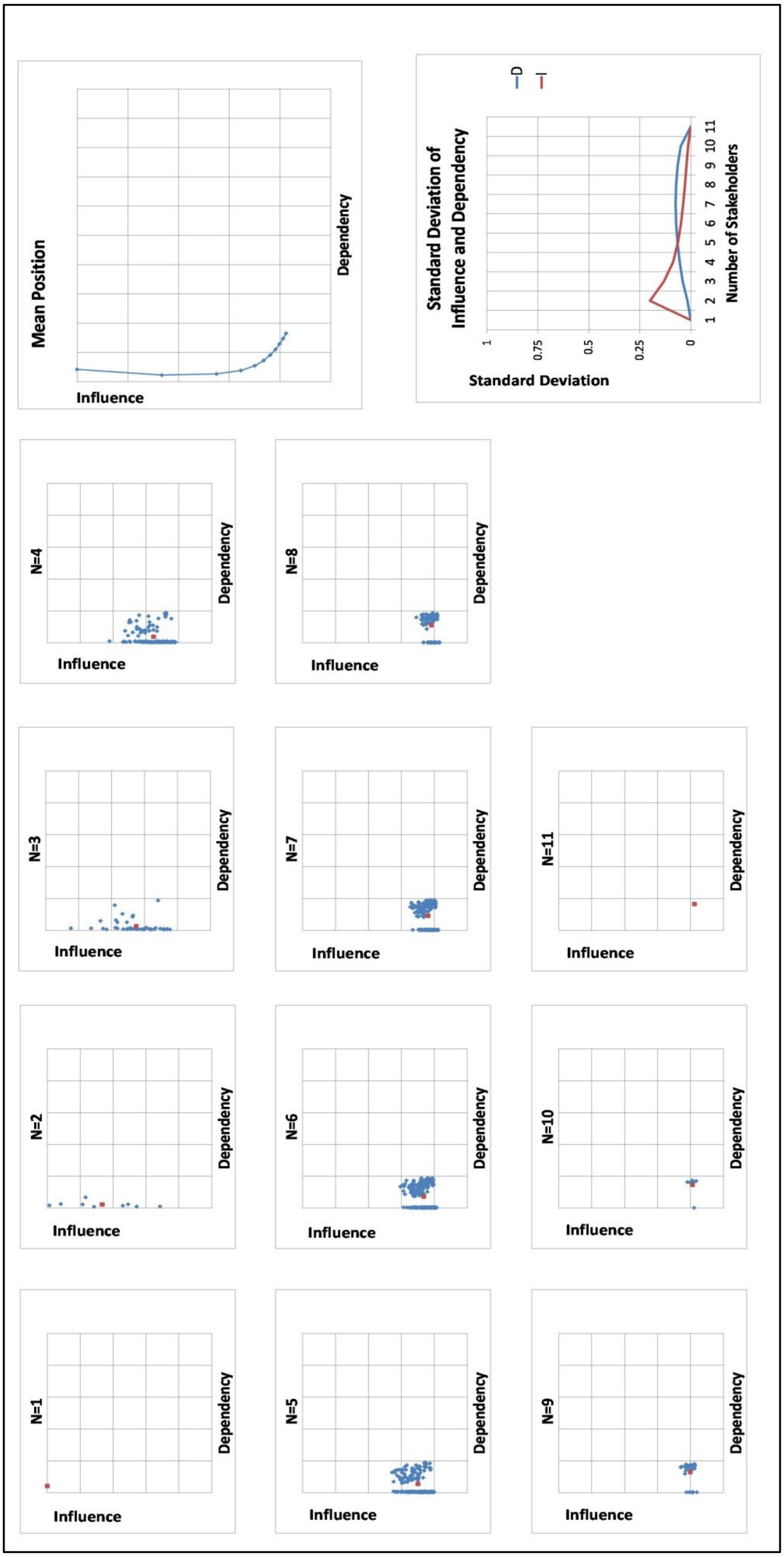


Figure 8-13 Council Policy to Favour Leamside Line for Freight

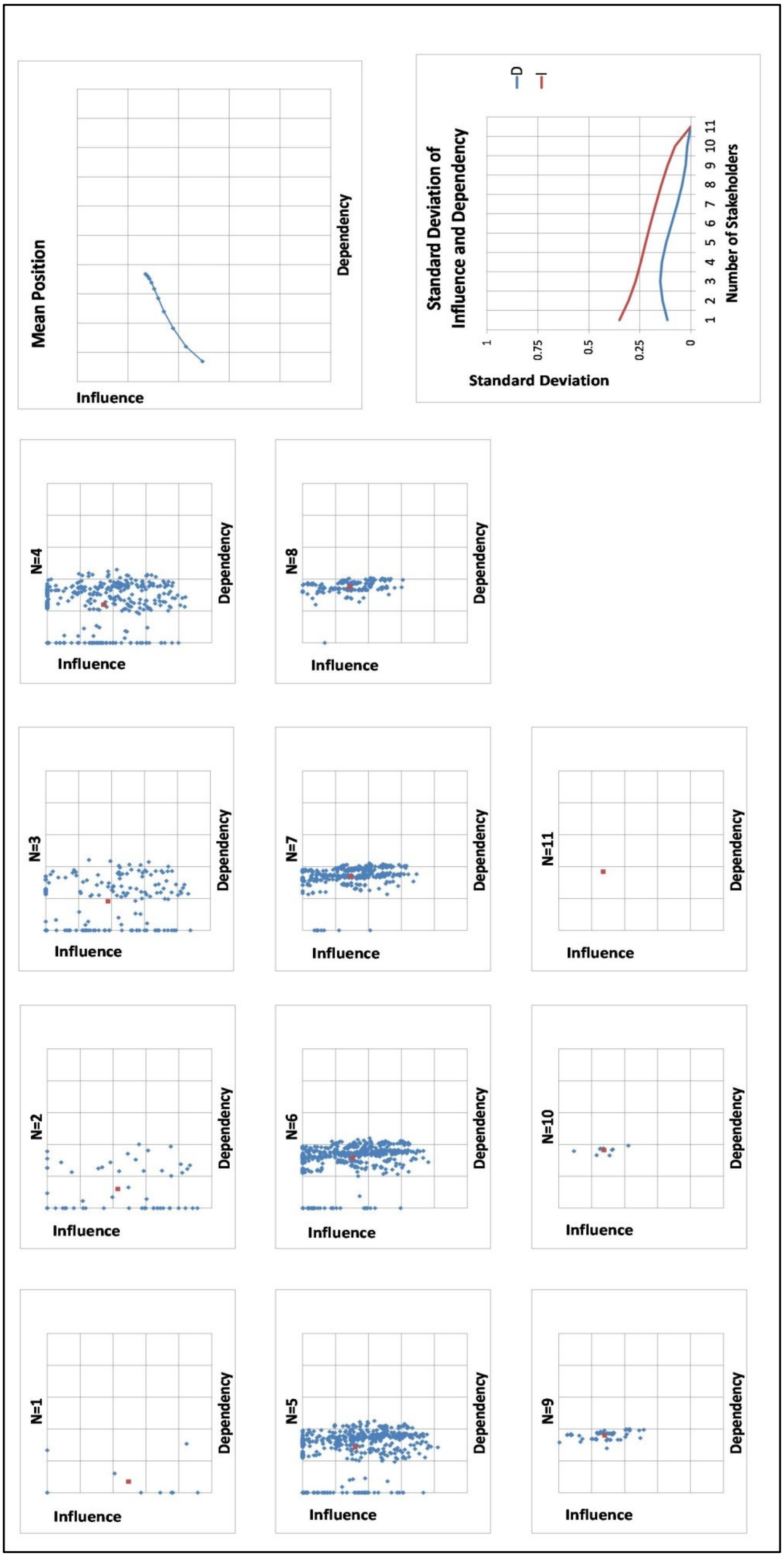


Figure 8-14 Local Authority Political (dis)unity

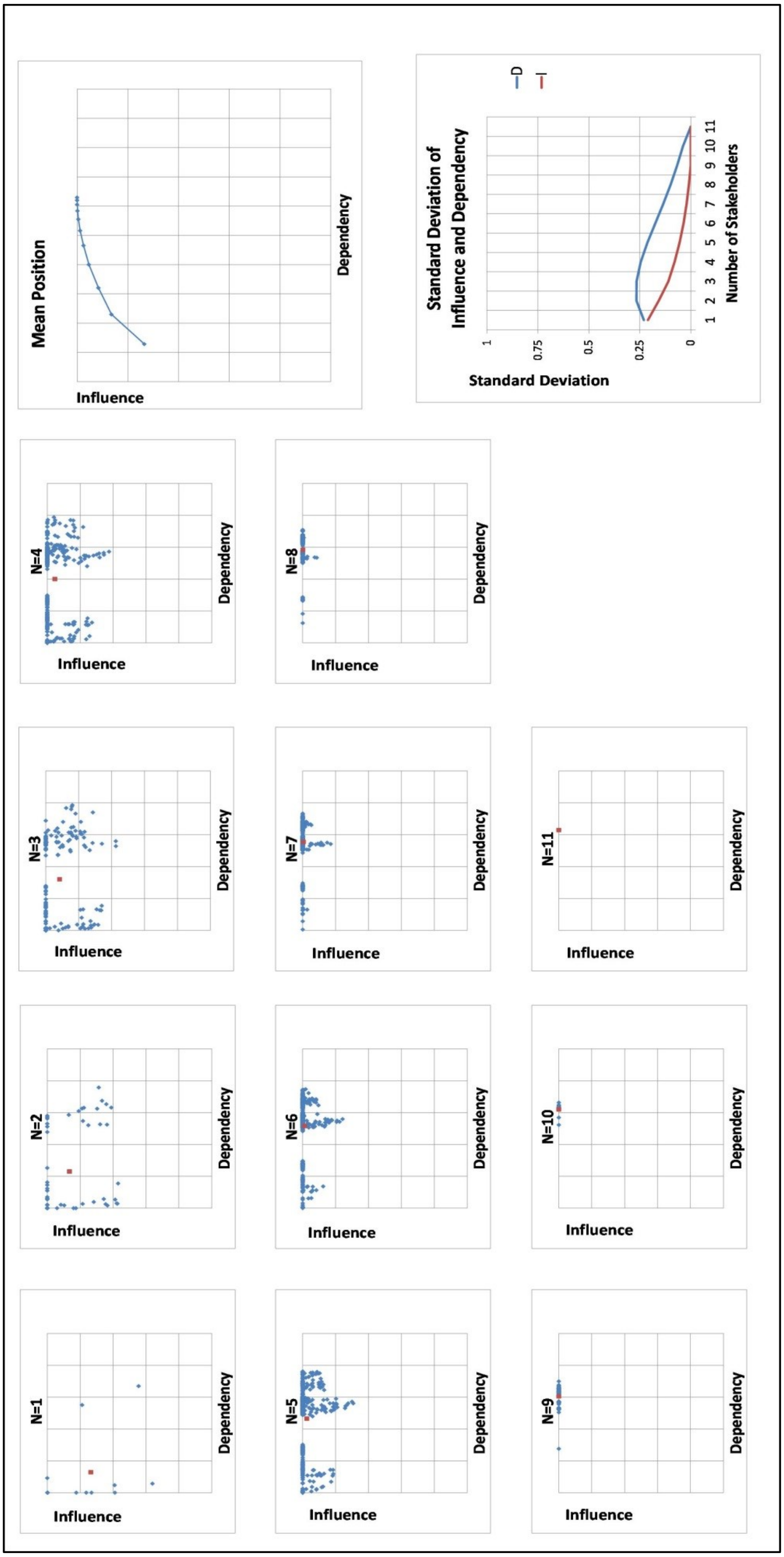


Figure 8-15 Political Action Initiated

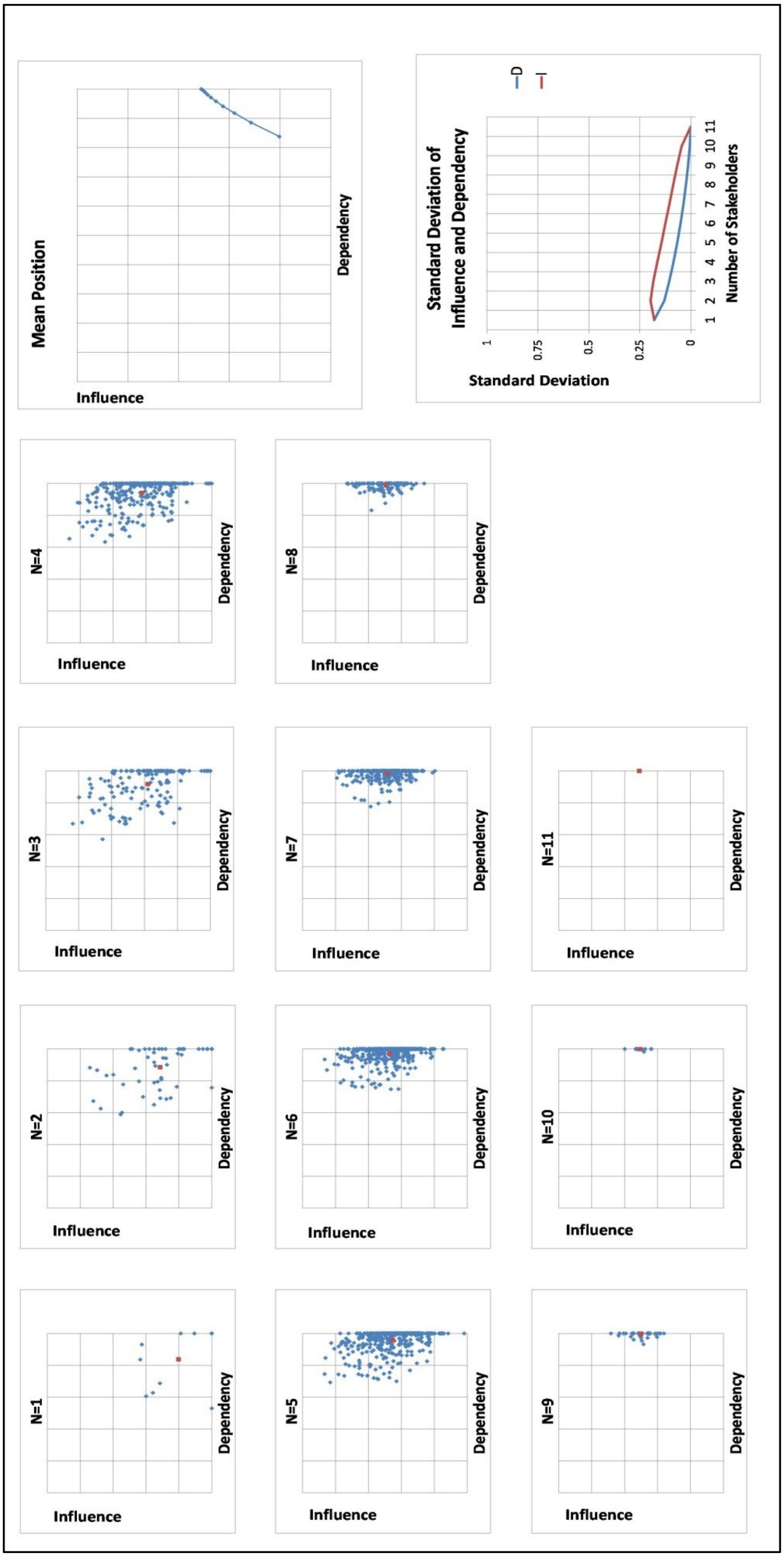


Figure 8-16 Leamside Re-opened

8.3.3 Recommendations

When looking at the reaction of the system to the number of stakeholders included in the analysis, the narrative describing the reaction is independent of the measure used to quantify that reaction and there is no requirement to repeat the analysis with other measures. The ID measure, which computes the instability measure using distance from the point of greatest instability (1,1) will therefore be used. The analysis of the variable movement by number of stakeholders reveals a generally systematic trend of increasing Influence and Dependency with some anomalies meriting further investigation but no further recommendations for changes to parameters in the analysis. Finally the range of instability of the system in this case study increases as the number of stakeholders increases up to ~6 and subsequently decreases as more are added. This effect will be dependent on the homogeneity and size of the stakeholder group; here it is only possible to infer that the addition of the last stakeholder to the cohort has a smaller effect in a group of size 6-11 but a larger effect in a group size 2-6.

8.4 Sensitivity Analysis Overview

In this sensitivity analysis stage, values for the parameters that control the RBO indices, the summation method for the numbers of stakeholders and the depth and weight calculations have been comprehensively investigated and optimal values have been identified and justified as appropriate to be used in the next stage, which is to undertake the uncertainty analysis.

In general, the results of the uncertainty analysis were shown to change significantly as the depth of causality was increased above Vester's (2012), basic linking to embrace Godet's (2011) extension which includes indirect causality, but after this change was made, the results of the analysis were shown to not be unduly sensitive to the choice of parameters in depth and weight, or the choice of stability index used. While the detailed ordering and positions may change, the narrative that describes the uncertainty essentially remains the same. Also, insights have been gained into how the variables move in the I-D space as the number of stakeholders changes and how the uncertainty indices change as the number of stakeholders increases. The empirical advice offered by Godet (2011):

> *Generally, the ranking of variables according to influence or dependence indicators is becoming stable by the time paths of length 4 to 5 are taken into account.*

has also been validated in the analysis shown here.

In Chapter 9, the Cross Impact Matrix Method is applied to the data from the case study, using the parameters recommended by the analysis in this chapter, and the characteristics of the Leamside Line case study examined in detail.

Chapter 9 Leamside Line Case Study Analysis

This chapter presents the results of the uncertainty analysis undertaken on the case study, used in this research. Were this analysis to be commissioned to be used purposefully to investigate the uncertainty in a developing project - one that had a budget and committed cohort of stakeholders - then this stage would form the output of the method and would then be expected to lead into actions that could be taken by those stakeholders to reduce the uncertainty or mitigate the effect of it. The actions to do this might include breaking causal links between variables, to resolve internal conflicts, to mitigate significant concerns held by a group of stakeholders, or to take policy actions to enable the project to proceed. The goal of this investigative method however is not to initiate these actions, but to uncover where the actions should be directed and, by exposing how the different variables in the decision system interact, provide guidance as to how mitigation actions may proceed.

The case study examined here, to re-open the Leamside Line, has not had a project sponsor nor has it had a budget attached to the proposal during the time of this research. Hence, in this case, the end point of the study is the analysis of the reasons why the project has no apparent forward looking path for progress and no actions are anticipated. The analysis presented here stops at describing the consolidated view of the project decision system and studying the effect of breaking the most significant causal links. It cannot move into evaluation of any proposed actions, as these must come from the stakeholders and project decision makers and the Leamside Line has not had stakeholders with those capabilities as this research was undertaken.

The stages of the uncertainty analysis are based around the three classes of object in the extended Cross Impact Matrix Method:

- **Variables**: Identify the key variables and categories of variables and, by reference back to the elicitation interviews, examine the stakeholder's descriptions of them and their roles to reveal why those variables achieve their status in the decision system.
- **Stakeholders**: Use the Influence- Dependency graphs, to reconstruct the stakeholder interview and identify the primary influences on the project in their view.
- **Links**: Identify the key causal links and investigate the effect of breaking them.

9.1 Variables Analysis

The goal of this analysis was to gain insight into the role of the variables identified in the project, both by category and individually. In this section, after a brief review of the consolidated list of all variables, the categories are first analysed and subsequently the ten most significant variables are examined in more detail by referencing back to the original interviews with the stakeholders.

The Influence-Dependency graph for the full set of variables for all eleven stakeholders is shown in Figure 9-1. Only the variables in the upper half of the space have been labelled for clarity, when the graph is presented broken down by category in section 9.1.1, all variables are labelled.

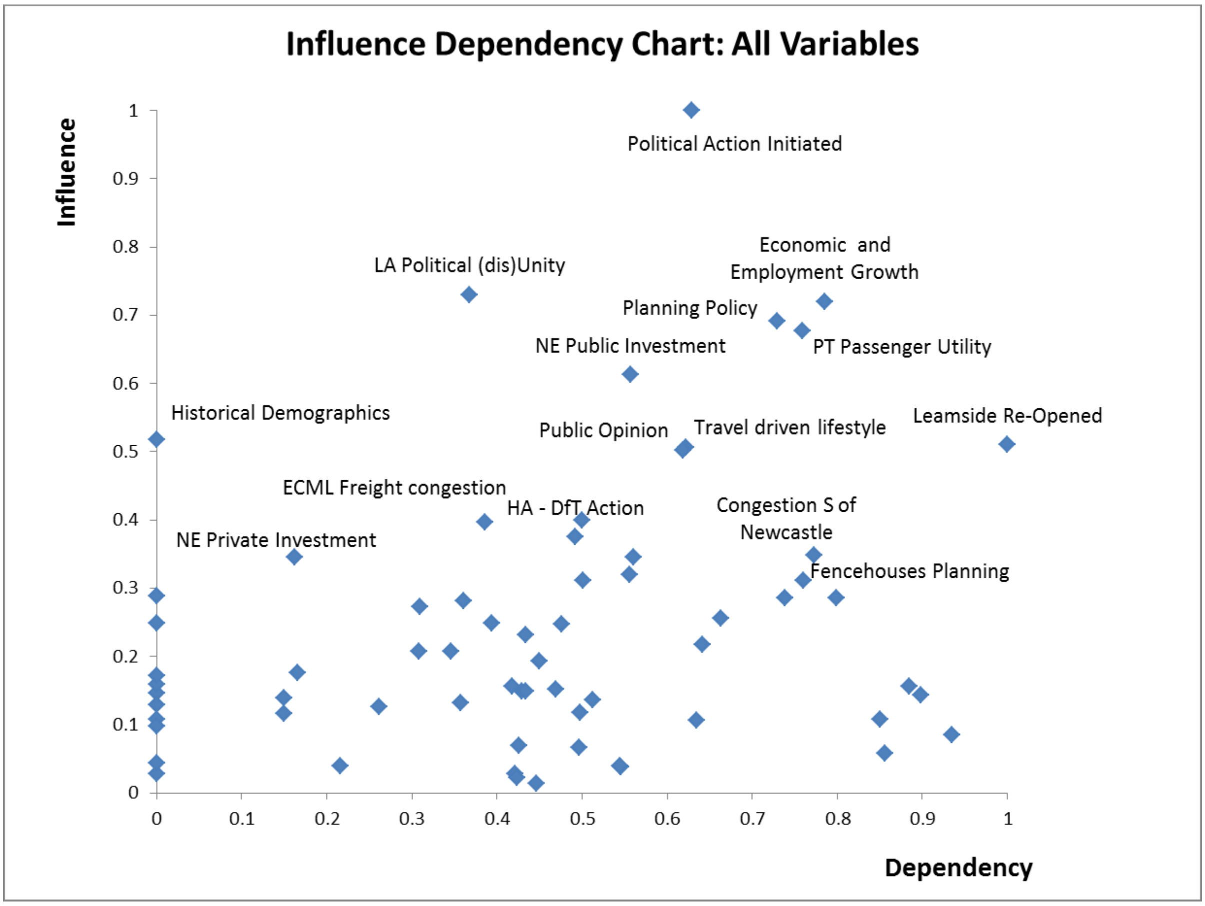


Figure 9-1 Complete Set of Variables

The most influential variable is the ability of the political leaders to initiate action, the "Political Action Initiated" variable, in effect their success in finding a project champion. The second most influential variable is the ability of the Local Authorities to work together with their tendency to compete with each other rather than co-ordinate their actions together, the “LA Political (dis)unity” variable. Discussion of these two together reveals the importance of forward looking collaboration and leadership in promoting a transport project: which is one of the key findings of this investigation.

The most dependent variable was the act of reopening the Leamside Line. As this is the target of the exercise, this is to be expected but it is also an influential variable indicating that the new rail link does have an effect on the surrounding plans.

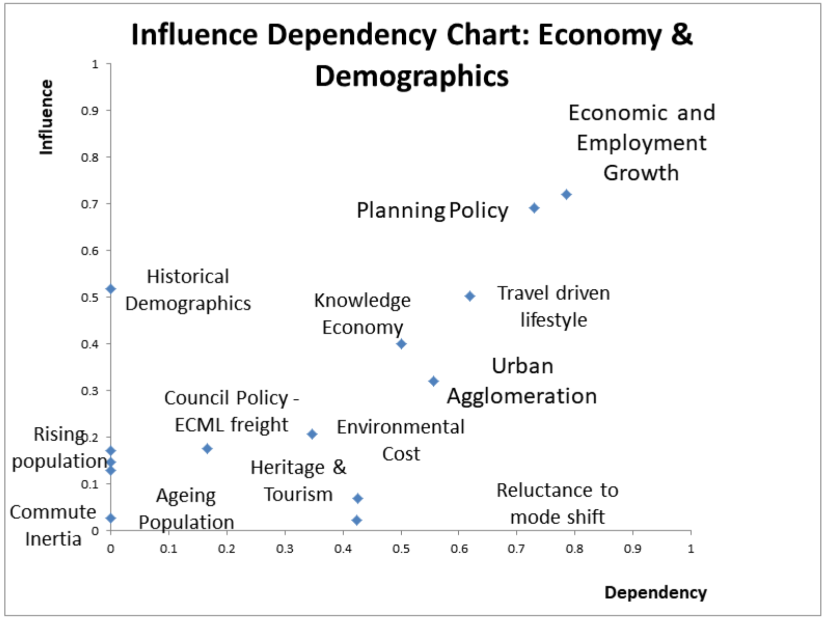
The variables with the highest uncertainty rating on the Inverse Distance score were the ”Economic and Employment“ the “PT Passenger Utility” and the “Planning Policy” variables. This first indicates that economic growth influences the probability of transport developments, and also recognises that factors related transport developments influence economic growth. The position of the “Planning Policy” variable shows that while policy is influential, it is also influenced by external factors and not set in a policy vacuum. The “PT Passenger Utility” variable similarly shows that the value of a public transport development depends on the service it offers and that this is dependent on the context in which it is placed.

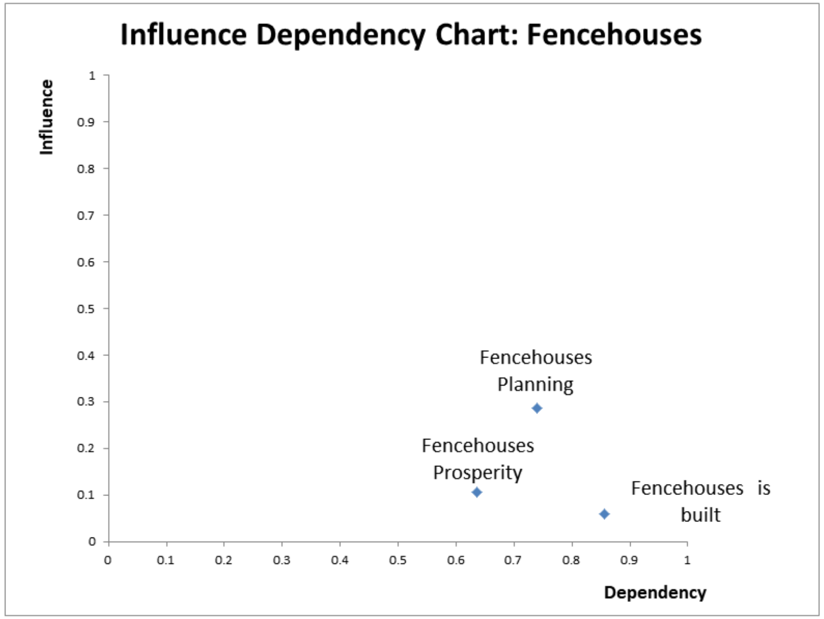
Variables are discussed in more detail by category in Section 9.1.1 and the key variables discussed in Section 9.1.2.

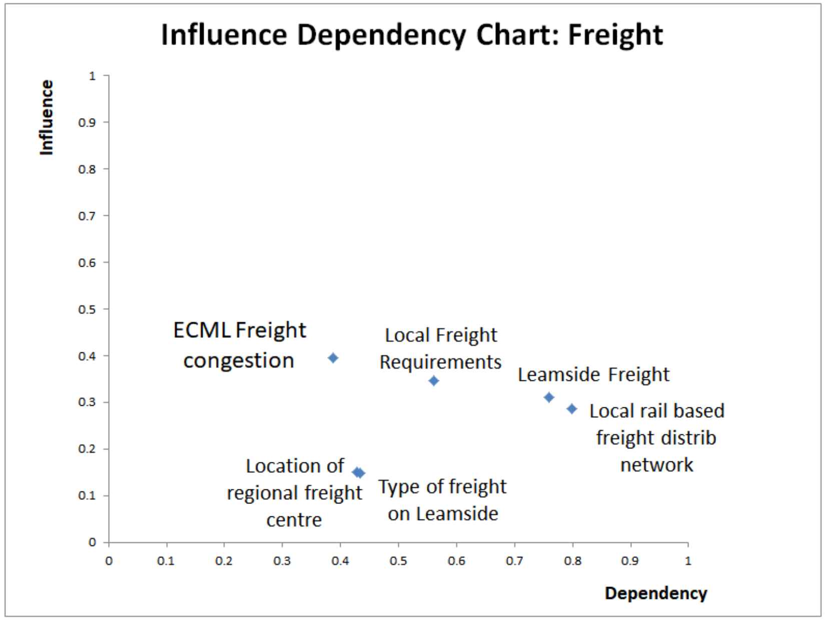
9.1.1 Variables by Category

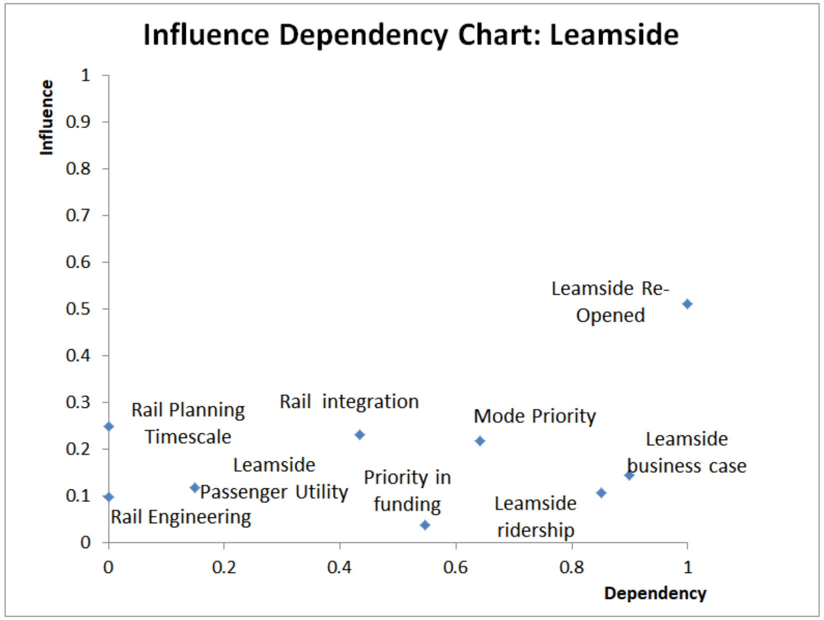
Each variable was categorised into one of eight groups as it was coded, and in this analysis, the Influence-Dependency plot is filtered to display only the variables in each category. The goal is to study the impact of the categories of variables rather than the individual variables. The results are shown in Figure 9-2 for all categories.

In the subsequent sub-sections, the impact of each category is discussed and a selection of variables in each group are commented on further where these are not explicitly referred to in section 9.1.2 which discusses the key variables in the whole system.


Influence Dependency Chart: Economy & Demographics
Influence
Dependency
Economic and Employment Growth
Planning Policy
Historical Demographics
Knowledge Economy
Travel driven lifestyle
Urban Agglomeration
Council Policy - ECML freight
Environmental Cost
Rising population
Heritage & Tourism
Ageing Population
Commute Inertia
Reluctance to mode shift


Influence Dependency Chart: Fencehouses
Influence
Dependency
Fencehouses Planning
Fencehouses Prosperity
Fencehouses is built


Influence Dependency Chart: Freight
Influence
Dependency
ECML Freight congestion
Local Freight Requirements
Leamside Freight
Local rail based freight distrib network
Location of regional freight centre
Type of freight on Leamside


Influence Dependency Chart: Leamside
Influence
Dependency
Leamside Re-Opened
Rail Planning Timescale
Rail integration
Mode Priority
Leamside business case
Leamside Passenger Utility
Priority in funding
Leamside ridership
Rail Engineering

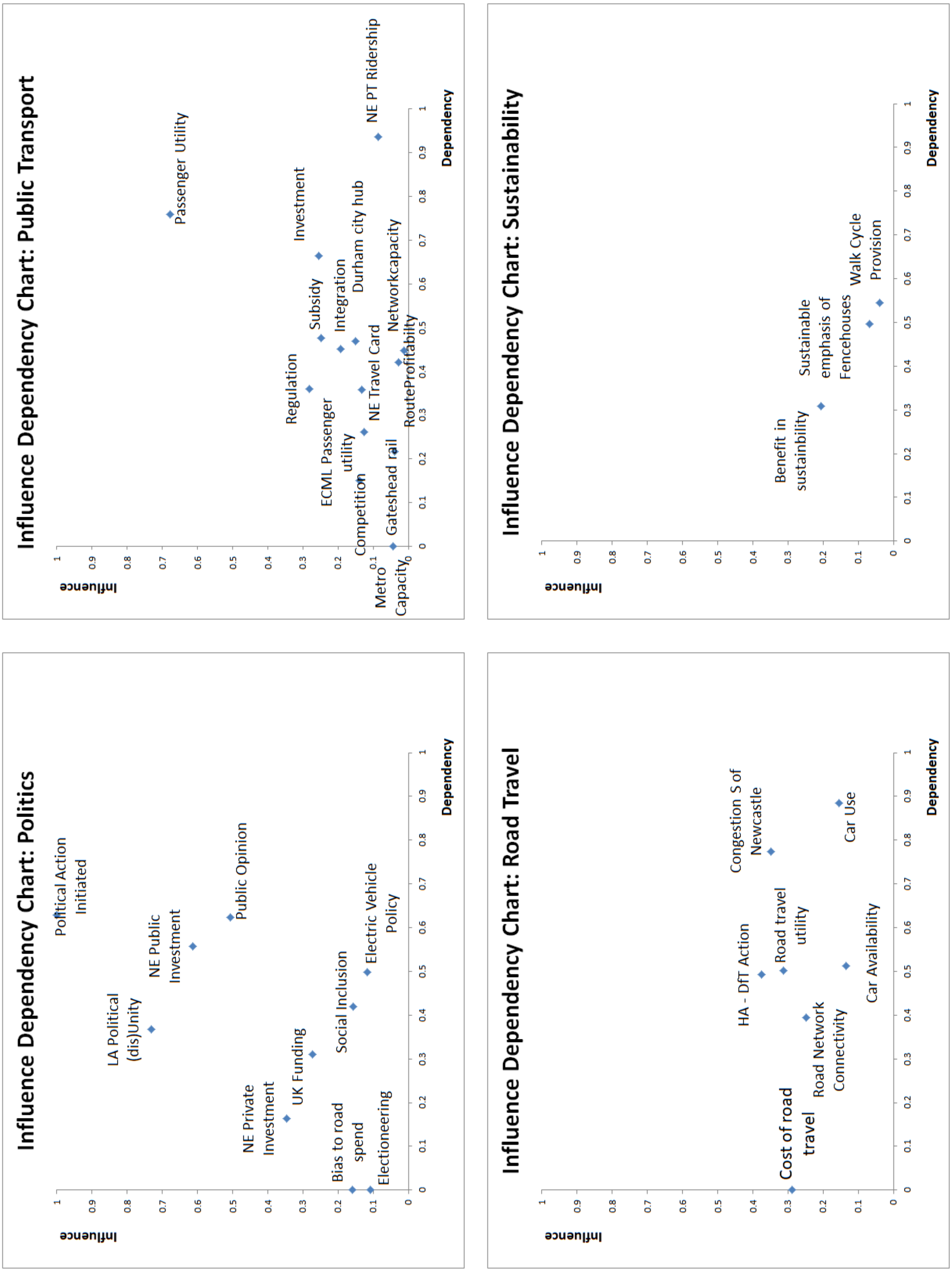


Figure 9-2 Variables by Category

Economy and Demographics

The Economy and Demographics group holds some of the variables most responsible for instability in the system as well as some of the least Influential and least Dependent. It occupies a wide range across the Influence- Dependency space. Within this category; to comment on some of the variables:

The “Historical Demographics” variable has no dependencies, which is predictable as it is established and unchangeable. It is however moderately influential as it influences the “Travel Driven Lifestyle”, the public transport patronage and subsidies required and also, due to pre-existing infrastructure, the local economic growth. Similarly, the “Ageing Population” and the ”Rising Population” variables have no dependencies within the scope of this project, but are less influential in their effect on the system indicating that historical planning demographics is more influential than population demographics.

The “Travel Driven Lifestyle” variable is heavily dependent on the “Historical Demographics” variable and the move to “Urban Agglomeration”. It has both an influence and a dependency on “Planning Policy”. It also has a strong influence on “Car Use”.

The “Knowledge Economy” variable refers new methods of working and a move towards service industries. It has a bidirectional link to the “Planning Policy” variable indicating contradictory views on causality. Its strong influences are to “Economic and Employment Growth” and to “Political Action Initiated” demonstrating that as the economy changes, so politicians see a need to act.

Politics

The Politics group also covers a wide range of the Influence-Dependency space. It has a number of variables in Vester’s (2012) area 5,6,7 – the sluggish indicators, weak controls and insignificant variables with key variables in area 2 – the critical variables (refer to Section 2.4.4) these being “Bias to Road Spend”, which has no identified dependency, “Social Inclusion” and “Policy to promote Electric Vehicles”. It also has two of the most critical and influential variables.

The “Political Action Initiated” variable influences many other variables. Its primary influence is on the act of re-opening the Leamside line which in turn has further influences. It also has a bidirectional link to the “Local Authority (Dis)unity” variable indicating the role of leadership in collaboration.

The “Local Authority (Dis)unity” variable also has a strong influence on the ”Leamside Line Re-opening” variable and on development in Fencehouses with influence on a number of minor variables such as creating a Travel Card for the NE region, the Leamside Line’s priority in funding and Public Transport regulation and investment.

The “Public Opinion” variable is closer to the “indicator” space than the “control” space in Vester’s description of the Influence-Dependency space showing that although action is influenced by public opinion, that opinion is also formed by the actions observed by the public.

Fencehouses

The three Fencehouses variables are all of low influence and medium to high dependency. This indicates that while development of Fencehouses would be dependent on the Leamside Line, the Leamside Line is not dependent on the development of Fencehouses.

Freight

Like the Fencehouses variables, the Freight related variables are of medium to low influence, and medium to high dependency. The inference is that as for the development of Fencehouses, the Leamside line does not depend directly on freight. This is contradicted by the views of stakeholders based in Co Durham (Stakeholders #1 and #2) who regard the use of the Leamside line for freight as the primary reason for its reopening. The variable “ECML Freight Congestion” does however exert a major influence on the use of the Leamside for freight and the line being re-opened. The “Political Action Initiated” variable is dependent on “ECML Freight Congestion” and this could be regarded as one of the triggers to find leadership for the Leamside initiative. A sequence which is clearly identified, and is prominent, in the stakeholder interviews.

Public Transport

The Public Transport variables show similar behaviour to the Fencehouses and Freight variables with one exception; the “PT Passenger Utility” variable which encapsulates the passenger experience and principally influences the “NE Public Transport Ridership” variable.

It also influences many other variables raising its overall influence and has many dependencies which place it in the "instability" zone.

Road Transport

The key variable in the Road Transport category is the action of the Department for Transport and the Highways Agency[12] "HA-DfT Action" This variable is strongly influenced by the "Congestion south of Newcastle" variable and, through their road transport responsibilities, influence this congestion too. They influence planning policy, the Leamside business case, and public investment. This analysis has placed the DfT and the HA in the zone that in the Cross Impact Matrix Method according to Vester (2012) and shown in Figure 2-3 on page 54 is described as the "control" zone. These variables are used to influence the system and bring stability. The stated role of these two organisations is to control and co-ordinate transport developments in the UK, and this analysis confirms that role in the view of the stakeholders.

Leamside Line

The Leamside Line category of variables are also primarily in the lower quartile of influence and spread over the range of dependency. The two most influential variables in this category are the "Rail Planning Timescale" variable and the action of re-opening the Leamside line.

The "Rail Planning Timescale" variable is influential, but nothing in the Leamside decision system influences it. This is not unexpected as rail planning periods are nationally fixed to be 5 year blocks and the needs of a provincial line such as the Leamside will have no effect on that timescale. In other words, the Leamside Line project must work to that timescale, that timescale will not adapt itself to the Leamside Line.

The action of reopening the Leamside line is densely connected. It is dependent on the political actions and Local Authority unity to provide the environment to initiate it and to bring the project to completion. It also influences variables in the public transport category, and in the freight category.

Sustainability

The sustainability nodes are low in influence. The "Benefits of sustainability" variable influences planning policy, the actions of the DfT and HA, and the "Political action Initiated"

[12] During the course of this research project, The Highways Agency rebranded itself and became known as Highways England. Both names are used in this thesis.

variable. Sustainability is influenced by "Public Opinion", revealing a chain where public pressure to move to a sustainable transport network influences both planning policy and the gatekeepers of transport planning policy, but this does not emerge as the largest influence in this case study of the Leamside Line.

9.1.2 Key Variables

This section describes the ten key variables which have been revealed by the analysis to be the most Influential and most Dependent in the system. Each variable is quantified by the number of stakeholders referring to it and the number of links made to it. To expand on the role of each of these variables, the narrative for it refers back to the text of the original interviews to gain an insight into what factors, in detail, contributed to the status of each of these key variables.

Political Action Initiated

Category	Stake-holders	Links In/Out	Summary
Politics	11	24/67	The need for motivation by the Local Authorities to bring stakeholders together, to have ambition to push a project through, to find the funding for it, and the need for a specific project champion.

This variable was initially coded as two: "Strong Political Driver"; and "Political Ambition and Foresight". On review, it was noted that both refer to the leadership required to instigate and carry out a transport project. The former tended to be used to refer to institutional leadership, the latter to the need for an individual leader, a project champion, to promote the project. The comments made by the stakeholders were similar and therefore, these two variables were merged.

Conversations around this variable refer to the belief that the decision to undertake a development is primarily a political decision:

> ***Consultant**: "Drive from Government in creating a sustainable Fencehouses, it won't happen organically " ….. "Needs regional Government to make a case for rail line."*
>
> ***Activist**: "needs a political decision to open Leamside and provide investment."*
>
> ***User**: … "Freight tram… it does take council to say OK and make a decision and really want to limit the number of white vans (... on the road)."*

***Planner**: "Investment, political will and community interest all required in sustainability "*

Not all comments referred to a positive drive and the need for leadership, some referred to the negative pressures as leaders looked in other directions:

***Planner**: "I've been a bit negative about passenger rail because of the council position."*

***Activist**: "Needs public ownership but politicians don't want that."*

***Consultant**: "Some frustrating lack of development for 20 years due to lack of political initiative, no regional planning since heavy industry decline."*

***Planner**: "but it's a case of ambition and I think where the Leamside is, at the moment, is at the bottom end of ambition."*

Other comments were made about the need for ambition, or the lack of it:

***Planner**:"… is the council that seems to be as dramatically affected by central govt cutbacks as the rest but also by its own (in)ability to generate income which is working against them."*

***Consultant**: "Northern Powerhouse gives political will."*

Comments were also made about the need for an individual or set of individuals within an authority to take ownership of the project. These comments focussed around two aspects of human involvement as compared to institutional involvement, the first that institutions are driven by people and their priorities and the second that within an institution, a specific individual must take the initiative for the project, and have the expertise and status to do it if the project is to proceed.

***Planner**: "That's the sort of NE political pressure level - the leaders and elected mayors group."*

***Planner**: "well its* [The Leamside Line]*got potential but the institution I'm in; it doesn't want that so if there's not the aspiration from the council to do that then how is it ever going to happen if the people in the centre aren't supporting it."*

***Planner**: "Needs a strong officer in the council" … "I think you need a strength of will that you are going to build somewhere sustainable."*

***Planner**: Freight provision – "poor as Government does not lead"… "If they want to do it, they'll do it but someone with the expertise of doing it has to come and lead it."*

***Consultant**: “Integration needs someone in Government”…. “It needs to be brokered.”*

LA Political (Dis)unity

Category	**Stake-holders**	**Links In/Out**	**Summary**
Politics	11	9/64	The tendency of the Local Authorities to compete for investment or to require parity in investment, and the disjoint policy on public transport. Combined with the counterpoint ability to collaborate in Local Enterprise Partnerships.

This variable was initially coded as “LEPs (Local Enterprise Partnerships) Collaboration” and “Parochial Attitude of Local Authorities”. These, on examination, were observed to be opposing descriptions of a similar attribute, the tendency of Local Authorities to compete or collaborate and were combined into a single “LA Political (dis)Unity” variable in the “Politics” category.

The disunity is shown by comments such as:

> ***Planner**: “we wouldn’t be happy with a service that goes out to Metro Centre and Team Valley but you can’t get it from Gateshead.”*
>
> ***Planner**: “because we are all quite parochial in the North East and local authorities don’t work together in that way” … “we still have vast parochial problems in the NE.”*
>
> ***Planner**: […Integrated public transport] “requires those areas that are out* [outside the region] - *first to be integrated into the NE authorities.“*

The recognition of a need for unity is illustrated by:

> ***Consultant**:* “[Northern powerhouse]*gets LAs to collaborate.”*

There is also an initiative in the North East; the Adonis Review (Adonis et al., 2013), mentioned by three interviewees, which examined the options for economic development and the corresponding business, industry and transport developments with one interviewer remarking:

> ***Planner**: “…and the new impetus is the Adonis Review which helps that and there is more of an integrated narrative so its plausible.“*

Another was rather more direct on the need for unity:

> ***Planner**: "Well the Adonis report helped because it said things like: look NE, you are useless, you can't even get your act together to agree on transport."*

The same interviewee went on to compare the NE region with other parts of the UK:

> ***Planner**: "Manchester has been relatively successful –they have a combined transport authority covering whole of Manchester. The NE is in words only moving towards a combined transport authority."*

A similar observation was made in another interview:

> ***Interviewer**: "So the causality is more consolidated views in Local Authorities means you might see a better application which means you might get more funding?"*
> ***Planner**: "yes directors need to learn from others such as Manchester by putting the money into certain things and by borrowing."*

In short the Leamside Line crosses Local Enterprise Partnership (LEP) boundaries, and the common view expressed was that collaboration would be essential for a successful bid for national funding to re-open it. However, as it does not equally benefit all Local Authorities, either balancing benefits would need to be offered, the line would need to be augmented with other extensions, or the project would stall with no agreement.

Reasons emerge for the rivalry:

> ***User**: "City competition for jobs."*

And in one exchange:

> ***Consultant**: "One of the big issues between many local authorities is always some tensions between housing numbers. Going back, the old regions, the RSS spatial strategy, there was always debate and argument how many houses would be built in each individual local authority - to have that embedded in the planning system, the planning process that will allow the Leamside to be operational in 2030 those sorts of decisions have to be taken more or less immediately for it all to happen."*
>
> ***Interviewer** "Is there a sort of inter local authority competitiveness to get more houses for each one or is it …"*
>
> ***Consultant**: "..always has been, there always has been, I think it goes back to council tax by number of dwellings that are occupied. "*
>
> ***Interviewer**: "They compete to get more council tax?"*

> ***Consultant**: “They do compete for more housing, part of that will be financial reward by having houses occupied in terms of how much council tax they will raise.”*

During the interviews undertaken to write the normative scenario (Chapter 6) it should be noted that one stakeholder stated that the new town of Fencehouses would span a Local Authority boundary and the perceived problem was that this could mean one Local Authority subsidised transport while another benefitted from the consequent economic development. This tension was not mentioned in the scenario, but similar concerns emerged during the elicitation interviews.

Economic and Employment Growth

Category	Stake-holders	Links In/Out	Summary
Economy and Demographics	10	32/43	The economic performance of the area, with an impact on employment and on the available budget for transport.

This variable is primarily concerned with the local economy of the North East and though it was noted by some interviewees that it is not dissimilar from the overall economy of the UK and the global economy, others commented that recession (specifically the 2008-10 crash) may be deeper and differently timed relative to other UK regions and that, in general, the North East is less affluent than the rest of the UK.

The specific roles of this variable, in the context of the Leamside Line, are in freight, public, and private transport, and in the levels of funding required to develop or subsidise transport. There are also links to the policy to promote electric vehicles in the North East of England as one of the larger manufacturers is based in the region.

The effect of economic growth on private car transport and on freight is discussed in interviews and the effect of travel on employment patterns which are changing. One comment from a consultant on the change in travel patterns and the effect on planning and jobs captures, in one passage, several similar conversations with other stakeholders.

> ***Consultant**: “… part of the discussion we had about creating jobs in Tyne and Wear… in Tyneside people’s travel horizons to work were always regarded as much shorter than anybody else… people use to live in terraced house and walk down the street to go to work and that mind-set from that generation is probably still around … as new generations come through … the availability of*

various transport options is probably bigger now than it was in the 60s and 70s so the travel horizon to work has probably grown since then.”

Freight on the Leamside line is expected to reduce the congestion on the ECML and hence promote economic growth, but with some caveats on the actual growth expected.

> ***Planner**: “The question is how much the capacity issue on freight causes investment to not look in here or for business to think of that mode of freight.”*
>
> ***Consultant**: “Harwich example: more freight transport means more in the economy.”*
>
> ***Planner**: “The NE doesn’t have a big rail freight interchange and we realise we had better have one otherwise we are going to lose out economically.”*

Conversely, one consultant asserts that as the knowledge economy becomes more important to economic growth, the importance of heavy freight declines and the importance of passenger traffic rises.

Public transport is noted in interviews to depend on economic growth for capital and revenue subsidy and to promote employment through a “corridor for growth” urban agglomeration and public transport hub developments, specifically at Belmont near Durham. Public transport is seen to make jobs accessible when they are remote from the community, even if there is a presumption that commute distances should be short. In general, as public transport is more heavily used, public opinion about its efficiency and convenience forces an influence on policy and politics to develop better public transport.

> ***Consultant**: “what’s always been lacking is the revenue support [for public transport] to promote it, market it, subsidises fares, get teenagers and young adults back into employment.”*
>
> ***Consultant**: “…discussion we had about creating jobs in Tyne and Wear and I think – particularly in Tyneside people’s travel horizons to work were always regarded as much shorter than anybody else,…”*
>
> ***Planner**: “if you look at it from an economic development term you want people with the right skills to be able to get to businesses across the place …”*
>
> ***Consultant**: “thinking about the economy of the region and the connection of lines, including HS2.”*
>
> ***Consultant**: “Can see the economic case [for the Leamside Line] and how this will open up a corridor for growth without people getting stuck on congested roads.”*

Planning Policy

Group	S'hldrs	Links In/Out	Summary
Politics	11	82/78	Planned residential and employment distribution including a policy for incremental development and the planning timescales.

This variable is a combination of four variables. The first two, "Planned Employment Distribution" and "Planned Housing Distribution" both refer to different aspects of current planning policy but showed strong similarity in the links made to and from them, and hence were candidates to be merged. Two other variables "Policy for Incremental Development" and "Regional Planning Timescales" also refer different aspects of planning policy, one to the strategy for development adopted by a Local Authority, and the other to the existence of local structure plans, that are infrequently updated, as well as the inertia in the planning system. These four all referred to one common concept, Local Authority Planning Policy, and therefore were merged to a single "Planning Policy" variable in the "Economy and Demographics" category.

The composite "Planning Policy" variable is both influenced by and dependent on "Travel Driven Lifestyle" and "Urban Agglomeration". The anomaly detected here is that it is influenced by "Economic Growth", but no stakeholder identified a complementary link from "Planning Policy" back to "Economic Growth". Planning Policy, not unsurprisingly, has a strong influence on the re-opening of the Leamside Line and the decision to build the new town of Fencehouses.

Planning policy, for one Local Authority is based not on large developments such as new towns, but instead the agreed strategy is for "organic growth". This leads to problems when planning developments such as Fencehouses with different sustainability policies as first, the size contradicts the agreed strategy and second it requires more involvement from local and national government which complicates the planning process. The policy for organic growth favours incremental development over the creation of a new town.

> ***Planner**: "We are not talking about building anywhere like that there are villages with existing infrastructure and skills we are not aiming for a new town … more of an organic growth than a planned growth. With a planned growth you might have difficult investment or a need a national government interest with one of these green towns or whatever … and you might need more*

dedicated resources and opportunity …rather than tweaking a current town you build a new one with new infrastructure."

Planning policy is both influenced by, and dependent on, the "Travel Driven Lifestyle" and "Urban Agglomeration" variables. Two stakeholders, both of whom are planners, discussed the conflict between the actions of planners, people, and developers. The planner's goal is to place jobs and houses in deprived areas to develop them. The population of the North East however tend to commute to jobs in the larger cities, so zoning areas for business development and housing does not guarantee development will occur. Investors do not necessarily invest where they are unsure of a profit. The influence of "NE Private Investment" represents the compromises planners make to entice investment and placing employment in an area does not necessarily imply jobs will go to people living locally.

> ***Planner**: "[our plan] for the last 10 years - we have tried to push more housing in some of the smaller settlements to try and reinforce them – because they are going down - we have also allocated quite a lot of employment land around the area, around settlements - in places like Consett and Stanley and Peterlee and it's all standing spectacularly empty because nobody wants to be there. So rather than saying theoretically we'll have more jobs in the Tames, Peterlees and Stanleys of this world we are saying let's put the jobs where people will have them - where people will come."*
> *…*
> *"The other issue is that even if you did get an employer who did want to move to Consett, there is nothing to say that that will be the people who will go to that employment who live in Consett ….. it's totally counter intuitive you'd think people from that town would go to that job, but they don't "*

> ***Planner**: "The principle is to try and plan around key corridors so the majority of the development is planned in key corridors with access to sustainable travel but the statement on people living in Fencehouses will also work in Fencehouses is probably incorrect because we have a very integrated labour market in the NE and people do travel so to make an assumption that people will be living and working in the same place is probably incorrect."*

Influences on planning policy include the need to plan for "Employment and Economic Growth", the transport policy determined by "HA - DfT Action" and the investment from public bodies as well as private investors. Planning policy has a strong influence on development in Fencehouses.

NE Public Investment

Category	Stake-holders	Links In/Out	Summary
Politics	10	27/39	Investment in the North East region by public bodies.

This variable refers to public sector funding in the North East area. It has a direct influence on aspects of the re-opening of the Leamside Line for both freight and passenger traffic; it controls development in Fencehouses; it influences public transport provision and subsidy; and it influences sustainability developments such as walking and cycling provision and support for electric vehicles. It is the key driver for developments through financing of those developments, sometimes as the sole funder, sometimes in partnership.

This variable is influenced by leadership in the Local Authorities and collaboration between them. Stakeholders have different views on the status of the collaboration between the authorities in seeking finance for transport projects.

> ***Planner**: "we aren't very good at seeking money, not as good as Manchester or the Midlands … not as geared up as we are not such a big MET we don't have joint teams … but there is enough interest now from economic directors in trying to attract some inward investment."*

> ***Consultant**: "If its involved in NE funding then currently being drafted then there is a LEP, a NE combined authority, busy prioritising and pulling together a local funding so to have any status, the North East LEP needs to support it."*

This variable is also influenced by public opinion via local politicians If there is a public perception of need, then funding is more likely and that local perception is realised through electioneering, access to UK wide funding, and the presence of political leadership.

> ***Planner**: "no one's got any money and that's not going to change in the short term - and in the freight one – it's how much people perceived freight to be a problem in the NE and I don't think the public and the politicians in the NE would consider freight to be a big issue. they'll consider congestion as an issue, as will the public in Durham."*

Funding is however seen as a key driver for the Leamside line, Fencehouses and associated developments

> ***Local Authority Official:** " all comes back to funding, funding, funding, and my life is cuts, cuts, cuts. That said, local Government does spend an enormous amount of money… an enormous amount of money."*

> ***Planner:*** *"The timescale may not be possible to have by 2030 it'll be an integral part of the transport network. The timescale will be a bit later … because of funding mainly, trying to secure a funding position for the project."*

PT Passenger Utility

Category	Stake-holders	Links In/Out	Summary
Public Transport	11	34/46	The desirability of Public Transport. A combination of fares, safety, environment, timetable, and network coverage.

Initially, four variables were coded to describe Public Transport desirability. These were:

- Fare cost
- Comprehensive network
- Pleasant environment and convenience
- Service Frequency.

These were merged into one and linked as one composite variable, "Public Transport Utility" and used to represent the multiple facets controlling the attractiveness of public transport as directly experienced by the traveller.

The route network was commented upon in terms of how it of poor quality in rural areas and tends to focus on urban areas where passenger numbers are greater, which in turn reinforces the observations concerning planning policy of focussing development in the key corridors.

> ***Planner***: *"what you have in Co. Durham is a lot of people living in old pit villages which don't have pits anymore and there is no purpose to them other than they are located where the pit was so they are not located necessarily on good* [PT]*nodes and links therefore they use private cars."*

> ***Planner***: *"the current journey patterns across the NE – the distance travelled in the NE is one of the longest in the country - so there was work to try to change this but there are so many people in Co. Durham who live on a disconnected network."*

> ***Planner***: *"but some of our more remote rural areas do not have public transport or a public transport option in regards to rail and then public subsidies for transport in rural areas are being hardly hit at the moment"* [as in hit hard financially, not hardly hit at all].

This is noted also in the variable "PT Route Profitability" where the profit for the bus companies is in the busy urban routes, not on the sparsely used rural routes which implies subsidy is needed resulting in a bi-directional link to the "PT Running Costs" variable. Attitudes to "Fare Costs" were variable; two stakeholders stated costs were an issue that drove travellers into cars while another was of the opinion that "cost is less of an issue" and the "need for convenience" was more important. A further stakeholder proposed positive action on fares.

> ***Consultant**: "the cost of fares is always an issue, its high on everybody's agenda and I think if the fare structure was re-considered with some additional subsidy certainly for certain sectors of society – even getting people into jobs, the cost of public transport fare – for someone in new employment is always cost prohibitive so in the NE and certainly in Tyne and Wear we look for ways of kick starting introduction into employment where the cost* [is a barrier]."

This variable is well connected Its strongest influences are to "NE PT Ridership", "Leamside Ridership" and "Car Use" as well as "Economic and Employment growth". The latter implies a link between the use of transport and regional prosperity, reinforced by PT passenger utility also influencing the "Knowledge Economy", "Urban Agglomeration", "Heritage and Tourism" and the "Travel Driven Lifestyle". No direct links are made to the political variables, but "PT Passenger Utility" does influence "Public Opinion" which in turn influences "Political Action" and "NE Public Investment".

Historical Demographics

Category	Stake-holders	Links In/Out	Summary
Economy and Demographics	8	00/42	The distribution of employment and residential areas, in the NE, this tends to be based on old colliery towns, which no longer have collieries or ship yards as they have now closed. Replacement jobs are largely in the public sector in different locations.

This variable is formed from two variables originally coded as "Historical Employment Distribution" and "Historical Population Distribution". It essentially describes the current distribution of jobs and housing in the area based on how the North East of England evolved from its old industrial past "*Settlement is so dispersed based on old mining communities*". It has no dependencies; as a statement of historical fact, it cannot have any. It has strongest influence on the "PT Running Costs (Subsidy)", "Travel Driven Lifestyle", and "Economic and

Employment Growth" variables showing how links to the old industrial settlements clash with the new distribution of housing and jobs.

> ***Planner**: "and that is a principle that for local authorities in the NE there is a balance between the status quo and regeneration trying to prop up communities on long established settlement pattern which is quite dispersed and an industrial pattern which is equally as well dispersed - so trying to work out transport movements and where to put development is quite a challenging thing."*

The "Historical Demographics" variable is not solely concerned with the geography of the area. The type of employment also is included:

> ***Planner**: "Durham city centre has pretty high employment area, the downside is that is nearly all public sector … somebody at a desk in Whitehall probably wouldn't realise that - that places in the north like Durham are so dependent on the public sector - and the public sector is decreasing…"*

This comment continues to show how this influences current planning:

> ***Planner**: " …which is why our plan is that we accept the fact that public sector is decreasing so instead of trying to get more of it we build areas that are attractive to the private sector so our employment area is there"* [Points out window at Durham city centre].

This comment from another stakeholder then shows how historical demographics influences people's behaviour which is also related to the variable "Commute Inertia":

> ***Consultant**: "I think the reason behind that was probably going back to the 60s 70s when shipbuilding was the biggest industry on the Tyne, people used to live in terraced house and walk down the street to go to work or walk through the Tyne tunnel to the shipyards on the other side of the Tyne and that mind-set from that generation is probably still around."*

Although this latter comment is contradicted by others discussing the "Travel Driven Lifestyle" (See page 236).

The "Historical Demographics" variable also influences public transport use, investment, and integration as well as influencing car use and planning and the "Heritage and Tourism" industry.

Public Opinion

Category	Stake-holders	Links In/Out	Summary
Politics	8	12/29	Public attitude to change, sustainability, costs, and establishment.

The "Public Opinion" variable refers to public pressure for action and is expressed as "*Community interest*", "*Sell to the public*" and "*people perceived freight to be a problem in the NE*".

It influences actions related to the transport variables; "Leamside Re-opened", "NE PT Ridership", "Car Use", "Local Rail Based Freight " and "Walk Cycle Provision". It also influences investment from "UK Funding" and "NE Public investment" as well as directly influencing the "Leamside priority in Funding", the "PT Investment" and the "Electric Vehicle Policy". It has an influence on "Political Action Initiated" illustrated by one consultant stakeholder who's causal diagram notes linked action on public transport growth to public values as well as Government direction (Coded as "Political Action Initiated") and asked "*Who is the mover*?".

This variable is influenced by transport factors: "PT Utility", "Road Travel Utility" and "Congestion South of Newcastle" indicating the public respond to their environment and expect change. Its stronger influences are from "Social Inclusion" and "Environmental Cost" implying some altruism in expectations.

Travel Driven Lifestyle

Category	Stake-holders	Links In/Out	Summary
Economy and Demographics	6	46/34	A lifestyle dependent on mobility

The "Travel Driven Lifestyle" variable codes behaviour which depends on mobility. Its strongest influence is on "Car Use" and "Car Availability" which indicates that the travel in "Travel Driven Lifestyle" primarily refers to car based transport, but it also influences transport planning, the "Leamside Re-opened", "NE PT Ridership", "Walk Cycle Provision variables, and land use planning, the "Planning Policy", "Fencehouses is built" variables. It is influenced by the "Historical Demographics", "Urban Agglomeration", "Economic and

Employment Growth", and the "Knowledge Based Economy" variables. It is also influenced by "Road Travel Utility" similarly indicating that it refers primarily to private car transport.

The motives for a travel driven lifestyle revolve mainly about employment but other reasons are discussed:

> ***Consultant****: "Age profile - high value individuals move out of town."*
>
> ***Local Authority Official:*** *"With the best will in the world you won't get a practical system to replace the car for the job [of running children round to their family activities]…. but I couldn't maintain my existing lifestyle on a purely electric vehicle living where I do*." [A rural village in Northumbria with a weekly public transport service and 3 daughters].
>
> ***Activist****:" It's a life style choice."*

Two stakeholders do observe that the current generation entering the workplace are less inclined to pursue a car based lifestyle than previous generations, one stakeholder states:

> ***Consultant****: "when I was younger you got a job and the first thing you thought of was when you had a reasonable disposable income was to learn to drive and own a car but I think its becoming more … not in the forefront of people's minds these days."*

This does not imply a reduction in the "Travel Driven Lifestyle" but a change in how it may be realised.

Leamside Re-opened

Category	**Stake-holders**	**Links In/Out**	**Summary**
Politics	11	107/36	The action that the Leamside is re-opened.

This variable refers to the re-opening of the Leamside and is commonly coded as a general area in the notes, recording or transcriptions as it is a longer duration topic of conversation not a specific point being made.

Re-opening the Leamside is primarily influenced by the "Political Action Initiated", "LA Political (dis)Unity", "NE public Investment" variables and the assessment of the scheme through the "Leamside Business Case". Other influences on this variable which themselves also have high influence scores are "Travel Driven Lifestyle" and "Public Opinion". There are also management influences, the "Rail Planning Timescale" is a significant factor as rail projects are selected on a five year planning cycle and subsequently undergo lengthy assessment; stakeholders were sceptical that the timescale proposed in the scenario was achievable.

This variable has a bi-directional link to "Planning Policy" as while these policies influence if the Leamside Line is to be re-opened, they are also influenced by the presence of the Leamside Line if it is re-opened. Similarly it has a bi-directional link to "Economic and Employment Growth" as this is both a reason to re-open the line as well as a beneficiary if the line is opened.

If the line is reopened, it influences subsequent developments in Fencehouses and in local freight as well as relieving "Congestion S of Newcastle", affecting "Car Use" and improving "PT Passenger Utility" with indirect influences from these variables.

9.1.3 Variables Overview

This analysis of the more influential, the more dependent and the more critical variables in the system reveals that political influences and especially leadership are the key drivers of the Leamside Line project and the key causes of uncertainty are the economic environment, the passenger utility of public transport and the local planning policies.

The three variables identified here as the drivers of uncertainty can be found in the normative scenario as 1) Economic environment: "*including the value of economic growth due to urban agglomeration"* , "*infrastructure investment projects as the UK came out of recession* " 2) Public Transport Utility: *"The Leamside line is however a key link*", *Stations are well lit, safe places with good connections to the road network and to the local bus services"* 3) Local Planning Policy: *"The case to reopen the Leamside line was partly built on redirection of heavy freight trains from the ECML"* and "*The Adonis report in 2013 on NE development made choices stark".*

The prime influential drivers of the project; the political leadership and the unity (or lack of unity) between Local Authorities emerged from the stakeholder interviews. Comparison with other more integrated LTAs were cited, in particular Transport for Greater Manchester (TfGM) as an example of the effectiveness of integrated policy in winning funding, whereas in the area of the Leamside Line, one comment that summarises the situation is:

Planner *"…if you are saying that what you want to do is connect Middlesbrough with Newcastle, suddenly you'll get Sunderland saying 'hold on this should come through us, we're being left out here'. So it'll only be successful if the whole of the North East is successful, but now they are all stuck in a 'we have to fight for our little bit' mode rather than for the North East as an area - it is slowly moving – but its slow very slow."*

Leadership is also key in driving the Leamside Line project and the presence of a project champion, with the ability to work within the local and national political system is regarded as vital.

These two variables which prove to be the most influential drivers were however not explicitly referenced in the normative scenario. These variables were created in response to stakeholder inputs, volunteered as they commented on the plausibility of the events leading to the scenario being realised in its target year of 2030 and containing their views of the necessary steps to be taken.

9.2 Stakeholder Analysis

The stakeholder analysis was conducted by first reviewing each stakeholder's individual view of the decision system expressed by the Influence-Dependency graph created from their variable and links only. This was used to re-construct the stakeholder interview and identify the key points in it.

Subsequently, the stakeholders were evaluated systematically through the quantitative questions analysis where their levels of "calibration" and "discrepancy" could be deduced and measured according to their agreement with the combined view aggregated from the values of the small number of quantitative measures elicited in the interviews. As this exercise was primarily intended to elicit causality, not to determine the most likely values of the measures, only the stakeholder related metrics were used in analysis in comparison with the level of stability revealed in the Influence-Dependency graph for that stakeholder.

Finally stakeholders are clustered using the variables they reference to identify common interests and the correlation between this clustering and their combined effect on the system examined.

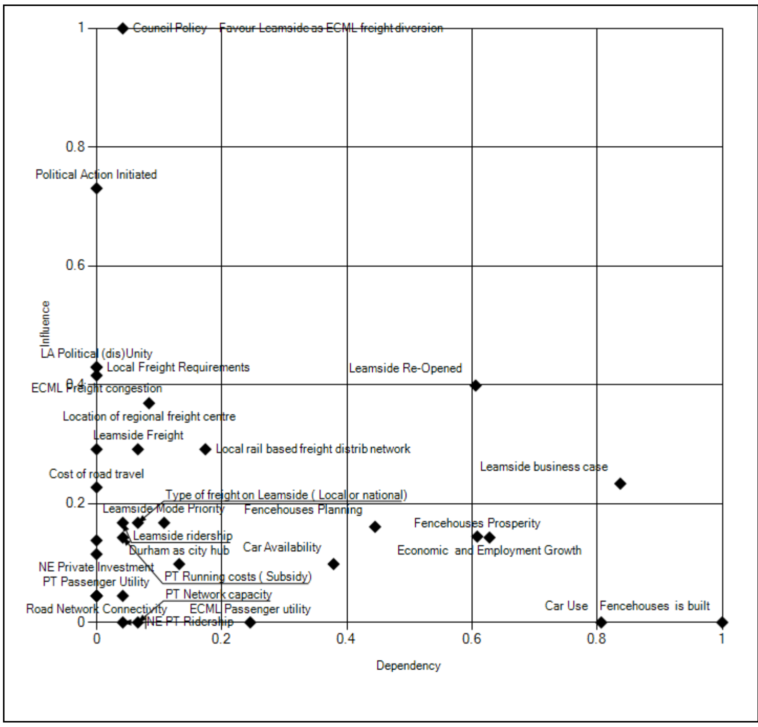
9.2.1 Individual Stakeholders

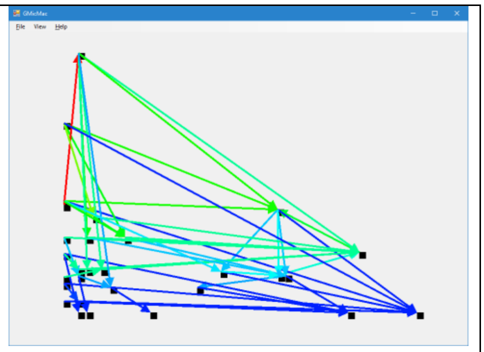
The individual stakeholders are described here. The data for each stakeholder is:

- Their Influence Dependency graph produced with the standard depth = 5, weight =5, with just that sole stakeholder selected.
- The same graph now showing only the links between variables, coloured by link potency where red carries the strongest causality. In essence this graphically summarise the stakeholder interview.
- Quantitative measures for the stakeholder:
    - The ID stability measure for their Cross Impact analysis.
    - The number of variables they reference in the form Unconsolidated/Consolidated where consolidated refers to the variables which were combined during the variable review process.
    - The number of links between variables.
    - Their scores from the quantitative elicitation in the form Calibration / Discrepancy.

This is followed by a narrative documenting the analysis for this stakeholder.

Stakeholder #1: Planner





ID stability	0.17
# Variables	38/33
# Links	58
Quantitative scores	0.74 / 1.81

Figure 9-3 Stakeholder #1

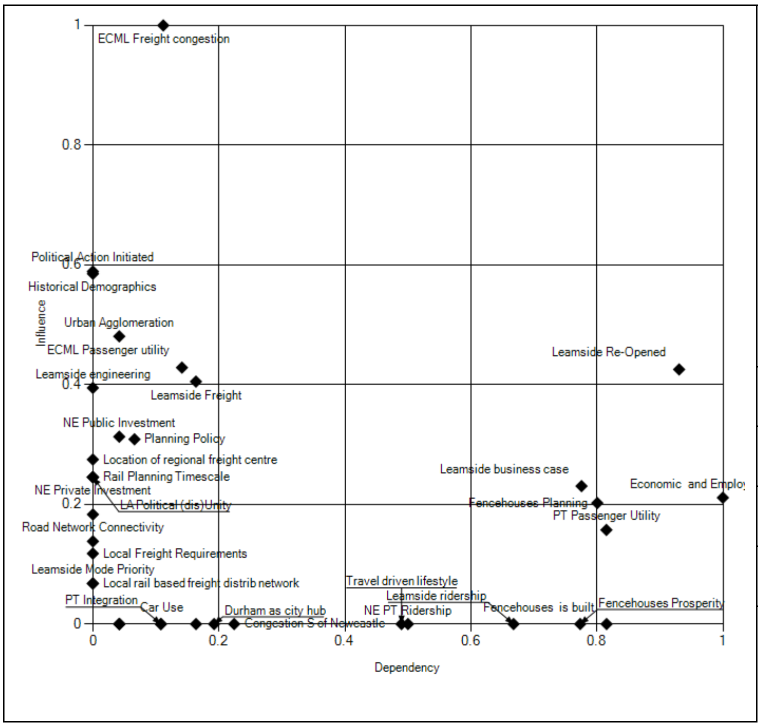
An Urban Planner; a Spatial Policy Advisor in a local authority with 18 months experience in transport planning and very familiar with the NE of England.

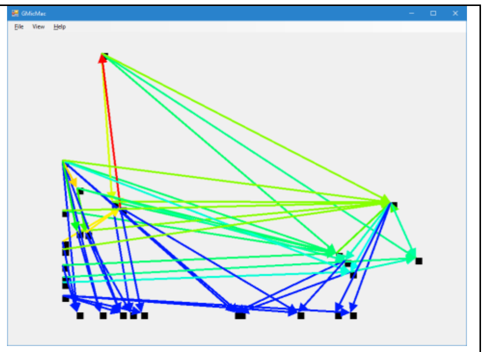
The most influential variable is the "Council Policy to favour the Leamside Line as an ECML Freight Diversion" This is an explicit policy statement which is directly influenced by ECML freight congestion, this latter link carrying the major influence in this stakeholder analysis (the sole red line). The variables influenced by this policy are the "Leamside Line Business Case" and it's re-opening, and the presence and type of freight on the Leamside line. The policy also favours "Durham as a city hub" which in turn promotes "Passenger Utility on the ECML".

This stakeholder's target goal is that Fencehouses is developed, the Leamside Line supports the planning case for Fencehouses and that it is built. The presence of Fencehouses does not conversely support the Leamside Line as the line is primarily used as freight diversion and not as commuter line.

A need for political action is identified and is influential, though not influenced by anything itself. Its influence is directed at the location and nature of freight handling facilities, the Leamside Line opening and the town of Fencehouses being built.

Stakeholder #2: Planner





ID stability	0.19
# Variables	43/37
# Links	69
Quantitative scores	0.31 / 2.00

Figure 9-4 Stakeholder #2

A Spatial Policy Team Leader in a local authority with responsibility for promoting economic development, including transport provision. The most influential variable in this stakeholder's view is the congestion on the ECML due to the volume of freight. This impacts the "Leamside Freight" and "ECML Passenger Utility" variables and the economic growth prospects. "Economic and Employment Growth" is the most dependent variable, in effect this is the primary variable that is "driven" and the Leamside Line is just one development to promote growth, others being the utility of the road network and the rest of the public transport network. It is worth mentioning that the LTP for this Local Authority places a heavy emphasis on connectivity to centres of employment (Newcastle and Middlesborough) for its own local economy.

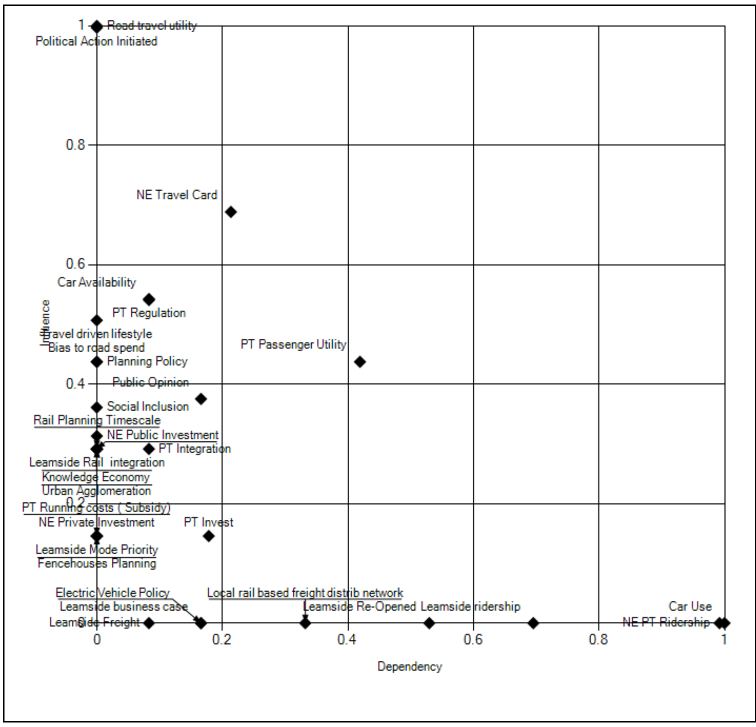
The "Historical Demographics" variable has no dependencies – it is a fixed quantity – but in this stakeholder's view it influences "Urban Agglomeration" through the pre-existing cityscape which in turn affects the "Leamside Line Business Case" and "Fencehouses Planning" variables, reinforcing the desire for good connectivity for the region and for new developments within it.

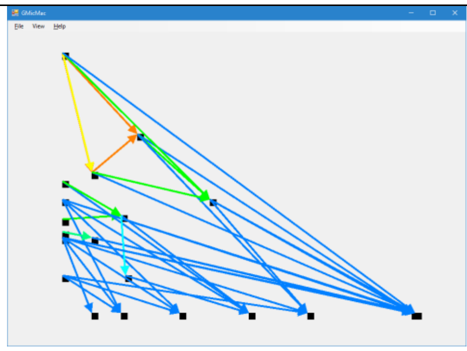
The freight mode used on the Leamside Line has a strong influence on the ECML freight congestion and this is influenced by planning policy and in particular the location of regional freight centres. The local freight requirements also have a direct influence on “Public Transport Utility” and hence on the “Economic and Employment Growth” variable.

Political influence, prominent in other stakeholder’s views is more muted here with the “Political Action Initiated” and the “Local Authority (dis)Unity” variables influencing the Leamside opening and the Leamside business case respectively but both political variables are of moderate influence and have no dependencies on any other aspect of the system

The stakeholder’s interview has several threads, Fencehouses, the Leamside Line, freight and the ECML, but all eventually led to one goal, Economic Growth, and that the way to achieve that is by new developments served by good transport links.

Stakeholder #3: Consultant





ID stability	0.19
# Variables	35/31
# Links	46
Quantitative scores	0.31 / 0.76

Figure 9-5 Stakeholder #3

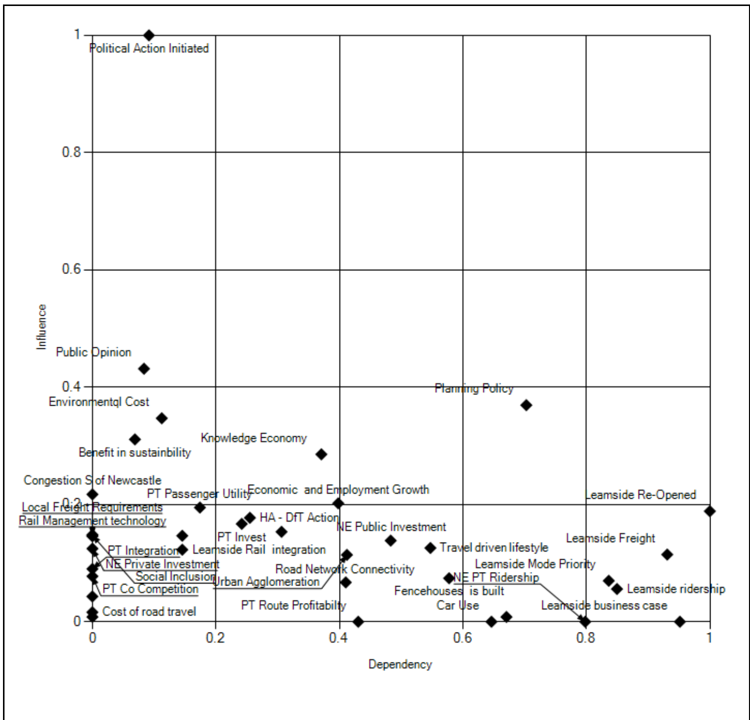
A consultant specialising in accessibility and public transport, but with no specific local knowledge of the North East of England or the Leamside Line.

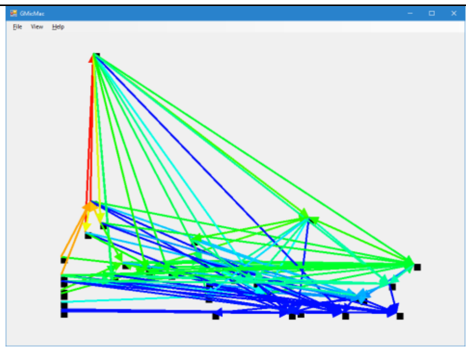
The two “endpoint” variables are car use and public transport ridership in the NE both with Dependency of 1 and Influence 0. This reflects the stakeholder’s professional point of view in accessibility studies, and also the lack of local knowledge and less engagement with the specific situation of the Leamside Line.

There are two distinct threads in the analysis of this interview. The first and the most influential is the upper most composite cluster in the causality diagram. This represents the interaction between public transport regulation, car availability and the utility of road travel and public transport passenger utility, and focusses on the presence of a NE England travel card with the political leadership required to create a comprehensive travel card system. All these factors influence car use and public transport use but these two variables have no effect on any other aspects of the decision system. These variables do however have influence in the system when other stakeholders are included.

The second thread originates in public opinion influenced by a travel driven lifestyle and by a need for social inclusion. Public opinion then drives the investment in public transport and specifically the Leamside Line. This second thread is a very simple system where only two variables (Public Opinion and Public Transport investment) exist in a location other than on one of the influence or dependency axes, and these two variables are linked to each other.

Stakeholder #4: Consultant





ID stability	0.21
# Variables	47/37
# Links	126
Quantitative scores	0.31 / 1.04

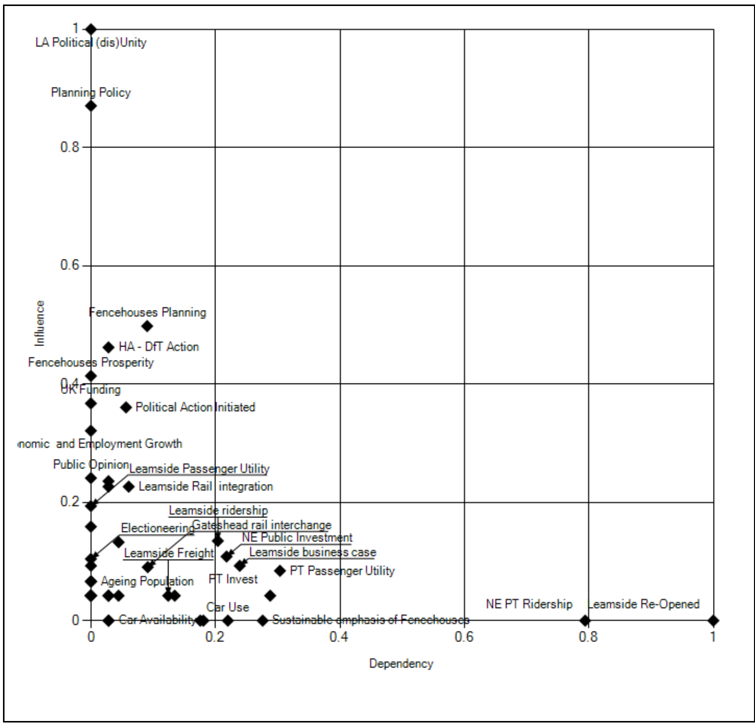
Figure 9-6 Stakeholder #4

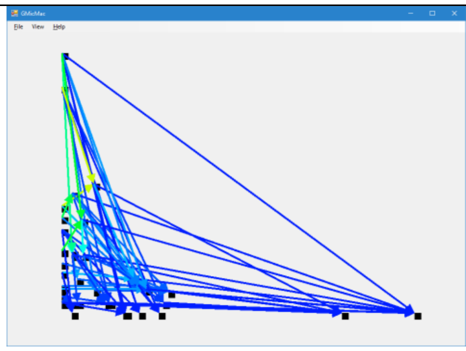
A strategy consultant with experience in transport planning scenario development.

The strongest influence in this stakeholder's view is the presence of strong politically oriented leadership which is influenced solely by public opinion and the perceived benefits of sustainability. The subsequent role of that leadership is wide, influencing directly on public transport in the NE, the opening of the Leamside Line and building the new town of Fencehouses. That leadership also influences the unity of the Local Authorities, planning policy and public investment. Public investment is seen as an influence on the unity of the Local Authorities and their ability to invest in public transport and the Leamside Line in particular.

This stakeholder sees the opening of the Leamside Line as having influence indirectly through the consequent effect on planning policy for other transport initiatives (freight, road network) and on the growth of the knowledge economy and the travel driven lifestyle.

Stakeholder #5: Planners





ID stability	0.11
# Variables	58/47
# Links	94
Quantitative scores	0.67 / 0.93

Figure 9-7 Stakeholder #5

Two individuals, who are part of the Transport Planning Department in a Local Authority.

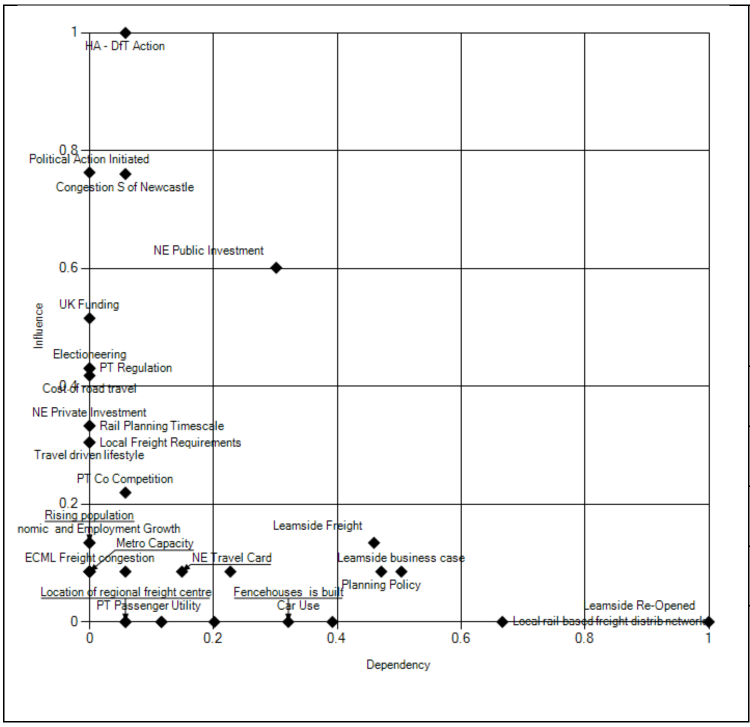
The shape of the Influence-Dependency plot shows a stable system with most variables clustered in the low influence and low dependency quadrant. The two key influencing factors are planning policy and local authority unity which are not influenced by any other factors. This composite stakeholder has the most stable view of the system of all those interviewed with almost all variables clustered in the low Influence and low Dependency zones. The strongest links are to the “Fencehouses Planning” variable from planning policy and the perceived future prosperity of Fencehouses.

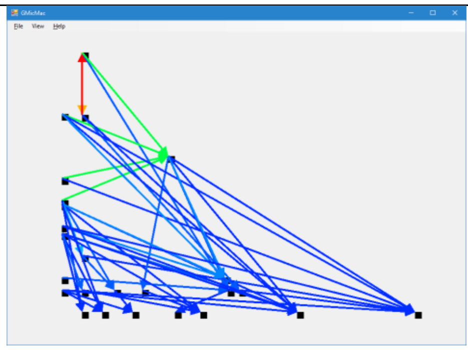
Further inspection of the two main political variables, the disunity between Local Authorities has an effect on the ability to initiate action – in contrast to stakeholder #1 whose opinion was that the causality was reversed and the emergence of strong leadership would have a positive effect on the local authority unity. These stakeholder's views on political disunity is summarised in two extracts from the interview:

> *"…we aren't very good at seeking money, not as good as Manchester or the Midlands … not as geared up as we are not such a big MET we don't have joint teams …"*

> *"Because of where the Tyne valley line ends up at the end of the King Edward bridge - you can't then get up into Gateshead interchange so as a council we wouldn't be happy with a service that goes out to Metro Centre and Team Valley but you can't get it from Gateshead."*

Stakeholder #6: Sustainability Manager





ID stability	0.15
# Variables	41/36
# Links	59
Quantitative scores	0.31/ 0.80

Figure 9-8 Stakeholder #6

A Sustainability Programme Manager for a Local Authority with 30 years of experience working with Transport Planners in the North East of England.

The shape of the Influence-Dependency chart here show a nexus around the "NE Public Investment" variable – an emphasis on funding revealed in the interview as:

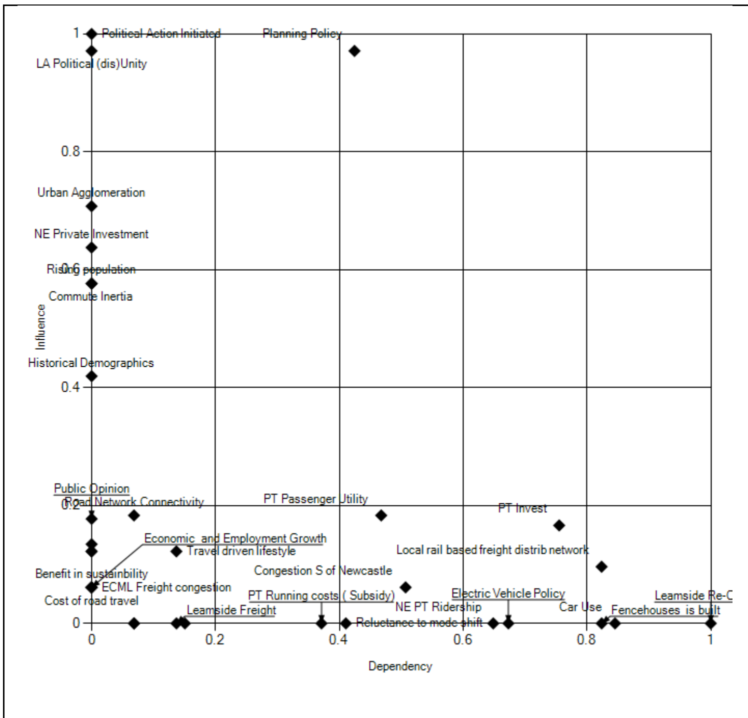
> *"It all comes back to funding, funding, funding, and my life is cuts, cuts, cuts."*

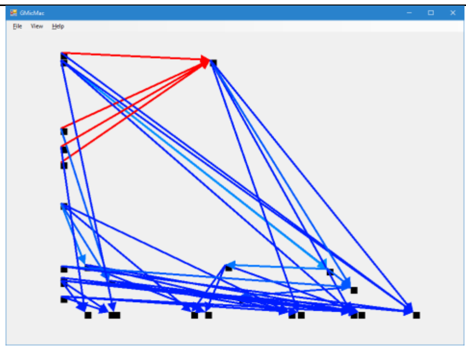
The main influence in the case to re-open the Leamside Line is the influence of the DfT and their reaction to congestion south of Newcastle. This places the DfT as the most influential actor in a relatively stable system. The variable that focusses their influence is the “NE Public Investment” variable which is also influenced by UK wide funding, the ability to initiate action, in this case to win the funding for the Leamside Line in competition with other projects and political electioneering with election promises.

The “Planning Policy” variable is highly connected in this stakeholder’s system influenced by the “DfT and HE actions”, “Public Investment”, “Population Growth” and “Economic and Employment growth”. In this case though, the “Planning Policy” variable only has influence over the development in Fencehouses and no connection was made in the interview between Fencehouses and any transport related development. Freight on the Leamside line contributes to its business case (and hence re-opening) and focusses political action and both public and private investment but the main influences on the re-opening on the line are directly from elements which are not influenced by any other factor in the system; “Public Opinion”, “LA (Dis) unity”, The “Rail Planning Timescale”, “UK Funding” and the “Political Action initiated” variables.

This stakeholder did not involve sustainability variables in the discussion.

Stakeholder #7: Planner





ID stability	0.18
# Variables	45/33
# Links	62
Quantitative scores	0.74 / 0.63

Figure 9-9 Stakeholder #7

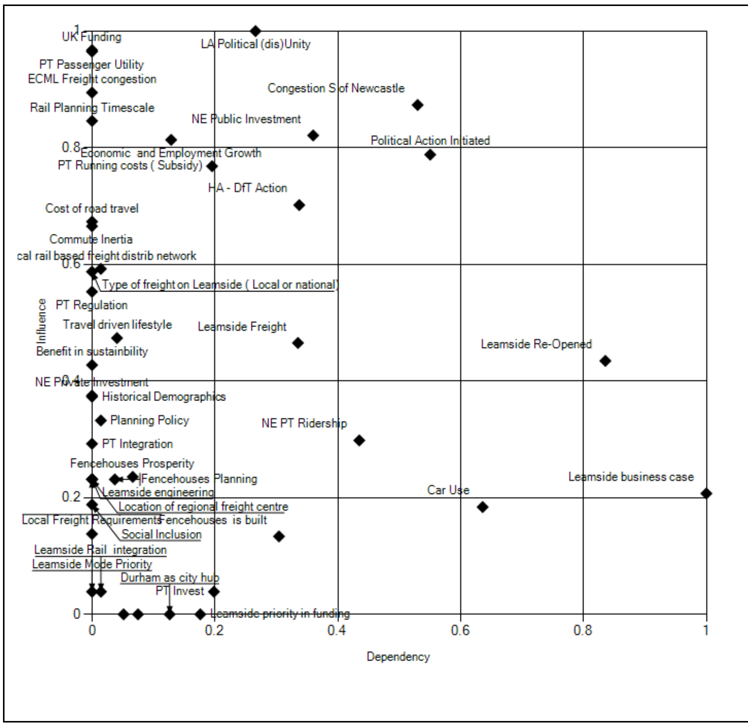
An experienced Transport Planning Officer in a Local Authority.

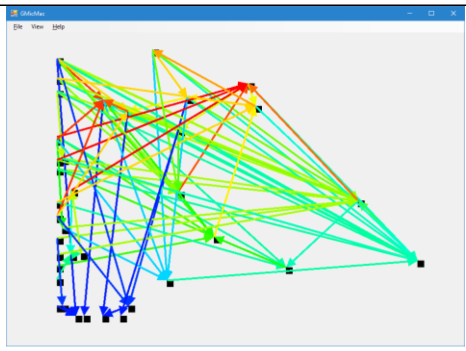
The key variable in the graph here is the highly influential “Planning Policy” variable which is influenced by urban agglomeration, a reluctance to change commuting habits and private investment, the latter two are related in that this stakeholder observes that developers only develop land that will be profitable for them; and that profitability depends on the willingness of people to move to new housing or jobs and to change how they commute. Policy is formed by these considerations and has an effect on Fencehouses, the Leamside Line, local freight, investment in public transport and the policy on provision for electric vehicles.

The two most influential variables, with nothing influencing them are the need for political initiative and the lack of unity in local authorities. Together these influence general investment in public transport and the Leamside Line in particular.

Historical demographics is moderately influential in this stakeholder’s view, it is affected by no other factors, which is axiomatic. It influences the road network connectivity through past development and is now influencing a travel driven lifestyle and the use, and subsidy, of public transport. On inspection a significant portion of the interview was found to be on the topic of the pre-existing distribution of housing and employment, yet the key factors emerging in analysis are those on which the interviewee spent less time.

Stakeholder #8 Consultant





ID stability	0.25
# Variables	50/42
# Links	97
Quantitative scores	0.31 / 1.76

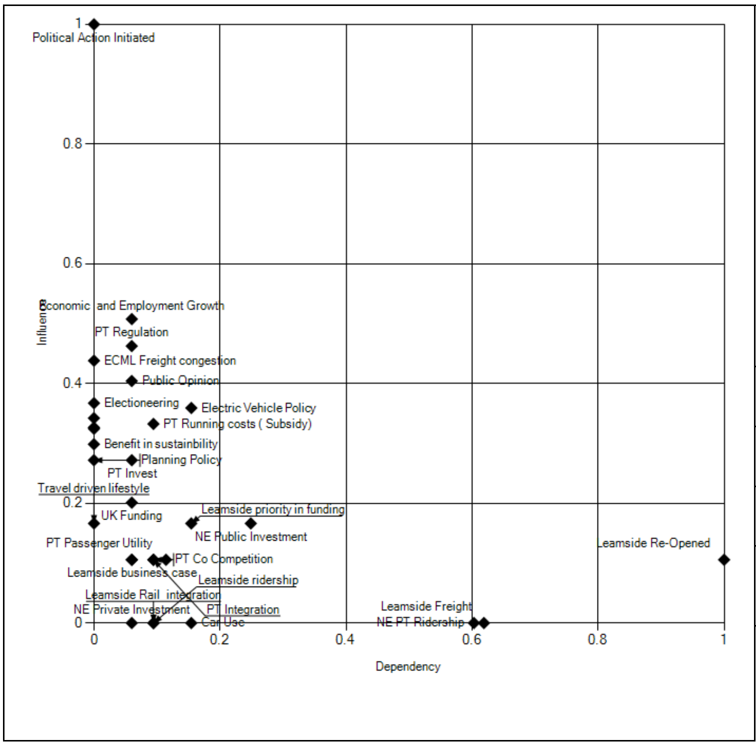
Figure 9-10 Stakeholder #8

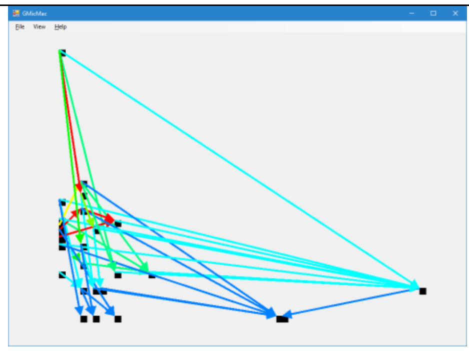
A director for the North East region of a large international transport planning consultancy. This stakeholder has the highest instability rating as can be seen by the concentration of variables in the areas of higher Influence, largely due to the contributions of the “Congestion south of Newcastle”, the “Political Action Initiated”, and the “NE Public Investment” variables which cluster between Vester’s “active” and “critical” zones in the upper left quadrant One of the reasons the congestion variable is rated as unstable is that it both influences and is influenced by the actions of the DfT and the Highways Agency, the ridership of the Leamside Line and the political action. Other key drivers of congestion (the red lines to that variable) are the cost of road travel, the type of freight on the Leamside line and the travel driven lifestyle

Thirteen variables contribute to the Leamside business plan including the presence of Fencehouses, freight requirements, public transport utility and subsidy, the influence of the regulatory authorities (HA and DfT) and the need for leadership and for unity in the local authorities. The business plan becomes a key driver to re-opening the Leamside line with consequential effect on the congestion around Newcastle and the variables that influence the business plan. Note this stakeholder’s job function is to provide decision support for transport business plans and hence this emphasis is cannot be unexpected.

The other key nexus in this interview is the “Economic are Employment Growth” variable which has strong influences from the “Historical Demographic” and the “Reluctance to change commuting patterns” variables, echoing stakeholder #3 but there, the influence of these variables was to “Planning Policy”, “Leamside Re-opened” and the development of Fencehouses variables. Here, with stakeholder #8, it is via “Economic and Employment Growth”.

Stakeholder #9: Transport Activist





ID stability	0.16
# Variables	34/30
# Links	39
Quantitative scores	Not undertaken

Figure 9-11 Stakeholder #9

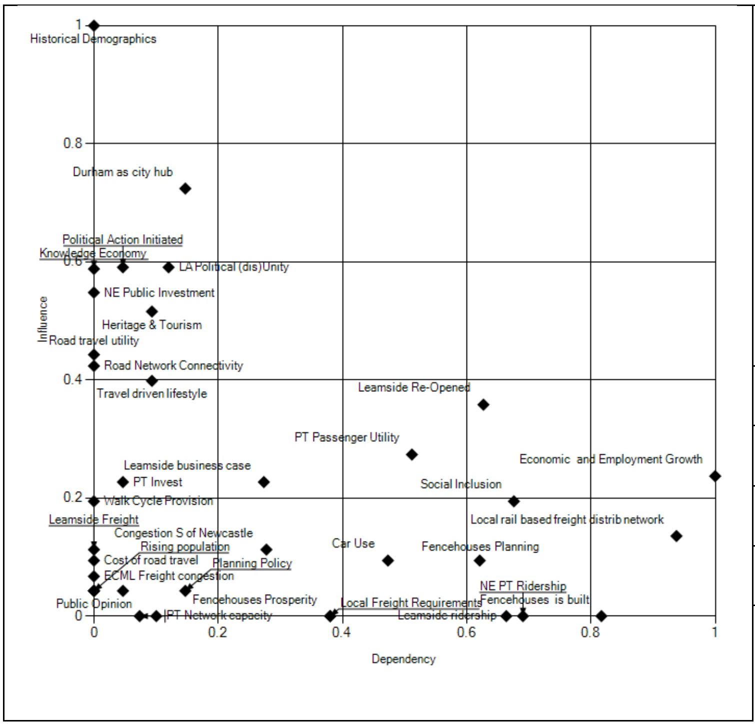
A Transport Activist promoting sustainable transport in the North East of England.

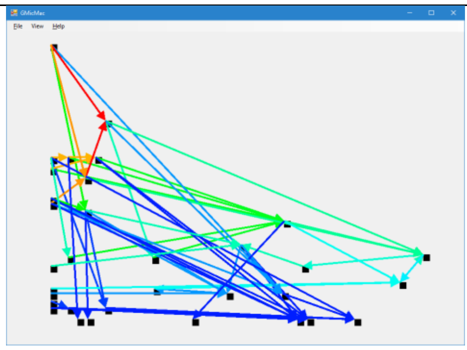
The simple interpretation of this interview is that the stakeholder has a strong view that political action is required to initiate a transport development, to regulate public transport and to invest in it, with other factors very much secondary and hence in the lower influence and lower dependency quadrant. Closer examination within this quadrant shows that the “Environment Cost” on “Public Opinion” and a “Benefit in Sustainability” have influence on the “Electric Vehicle Policy” but that separately in the interview, “Electric Vehicle Policy” influences the Leamside Line opening through the presence of an electric vehicle manufacturer adjacent to the line. The variable concerning the manufacturer was merged with “Electric Vehicle Policy”.

Investment for the Leamside line is influenced by “Electioneering”, “Economic Growth”, and “UK Funding”, the latter influenced by a “Bias to road spending” rather than spending on public transport.

Variables such as “Car Use”, “Leamside Freight” and “NE PT Ridership” are all dependent on other variables in the system, but the interview did not discuss subsequent influences of these variables. Similarly, with one exception, the variable “Leamside Re-opened” is an end node only indicating that its re-opening has no effect on any other variable. The sole exception is that it influences freight on the line which coincides with the observation that “Electric Vehicle Policy” also is an influence on the line’s re-opening.

Stakeholder #10: Consultant





ID stability	0.21
# Variables	44/36
# Links	68
Quantitative scores	0.67 / 0.69

Figure 9-12 Stakeholder #10

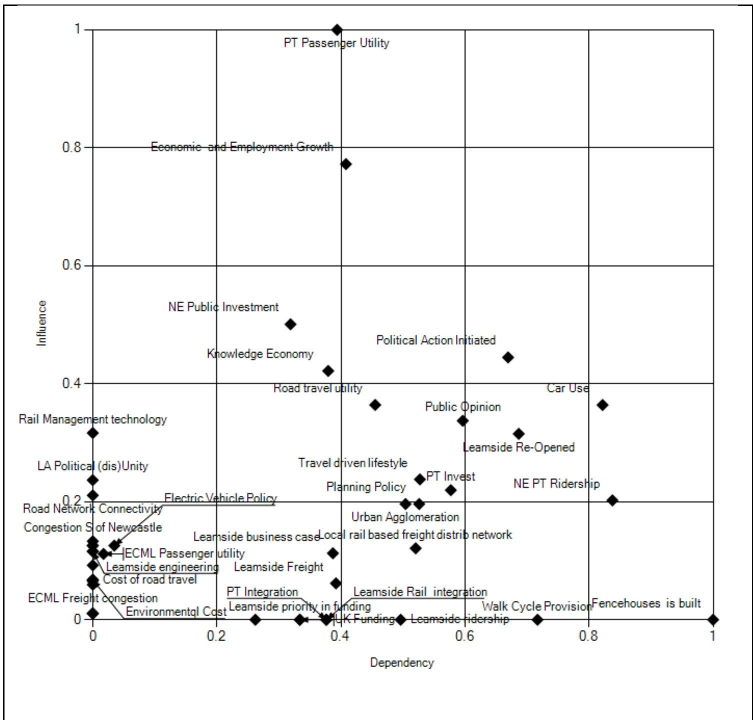
A senior ITS professional (Intelligent Transport Systems) with a strong local knowledge of the NE of England.

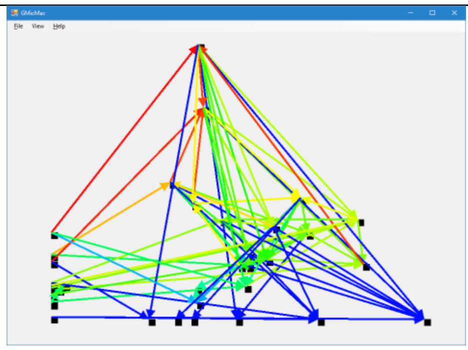
The key factor here is based about “Durham as a city hub” driven by the “Historical Demographics” and the “Heritage and Tourism” variables and driving “Economic and Employment growth” which is the most dependent variable. The detail of the interview yields comparisons with villages where a small cluster of active businesses can give a high benefit to the micro economy and extrapolation of this to the larger city of Durham with the tourism industry benefiting from transport network connectivity. Activity in Durham drives

"Economic and Employment growth" and also influences "Fencehouses Planning". The style of Fencehouses planning is influenced by the growing "Knowledge Economy" which also influences the likelihood of "Political Action initiated", this being an important new development in planning policy to support a new economy.

One variable with multiple connections is the "Travel Driven Lifestyle" influenced by "Historical Demographics" and "Road Travel Utility". This in turn effects "Public Transport Passenger Utility" as a response to the demand for travel and "Planning Policy" and hence the development of Fencehouses. However, no link is made between the Leamside Line and Fencehouses save that the presence of the Leamside contributes to the "Fencehouses Prosperity" indirectly, due to the type of economy planned and supported in Fencehouses.

Stakeholder #11: Local Authority Department Manager: Transport User





ID stability	0.22
# Variables	48/43
# Links	94
Quantitative scores	0.74 / 0.70

Figure 9-13 Stakeholder #11

A Departmental Manager in a City Local Authority in a department which relies on the transport network in the area.

This graph of Influence-Dependency space emphasises the role of public transport passenger utility as the most influential variable being driven by technology to provide a high quality experience and in turn influencing economic development, tourism, the knowledge driven economy and travel driven lifestyle, public opinion as well as those variables concerned with car and public transport use.

The second most influential variable concerns “Economic and Employment growth” which is derived from a well-connected road transport system, public investment and the growth of the knowledge economy. It is also heavily influenced by public transport passenger utility which in turn depends on better rail management technology. The “Public Investment” variable is however influenced by “Local Authority (dis)Unity”. “Planning Policy” is similarly adversely affected.

There is a feedback loop where “Economic and Employment growth” is influenced by the “Knowledge Economy” which is in turn influenced by “Urban Agglomeration” which then helps promote the “Knowledge Economy”. The “Knowledge Economy” also influences “Planning Policy” and the “Political Actions Initiated” by the Local Authorities.

One of the influences on the “Knowledge Economy” is the “Utility of Public Transport variable implying this stakeholder believes strong transport links grow the economy, and specifically the new economy.

9.2.2 Stakeholder Clustering

In Section 8.3.1 the effect of the number of stakeholders on the measured stability of the decision system was investigated. In that analysis, the goal was to study the effect due to the number of stakeholders and the sensitivity of the system to that number. In the analysis presented in section 9.2.1, the Influence-Dependency graph for each stakeholder was examined, the goal in this section is to examine the effect of groupings of stakeholders with similar concerns and investigate if together they complement each other to form more stable, systems. This was studied by first quantifying the similarity between stakeholders, then selecting similar pairings and examining the Influence-Dependency charts for those pairings.

Similarity between stakeholders was quantified using the commonality between the lists of variables they mentioned. This was undertaken with the NVivo software using the individually coded sources to generate a cluster analysis dendrogram. There are usually two sources for each stakeholder, the interviewer’s notes and the recorded interview. NVivo offers three similarity measures to generate a cluster analysis. Two are measures of association (Jacquard and Sorensen coefficient) where the presence of a variable in each source is counted and the measure derived from positive matches, discarding variables mentioned by neither source. The third is a correlation measure (Pearson) measuring the correlation between the vectors of variables for each source. In this case, the association measures are more appropriate measuring presence or absence of a variable and the clustering of stakeholders is similar between the two methods evidenced by the fact that the dendograms output by the two association measures were identical.

The output of the cluster analysis is shown in Figure 9-14, with the stakeholder documents coloured to indicate the job function of the stakeholder. Note, there is only one document for stakeholder #9 as no voice recording was made.

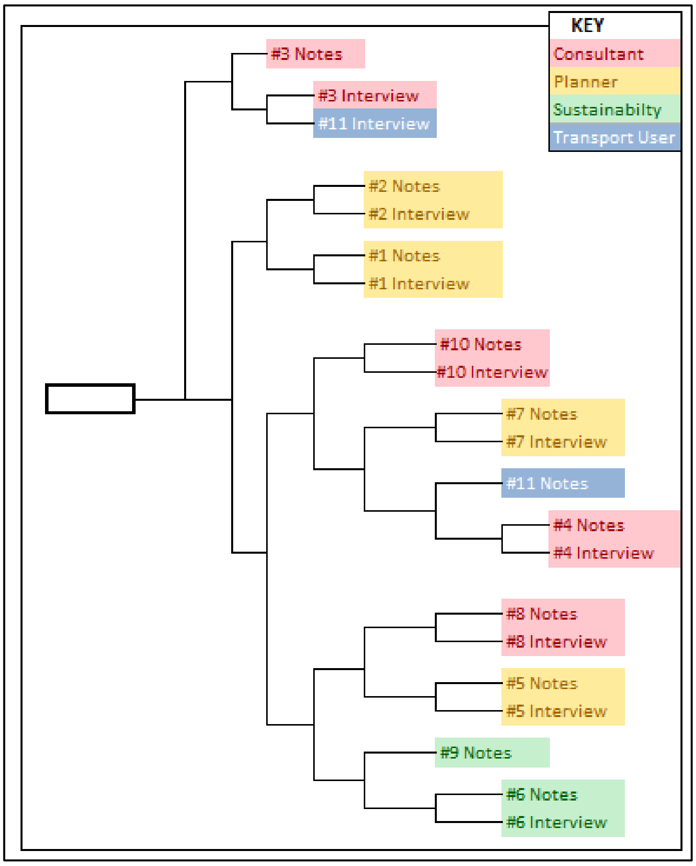


Figure 9-14 Cluster Analysis: Jaquard Measure (Association Measure)

Observations from the cluster analysis are:

- Two sources from one stakeholder (#11) are split indicating this stakeholder has more variance between the two documents. In the correlation measure (Pearson), this stakeholder's two documents were adjacent.
- Two stakeholders with stated sustainability interests (#9 and #6) are clustered together indicating they raised similar issues.

- Two stakeholders from the same department (#1 and #2) are clustered together indicating they raised similar issues though examination of the interviews reveals that they had different interpretations of the situation.
- The accessibility consultant (#3) who is at the periphery of the Leamside Line, but an expert in the issues that it addresses is most removed from the rest indicating that this stakeholder's input is different from the rest. This is attributed to this stakeholder's focus on generic public transport issues and not on the Leamside Line in particular.
- Three clusters are of individuals from different types of organisation and different roles indicating commonality of interest is not necessarily a predictor of commonality of role:
    - #7, #4, and #11 are a Council Planner and an Independent Transport Strategy Consultant and a Transport Systems User respectively.
    - #8 is a Transport Policy and Planning Consultant while #5 is two Transport Policy and Planning Council Officers.
    - #3 is an Independent Accessibility consultant and #11 is a council based Transport Systems User.

The results from the cluster analysis were then used in comparison with the results of the merging of stakeholders in the Cross Impact Matrix analysis shown in Section 8.3.1, Figure 8-11. First, pairs of similar stakeholders, adjacent to each other in the cluster analysis at the lowest level of clustering were combined (stakeholder #11 appears twice as the two documents for this interview are split in the dendogram) the ID stability score from their Cross Impact Matrix Method analysis derived and compared to the range of values for the Inverse Distance measure for all combinations of two stakeholders. Table 18 shows the measures and the range for the measure, and demonstrates there is no systematic bias to the lower range.

Examining the data from Figure 8-11 to identify those pairs of stakeholders with the lowest Inverse Distance measures shows that the lowest four are from stakeholder #5 paired with #7, #3, #9 and #6. All of which are remote from #5 in the dendrogram. This indicates that the hypothesis that stakeholders raising similar issues in interviews will combine to form less uncertain systems (those with a lower Inverse Distance measure) cannot be proved.

Range	0.10 -- 0.27					
Stakeholder pairs	**#5, #8**	**#1, #2**	**#6, #9**	**#4, #11**	**#3, #11**	**#7, #4**
ID Measure	0.20	0.20	0.14	0.24	0.24	0.20

Table 18 ID Measures for similar stakeholders

9.2.3 Stakeholder Quantitative Elicitation Analysis

During the elicitation exercise, five quantitative questions were discussed with two elicitation goals. One was to seed any potential modelling related to the SECURE project (Bell, 2013) with plausible values for quantities that had no current estimate, the second was to continue the discussions on causality with a fresh emphasis having moved from discussing the scenario to discussing estimates of quantifiable elements such as the expected size of Fencehouses, the year of peak car use and the likely use of the Leamside line. ***The primary goal of the analysis here however was not to develop estimates of quantities to use in modelling or in planning for the Leamside Line, but to elicit more causality influences.*** Not all stakeholders were confident to answer all questions and only 10 stakeholders contributed to the quantitative elicitation.

The questions that were developed to accompany the normative scenario are described in section 6.2 and the method that was used to analyse them in section 3.5.1. In summary; each stakeholder was asked to supply an expected value and a range for the quantity in question. The values sought are the expected value, a 25% probability range and a 1% range, expressed verbally as "The probable value", "It's probably within this range" and "It's really implausible that its outside this range. These estimates were merged to provide a consolidated view, but equally, by comparing the answers for a range of quantities, the stakeholders were compared and quantified in terms of their "*Discrepancy",* how much their estimates differ from the cohort and their "C*alibration*", which quantifies their uncertainty about their estimates.

The observations and results from each of the questions are discussed in turn here with the quantitative values calculated and charted by the Excalibur software package (Lighttwist, 2016) which implements Cooke's Classical Model (2013) for merging estimates. In the diagrams shown for each question taken from the Excalibur software (Lighttwist, 2016) the ranges given by each stakeholder are charted, a blank line implies no answer was offered, and the summary result is shown below the stakeholder estimates. This latter result is given the label “*DMa*” or “*DMaker* “ where space permits, and refers to the “Decision Maker” a termed used by the software package.

Question 1: Length of Birmingham Canal Network

The first question has no relevance to the project, it was introduced as a “transport trivia quiz” item and used to explain the concept of range elicitation to the stakeholder so that the discussion in the subsequent questions could focus on causality and values, and not on the method. The question concerned the length of the canal network in the City of Birmingham which is anecdotally longer than the canal network in Venice. No individual stakeholder claimed to know the answer, but all were able to reason what it might be. The actual length is 100 miles of waterway in the Birmingham Canal Network which includes Birmingham City Centre and the adjacent urban areas. The elicited response is shown in Figure 9-15. Note that only this question has a known answer hence only Figure 9-15 has a final “*Real*” line showing the actual value, to compare with the elicited value.

Scale	**1%**	**25%**	**Mid**	**75%**	**99%**
Birmingham Canals (BCL)	5	38	92	255	1190

```
Item no.: 1 Item name: BCL Scale: UNI
Experts
 1 [<--*->---]
 2 [<*>]
 3 [<*>--------------]
 4 [----------<-------*------>-----------------------------]
 5 [-<-----*--->]
 6 [-<---*--->--]
 7 |
 8 <--*>--]
 9 [-<*>-------------]
 10 [>]
DMa [<=*=====>==================================]
Real:::#:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

Figure 9-15 Question 1: Birmingham Canals Length

This example demonstrates the principle well, with a wide range of results converging on a mid-range value of 92 miles that has 8% error from the actual value. Expert #4 can be seen to offer a very wide and also very inaccurate range and hence this expert has a low calibration value. If the true goal of the exercise was a set of reliable numerical estimates, this would result in a low weighting for this expert based on the estimate provided for a subsequently discoverable quantity.

Question 2: Year of peak car use

"In your estimate what will be (or what was) the year of peak car use?"

In asking this question, it was made clear that this was in the context of the North East of England, not global car use. It was intended to elicit the causes of road travel and behaviour change in the context of the Leamside Line. The results are shown in Figure 9-16. The elicited mid-range point was 2011 but the probable range extended from 2005 to 2027. Stakeholder #4 offered no estimate.

Scale	**1%**	**25%**	**Mid**	**75%**	**99%**
Year of peak car use(PC)	1979	2005	2011	2027	2060

```
Item no.: 2 Item name: PC Scale: UNI
Experts
 1 [<--*--->--]
 2 <*]
 3 [-------------------------------<-*>-]
 4
 5 [-----<--*---->---]
 6 [--<-----------*----->-------------]
 7 [--<-------*------>------]
 8 [---------------------<--------*---->---------------------]
 9 [----<-*->---]
 10 [-----<---------------------*------->-----]
DMaker [==================<===*===========>======================]
```

Figure 9-16 Question 2: Year of peak car use

Question 3: The population of Fencehouses

"Assuming the New Town at Fencehouses is built, what is the likely population?"

This was explicitly asked to examine the factors and causalities associated with that estimate. All stakeholders provided estimates; the results are shown in Figure 9-17 .

Scale	1%	25%	Mid	75%	99%
Fencehouses Population (FP)	288	2,490	9,416	28,680	97,770

```
Item no.: 3 Item name: FP Scale: UNI
Experts
 1 [---<---*--->-]
 2 [*->-------]
 3 [-<-------*-------->---------------------------------------------]
 4 [-<---*-------->-------------------------]
 5 *-->]
 6 *]
 7 [---------<----------*---------->----------]
 8 *->-]
 9 *->-]
 10 [-<-*->-]
DMa <==*=======>==============================]
```

Figure 9-17 Question 3: The population of Fencehouses.

Question 4: The Leamside Line Patronage, and its Increase

"What would you estimate the ridership numbers to be in 2025 (year of opening) and 2030?"

This was initially asked as a two questions regarding the patronage in 2025 and in 2030 but subsequently changed to elicit the range of growth factors for the first five years instead. Stakeholders #5 and #7 were the first respondents to provide answers for the 2030 ridership and in effect offered a point estimate for growth by repeating their 2015 estimates with a single growth factor applied, stakeholder #10 also offered a single estimate for growth with no range. Stakeholders #1, #2, #4, and #6 made no quantitative responses as they expressed little confidence that they could make reliable estimates. The results for these two values are shown in Figure 9-18 and Figure 9-19.

Scale	5%	25%	Mid	75%	95%
Leamside Ridership (LR)	2586	129,400	604,700	2,034,000	2,134,000

```
Item no.: 4 Item name: LR Scale: UNI
Experts
 1
 2 [<*-->--]
 3 [*]
 4 <>---]
 5 *>]
 6
 7
 8 |
 9 [-<*--->---------------------]
 10 [----------<---*-------------------------------------->-----]
DMa <*===>========================================================]
```

Figure 9-18 Question 4.1: Leamside Line Patronage

Scale	5%	25%	50%	75%	95%
Change in Leamside ridership (LRC)	-8.7	0.1	14.9	232	100

```
Item no.: 5 Item name: LRC Scale: UNI
Experts
 1
 2
 3 [-------<*>-------]
 4
 5 |
 6
 7 |
 8 [-----------------<-----*------------>------------------------]
 9 [-<----*-->------]
 10 |
DMaker 1
[====<========*==========>=======================================]
```

Figure 9-19 Question 4.2: The increase in Leamside Line patronage

Question 5: The number of freight trains on the Leamside Line

"What is the likely number of freight trains on the Leamside Line per day?"

This question was intended to elicit more about the use of the Leamside Line and the planning choices made. Note that in this question there are estimates available from the Rail Utilisation Strategy Report (Network Rail, 2007) which states that 20 – 30 trains per day use the ECML between Newcastle and Ferryhill (The junction with the Stillington Freight Line) and there would be a predicted capacity gap of up to 18 trains per day in each direction by 2015. The ECML Capacity Review (Network Rail, 2010) states 7 freight trains per day are required to justify re-opening the Leamside Line. No attempt was made to estimate, from these disparate sources, the number that will move to the Leamside Line to provide a reference figure for this question as this too would be an elicited, not a measured value. No attempt was made to give these figures to the interviewees to avoid "*anchoring*" their responses on externally supplied figures.

Only 4 of 10 stakeholders felt confident to provide a response which is summarised in Figure 9-20.

Scale	**5%**	**25%**	**Mid**	**75%**	**95%**
Number of freight trains (NFT)	1.6	9.2	16.2	26.9	78.2

```
Item no.: 6 Item name: NFT Scale: UNI
Experts
 1
 2
 3 [------<---*-->-------]
 4
 5
 6
 7 [--<--*----->-------]
 8 [---<------*---------------------->--------------------------]
 9
 10 [-<------*------->------]
DMak [====<=====*=======>====================================]
```

Figure 9-20 Question 5: The number of freight trains on the Leamside Line

Quantitative Questions Summary

The analysis of the quantitative questions can be inverted to analyse how well a stakeholder's estimates fall in the aggregated range for the elicited variables. This provides two measures which are described in Cooke (2013), referred to in section 3.5.1: The "*Discrepancy",* how much their estimates differ from the cohort; and their "*Calibration*", which quantifies their uncertainty about their estimates.

To examine the relationship between the range of values in the quantitative elicitation and the Cross Impact Matrix Method, the calibration values, provided by the Excalibur software for the 11 stakeholders, were correlated with the metrics taken from the Cross Impact Matrix Method analysis:

- The Inverse Distance stability measure for the stakeholder's Influence Dependency graph.

- The number of links.
- The number of variables.
- The ratio of links to variables as a measure of connectivity.

The values for these measures are shown in Table 19 and the Pearson correlation coefficient *R* between these measures is shown in Table 20. These values indicate that there is no significant correlation between the measures of discrepancy and calibration and those derived from the Cross Impact Matrix Method. Hence no conclusion can be drawn about the relationship between the quality of the answers in the quantitative exercise and the Cross Impact Matrix Method analysis. Furthermore, there is also no significant correlation between the number of variables, their links and the uncertainty in the stakeholder's view of the decision process indicating that a rich response in terms of number of variables and their connectivity does not imply an uncertain system.

Stakeholder	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Calibration	0.74	0.31	0.31	0.31	0.67	0.31	0.74	0.31	-	0.67	0.74
Discrepancy	1.81	2	0.76	1.04	0.93	0.8	0.63	1.76	-	0.69	0.7
Links	58	69	46	136	94	59	62	97	39	68	94
Variables	33	37	31	37	45	36	33	42	30	36	33
L/V Ratio	1.75	1.86	1.48	3.68	2.09	1.64	1.88	2.31	1.30	1.89	2.85
ID Stability	0.17	0.19	0.19	0.21	0.11	0.15	0.18	0.25	0.16	0.21	0.22

Table 19 Stakeholder Measures

Measures	***R***
ID Stability – Calibration:	-0.23
ID Stability – Discrepancy	0.18
Calibration – Discrepancy	-0.30
ID Stability – Links	0.34
ID Stability – Variables	- 0.10
ID Stability – L/V ratio	0.44

Table 20 Correlations between stakeholder metrics

9.2.4 Stakeholder Overview

In this section the interview for each individual stakeholder was re-constructed from their Influence-Dependency chart and a narrative provided for each one which gave a deeper insight into the factors most affecting the stakeholder's view of the case study.

Grouping pairs of stakeholders where they were perceived as similar, having referenced a similar set of variables showed that the hypothesis that stakeholders with similar interests would together form a more stable system cannot be proved and in examining the stakeholders responses to the quantitative questions, the hypothesis that those stakeholders with either a high degree of uncertainty in their estimates or estimates which differed from the others in the cohort can similarly not be proved.

9.3 Links Analysis

The goal of the links analysis was to examine the changes to the system when a link was broken, and to investigate critical links that could be used to change the dynamics of the system. Here the analysis is limited to establishing the level of change that could be effected by breaking links; the complementary action of creating links would require consultation with actively involved stakeholders to determine which links to create and to have the authority to create them.

The goal was to investigate:

- The correlation between the strength of influence in each link and the changes in the stability of the system or in changes from the reference set as that link was removed.
- The quantitative effect of removing the strongest links.

The strength of influence in each link was derived for all 414 links. The change in the ID stability measures[13], and the change in order of Influence and Dependency bought about by removing each link were calculated by selectively removing that link for all stakeholders using the batch run mode of the bespoke project software to automate this task for all links.

9.3.1 Links Strength Correlations

The correlation between the strength of a link and the difference in stability and in ordering when that link is removed is shown in Figure 9-21. The link strength is shown on the X axis, normalised to the range 0 -100, the Y axis shows the difference in stability measure and the change in ordering index. Each point of the 414 present represents one link being independently broken.

As seen in the graphs, and quantified by the correlation coefficient, the strength of the link and the change in the RBO index of order of Influence and Dependency are not correlated and the ID stability measure is also largely uncorrelated with the link strength.

[13] The MS and CB measures were not presented as they show similar results.

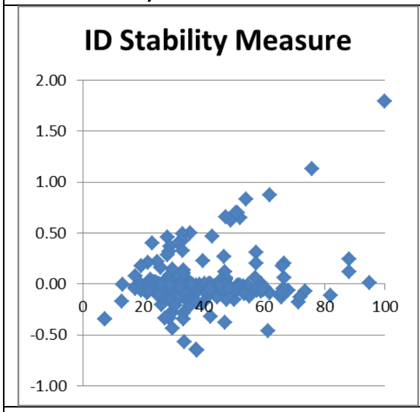
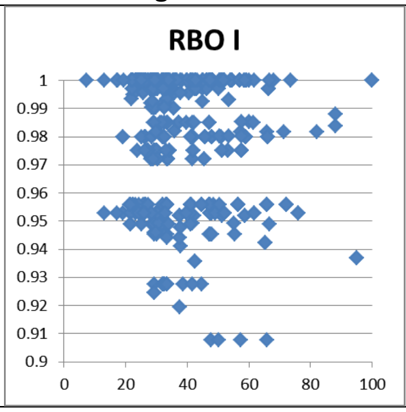
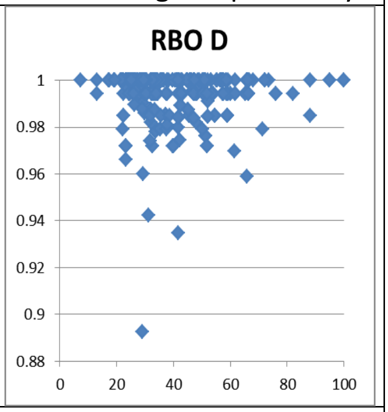
ID Stability Measure	Order Change: Influence	Order Change:Dependency
		
Correlation = 0.24	Correlation = -0.11	Correlation = -0.10

Figure 9-21 Correlation between link strength and effect of removing the link

Examination of the graphs does however show some points:

1. The ID Stability measure shows a subset of links with strong correlation; those with a change in ID stability measure above 0.25. On examination it was found these are all links which originate from the "Political Action Initiated" variable to other variables in the system and these have a positive correlation with the change in stability of 0.97 (sample size 23) and account for all differences in the stability measure above 0.5(11). This is the most influential variable in the system.
   The correlation between the change in the ID stability measure for the variables which are the origin of the next strongest five links was found, none were significant:
   - "LA (Dis)unity " correlation -0.09 (sample size 18)
   - "Economic and Employment Growth" correlation 0.36 (sample size 18)
   - "NE Public Investment" correlation 0.38 (sample size 14)
   - "Leamside Business Case" Not calculated (sample size 3)
   - "PT Passenger Utility" correlation 0.12 (sample size 17)
2. The RBO measure based on Influence shows two clusters above and below 0.96. This is based on the change in order of the second two high ranking variables: "Economic and Employment Growth" and "LA Political (dis)Unity" with Influence measures of 0.7204 and 0.7199 respectively. Small changes in the system which give small changes in these Influence measures readily invert their order. This leads to a significant change in the RBO measure which is based on order, not absolute value. For example, braking one of the weakest links from "PT Passenger Utility" to "Reluctance to Mode Shift" gives a significant change in the RBO measure as these two variables change order with value of

0.7198 and 0.7199 respectively. The clustering in the RBO index for Influence is therefore an artefact of the algorithm used to generate the index, and the closeness of the Influence measure of two significant variables. The clustering cannot be regarded as significant.

Further analysis was carried out to look at the effect of breaking the stronger links. The purpose in the Leamside Line project of this analysis would be to investigate the effect of breaking a link, either by working with stakeholders to change perceptions and beliefs, or by direct policy action to remove a causal effect which appears to create uncertainty in the system.

The following points were found by breaking the stronger links or the links with the highest measured effect on order.

A. The largest change in order of influence with an RBO measure of 0.90 occurs when links from the “Economic and Employment Growth” variable to “NE Public Investment” NE PT Ridership” “Leamside Re-opened” and ”Car use” are blocked which all result in a drop in status of “Economic and Employment Growth” from position 2 to 5.
B. The largest change in order of dependency with an RBO measure of 0.89 occurs when the link from “Leamside Reopened” to “NE PT Ridership” is blocked which results in a drop in status of “NE PT Ridership” from position 2 to 6 in dependency ordering. The second largest change occurs when the link from “Leamside Reopened” to “Car Use” is blocked which results in a drop in status of “Car Use ” from position 3 to 6 in dependency ordering.
C. When breaking the strongest links leading to the most dependent variable “Leamside Re-opened” :
    a. From “Political Action Initiated” : The “Leamside Re-opened” variable is still the most dependent and becomes more influential due to the relative drop in influence of the “Political Action” variable but the order of influence remains the same.
    b. From the “Local Authority (Dis)Unity”, “NE Public Investment” and “Rail Planning Timescale” variables, the next three strongest to the “Leamside Re-opened” variable: Blocking these links has no significant effect on the

dependency order – the “Leamside Re-opened“ variable remains the most dependent.

9.3.2 Links Overview

This investigation indicated no correlation, or very weak, correlation between the strength of the link and the effect on the system in all but one case. The conclusion is that only by breaking the stronger links for just one variable, the one with the highest influence, will there be a significant effect on the stability of the system. Whether this is a generic finding or unique to this case study is not known.

It can be envisioned that if the results of this analysis were to be used in a workshop situation with key stakeholders, insight into the operation of the decision system could be used to effect changes in policy or initiate actions to reduce the uncertainty surrounding the project.

9.4 Summary

This chapter has focussed on the uncertainty analysis of the Leamside Line case study. Three sets of objects have been examined: The variables which make up the description of the case study were examined by category and individually, and, by reference back to the original stakeholder interviews, greater insight was obtained into those variables which are either influential or contribute most to the uncertainty in the case study. Furthermore this list of variables was generated through an elicitation exercise which introduced new factors, not specified in the original normative scenario and these new factors were found to be significant in the analysis.

The study of the stakeholders, reconstructing their interviews from their Influence-Dependency charts, gave insight into their concerns over the case study. The analysis of their responses to the quantitative questions, however, did not provide any insight into the relationship between the uncertainty in their numerical estimates and the uncertainty in their view of the case study expressed in the Influence- Dependency chart.

Finally, in examining the links between variables, the observation was that breaking the most significant link, which could be achieved by changing the attitudes of key stakeholders or by policy decision, can have a limited effect on the uncertainty in the system but there is no one single action available to the potential future project sponsors that would resolve all the problems of uncertainty in the Leamside Line case study.

Chapter 10 Conclusions

10.1 Project Review

In this research, the goals were set to devise and trial a method to identify the causes of uncertainty in the delivery of a transport project.

The literature review first described the many definitions of uncertainty in transport modelling and development and in their associated decision making tasks. From this review, and in both modelling and decision making, a common theme emerged, first that there is a quantifiable class of uncertainty expressed as: model input parameters; in the stochastic nature of both recorded data and modelled outputs; and in the quantification of decision making criteria. Secondly, there also is an epistemic class of uncertainty: expressed as model completeness; the nature of the future environment for the proposed development; and in the qualitative aspects of decision making based in beliefs, bias, and political expediency. Techniques exist to attempt to manage both classes of uncertainty. Transport models have extended into more detailed agent based models and into systems dynamics models with a wide scope extending into policy and economic links to transport. Decision makers use scenario planning to give insights into future environments and elicitation techniques to gather “soft” information from stakeholders and experts. However, transport planning still embraces many problems described as “wicked problems” those with no rational solution and those that evolve into different problems as understanding of them develops.

This research project focussed on this latter area of “wicked problems” and has devised and trialled a method, not to solve the problem or provide a “go – no go” decision, but to identify the key drivers of uncertainty in the project from the initial inception to the decision to proceed. This methodology will then provide evidence as to why those drivers reach that status, such that the project owners may devise actions to mitigate that uncertainty and in doing so, facilitate the project’s progress.

The individual components, linked together in the integrated methodology were derived from areas outside of conventional transport modelling and planning. Scenario planning techniques were used to devise a backcast narrative of the project under study, elicitation was used to derive stakeholder opinions of the project and the Cross Impact Matrix method was extended to function with multiple stakeholders to identify the key drivers of uncertainty.

The integrated methodology was trialled using the Leamside Line as a case study, selected following a review of the Local Transport Plans in the North East of England. The Leamside Line is a disused railway between Durham and Newcastle with differing views from local and national authorities about its future role. While there are tentative proposals for re-opening it and several reports have been commissioned, there has been no apparent action over a period of the last decade during which rail passenger numbers have risen significantly The Leamside Line was therefore considered to be a good example of a nascent transport project struggling to gain the impetus for any concrete action.

In this final chapter, the methodology and the results are reviewed. Section 10.2 discusses the findings of the Leamside Line case study; what was learned about the proposed development and how this compared with observations from other projects or transport planning practice. Section 0 discusses the methodology, its robustness, and how it met the objectives set for it. Finally, in section 10.6, a set of recommendations are provided of how the methodology may be further developed and applied, based on the experiences with the Leamside Line case study.

10.2 The Leamside Line Transport Development

The findings from the Leamside Line case study showed some predictable results. For example, the role of the Department for Transport and Highways England is to manage and control transport developments in the UK. The position of these organisations in the Influence – Dependency diagram confirms that role placing them in what Vester (2012) describes as the “Neutral Regulation” zone. Similarly, some influences are known to be fixed namely the existing urban and rural infrastructure and the rigid planning timescales for rail development, both of which were confirmed by this analysis. Some results, however, were not predictable, for example, the prominence of politics manifested as collaboration (or as lack of collaboration) between Local Authorities, an aspect that was not mentioned in the normative scenario , but was introduced by stakeholders and found to be of significant influence.

The relatively low priority of the sustainability aspect of the Leamside Line as described in the case study was similarly unexpected considering the growing emphasis on reduction of carbon emissions, on maintaining urban air quality and on the need to reduce vehicle miles travelled to achieve these goals. This exposes a discrepancy between the factors found to be important in the opinions of the cohort of stakeholders, and the factors deemed to be important in the common understanding of transport development priorities. This finding invites action from environmental planners to raise the level of awareness of the role of sustainability in transport planning.

Also the need for leadership was not identified in the normative scenario, but was found to be the most influential factor in driving the project to re-open the Leamside Line. This is re-inforced by a comment in Hensher et al. (2015) who, after exhaustive analysis of the optimum choice between light rail based trams and BRT (Bus Rapid Transit) discovered that often the "wrong" choice was made but was still successful. Their closing comment was: "*What appeared to make a difference in these cases was the existence of a champion who drove through an implementation package that turned out to be successful".* Political developments in the UK in recent years have seen the creation of directly elected Mayors in English cities (UK Parliament, 2000) (Stevens, 2006) whose role it is to move decision making from a traditional committee-based system to an executive based model and, in the case of the mayor of the Greater Manchester Combined Authority (GMCA) area: *" to steer the work of Greater Manchester's Combined Authority, leading on issues such as the economy, transport, police and fire services,"* (GMCA, 2017). The findings of the Leamside Line case study emphasise the need for such direct political based leadership.

Comments in the interviews concerned with the collaboration between Local Authorities often drew comparison with Transport for Greater Manchester (TfGM) as an example of an agency within the GMCA Unified Authority which coordinates transport policy and planning over a regional area and hence the GMCA is more successful in winning funding for major transport projects compared to less coordinated regions. In June 2016, an announcement was made concerning the formation of a new similar body the West Midlands Combined Authority(WMCA) (WMCA, 2017) with a transport arm; Transport for West Midlands (TfWM). The role of the WMCA is to integrate the actions of seven regional metropolitan local authorities and negotiate a regional devolution settlement with national government which gives it more authority in the West Midlands Region. The announcement is shown in

Figure 10-1[14]. Here, there is a clear message of co-ordination to promote delivery of transport developments which resonates with the problems of Local Authority collaboration, identified in this research as being influential in transport project delivery. This is confirmed by May et al. (2005) who comment on integration that "*Even when cities have direct responsibility, they may well be influenced by adjacent authorities, regional bodies, and by national or European government*" and that "*collaboration, joint working, or in some cases, a legally binding partnership is therefore advised*".

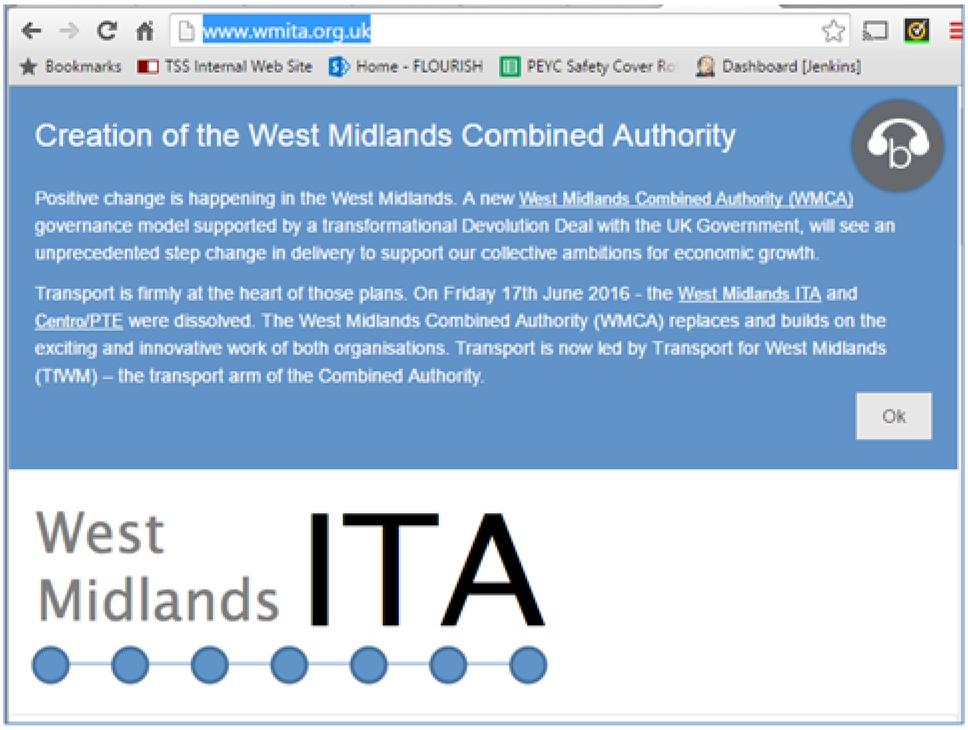


Figure 10-1 TfWM Formation Announcement

In the North East of England however, while there was a proposal for a Combined Authority, it was abandoned in 2016 (BBC, 2016) and at present, there is only one Mayor who represents multiple local authorities and this is just the subset of those in the Tees Valley Combined Authority, a post created in 2017. There is no Mayoral post covering the wider North East of England area and as yet, no larger Combined Authority[15].

In effect, the finding in this research uncovered in the Leamside Line case study- that a project champion is needed -can be shown to be addressed in other areas, such as in

[14] Note, the web page making the announcement was ephemeral, hence it is reproduced here.
[15] The researcher's professional contacts make him aware that as at the end of 2017, negotiations were once again underway to form such an authority, but progress was slow and fragmentation was hard to overcome.

Greater Manchester, an example mentioned by stakeholders, but remains unaddressed in the Local Authority areas involved in the Leamside Line.

The role of economic and employment growth in the uncertainty surrounding the Leamside Line project can also be compared with experience elsewhere. Research by Mapuro and Mazumder (2017) into the direction of the causality between transport provision and economic growth reported a range of different results concluding that is it context sensitive and causality can be in either direction. Banister and Berechman (2000) also argue that transport developments may change the location of economic activity, but not necessarily add to it. Both authors challenge the simple assumption that adding transport gives a faster rate of economic growth and here, in the Leamside Line case study, the analysis showed that the relationship between economic growth and the other factors controlling the project is a complex one and a major cause of uncertainty in the project.

Spending on national infrastructure during times of recession to promote economic growth is one of the fundamental tenets of Keynesian economics (Keynes, 1936) and that doctrine would suggest that investment in the Leamside Line would be advised to promote growth and recover from recession. The view from the stakeholders however was that the Leamside Line would not be funded until economic recovery was underway and the politics of austerity in the 2010 and the 2015 UK governments had passed. However, in the year after the stakeholder interviews were conducted, the UK infrastructure commission was created with a goal to invest more in UK infrastructure (HM Treasury, 2016) potentially changing the influences and dependencies on growth and on government spending as well as making more funding available for UK infrastructure, including transport. That action, a reversal of policy during the term of the Leamside Line case study, only reinforces the finding that the role of economic growth and its associated policies is a strong factor in promoting uncertainty in the decisions surrounding a transport project as is the availability of funding.

The comparability of the findings in the Leamside Line case study with those in observable developments in terms of collaboration and in leadership in other parts of the UK lends credibility to the results of the case study and show that these influential drivers of the project have been observed elsewhere and solutions found. Similarly the ambiguity surrounding the effect of the development on economic growth and the changes in government policy in the years during which the case study was made demonstrates the uncertainty in the role of economic growth in the Leamside Line development.

The proposed methodology therefore has revealed influences and uncertainties that are observed elsewhere and in the case of leaderships and unity, have solutions elsewhere, but not yet in the North East of England and relevant to the Leamside Line. It suggests that appointment of an elected Mayor with the capability to champion projects in a combined authority and rise above the conflicts therein would be a significant step to re-opening the Leamside line for sustainable travel and that some certainty about the local and national investment strategies in the light of the economic environment would give that Mayor a more stable environment to promote transport infrastructure expenditure.

10.3 Methodology Review

In applying the methodology, the lessons learned from the case study can be summarised in three groups:

1) The robustness of the analysis when the parameters that control it are varied.
2) A retrospective view of the subjective part of the methodology, coding the interviews and making the links.
3) Comparison of the experience of using the methodology with the objectives stated prior to developing it.

These are discussed here in the context of application of the methodology to the Leamside Line case study.

10.3.1 Sensitivity and Robustness

The results of the sensitivity analysis undertaken in the Leamside Line case study demonstrated that the process in the Cross Impact Matrix Method was robust and not unduly sensitive to its internal parameters. The detail of ordering of influence, uncertainty and dependency changed as the depth, weight and stakeholder summation parameters changed, but the narrative about the system remained constant. The sensitivity analysis also tested Godet's empirical assertion; that an analysis depth greater than 4 – 5 offered no increased benefit, and confirmed this to be true, demonstrating that there were no significant changes at higher depths.

The finding that the results from the methodology were not critically sensitive to the analysis parameters is reassuring because, in a methodology to identify uncertainty in a development proposal, it is essential that the results describe the uncertainty in the proposal and not an artefact of an unstable analysis of that data.

10.3.2 Interviews and Coding

The issues identified in this Leamside Line case study, were in the data gathering stages of stakeholder interviews and coding. Advice from Qualitative Data Analysis texts (Packer, 2011; Silverman, 2006; Hollway and Jefferson, 2000) is that the interviewer must remain neutral and that bias must be avoided (Tversky and Kahneman, 1974). This placed a responsibility on a lone interviewer with little more than self-awareness and post interview reviews to avoid the problem of anchoring the stakeholder's comments on their own interpretation of the scenario.

While there are advantages in a sole researcher conducting and coding the interviews in ensuring consistency and gaining experience with the process, a review stage is essential to justify the interpretation of the stakeholder's comments. An alternate approach would employ several researchers to code the interviews and come to a consensus on the definition of variables and on the linking. This does however raise the problems of consistency between individuals, of groupthink, and of the potential dominance of one of the team members. The nett result may not differ significantly from that obtained by a sole researcher. The review stage, conducted with external reviewers, is therefore essential to ensure the coding and in linking can be assured to properly reflect the opinions of the stakeholders.

In the Leamside Line case study, a presentation of early results of the analysis was made during a one day conference at the end of the SECURE project (Bell, 2013) and from that, more guidance on interviews was taken and further stakeholders were recruited to augment the current cohort. Interestingly, the number of variables after coding the additional interviews did not increase significantly and, by that measure, the stakeholder coverage was deemed adequate. However, by their nature, stakeholders have their own views and some of these will include their opinion on the selection of other stakeholders and the opinions of the project that should be included in the analysis. Stakeholder coverage therefore also has a subjective element which too needs to be addressed in an external review.

Ideally the issues of stakeholder coverage and coding would be tested by presenting the results of the analysis to an active stakeholder group for critique and discussion, and by implication to develop a set of actions to act upon the causes of uncertainty. Whilst presentation of results for a live project in a multi stakeholder workshop inevitably will raise queries about stakeholder selection, about coding, and about project scope, it will also lead to conclusions drawn from the findings and hence the actions that might be taken to mitigate the uncertainties the analysis can be devised and the project progressed. Therefore, ideally, in future applications of the methodology, a review workshop, held with the involvement of active project sponsors would form the culmination of the outputs and lead to positive actions to manage the uncertainties in the project identified by this methodology.

The Leamside Line is however not a live project and while reports have been commissioned in the past (refer to Chapter 5), announcements made in 2017 (DfT, 2017a) did not include the Leamside Line in the list of potential projects to re-open railway lines in the UK. Active critical post analysis review with a goal of mitigating the drivers of uncertainty in the project require that the project is one which has that political leadership to organise such a review workshop and to use it to resolve project issues, one of which as shown in the analysis presented here, is the lack of such leadership for the Leamside Line proposals.

10.3.3 Limitations

The limitations of the methodology lie in the subjective nature of the analysis of the interviews, the scope of the scenario and the stakeholder selection.

With regards to the coding of the interviews, the researcher is responsible for ensuring the concepts, as expressed by the stakeholders, are consistently interpreted in coding the interviews and that the resulting variables represent the same for all stakeholders. This requires careful review of the coding.

The normative scenario presented to the stakeholders describes the future goals for the proposed development under study. In the Leamside Line case study this scenario contained elements of traditional planning (a rail line) sustainable planning (the design of Fencehouses) and elements of innovation (the freight tram). Alternate scenarios could have been more closely drawn, focussed on just one aspect of the proposal; they may also have been more widely drawn bringing in more potential secondary effects of the proposal. More case studies would be required to ascertain how the scope of the scenario affects the result of the study, but it should be noted that the most influential effects observed in the Leamside Line case study were not mentioned in the scenario but were brought in by the stakeholders.

Finally stakeholder selection which is already programmed to be examined as part of the method is subject to a systematic bias if those stakeholders with a preference for a positive outcome, or those with stronger views, positive or negative, are more willing to participate in the elicitation exercise. Stakeholder selection should therefore be subject to critical review.

10.3.4 Comparison with Initial Objectives

The initial objectives were described in section 1.3.1 on page 9. The first two were concerned with the outputs from the application of the methodology:

> *To research a methodology which provides a quantified insight into the uncertainties in a proposed transport project.*

and:

> *To provide this insight in the entire scope of the proposed project without limiting the analysis to the assessment stage.*

These two objectives were met in the Leamside Line case study. The results provided a rank ordering of those attributes of the project which were influential in promoting the project and of those which are the key drivers of uncertainty within it. These findings are quantified by their order and relative Influence and Dependency scores and by an understanding of how they attained those scores from the opinions of the stakeholders. The summary of the Leamside Line findings and the comparison with experiences from other areas, described in section 10.2, showed that similar issues have been encountered in other areas, where solutions have been proposed; solutions which have not been applied to the case of the Leamside Line proposals. The scope of the analysis was also widened during the elicitation stage to include the political and economic environment, aspects of the proposals not included in the normative scenario as they were not prominently raised by the initial four stakeholders contributing to that scenario nor were they mentioned in the consulting reports or Local Transport Plans. In this respect the methodology developed here did not predetermine the scope of the analysis, nor did it narrow its focus to the quantifiable uncertainties in the business case for the Leamside Line, or the multiple criteria for the decision making. Instead the analysis was able to be widened to observe and critique the planning process from the point of view of a perceived successful implementation in the future and to comprehensively examine the environment for the decision to proceed rather than just coming to the decision itself.

The second two objectives were concerned with gaining an understanding of the functioning of the methodology:

> *To investigate the uncertainty inherent in the method and provide confidence that its findings were robust under changing parameters in the method.*

and:

> *To identify the strengths and weaknesses of the proposed method and to offer guidance for its future development.*

As described in section 10.3.1 the Cross Impact Matrix Method was not unduly sensitive to the primary parameters controlling the analysis. If the narrative describing the results had varied significantly as those parameters changed, then the results from applying the methodology would carry with them uncertainty inherent in the method of analysis as well as the uncertainty inherent in their role in the system. In this research, the stability of the analysis was investigated, recommendations made for the values of those parameters and confirmation of the empirical advice from Godet (2009) that a depth *of "about 4 - 5"* is right. Experience with the method is discussed in section 10.3.2 and, in this area of the methodology, important issues of subjectivity and the need for critical post analysis review were raised. In a live project, one with an active set of stakeholders and a practical and political imperative for the project to proceed, such a post analysis review is more assured to happen and therefore, in future work, a final stage to generate actions as a result of the uncertainty analysis should be included in the methodology.

10.4 Originality

The originality shown in this work lies in two areas; the first is in developing and trialling a method which focusses solely on identifying uncertainty in a transport development rather than taking a pre-existing model and re-purposing it to study uncertainty in the proposed development. The second is in extending the components of that method to enhance their capability in identifying the uncertainty in the development under study.

Many studies in uncertainty focus their attention on the modelling and assessment process, examining the sensitivity of the transport model to the parameterisation of the algorithms contained in it or the accuracy of the input data (Saltelli et al., 2008; Refsgaard et al., 2007; Refsgaard et al., 2005; van der Sluijs et al., 2005). These studies do however suffer from an observational bias succinctly summarised in social science thinking as “the principle of the drunkard's search” (Kaplan, 1998):

> *A policeman sees a drunken man searching for something under a street light and asks what he has lost. He says he lost his keys and they both look for them together. After a few minutes the policeman asks if he is sure he lost them here, and the reply is; “No, I lost them in the park”. The policeman asks why then is he is searching by the lamp post, and the man replies, "Well, this is where the light is".*

The comparison can be drawn between this, and a search for uncertainty using available assets or in already illuminated spaces. The key point of originality in this work is in breaking away from using existing modelling work made available through the assessment process and developing a new method capable of extending the horizons in the search for the drivers of uncertainty and capable of shedding light on uncertainty without being bound to remain in a search space which is pre-ordained and already illuminated by the tools in use.

The second set of points of originality, made in extending the capability of the components of the method are:

- The use of a backcast scenario as a narrative to examine uncertainty in a proposed development rather than to examine the viability of the proposal.
- Decomposing the text of multiple interviews which discussed that scenario using qualitative data analysis techniques to extract both variables and causality.
- Extending the Cross Impact Matrix Method to include the opinions of multiple stakeholders and to combine those opinions, hence shedding light on the different views of the stakeholders and of combinations of stakeholders.
- Performing sensitivity analysis on the Cross Impact Matrix Method to verify the robustness of the method and to identify a set of parameter values to use in subsequent uncertainty analysis.

- Including feedback loops in the methodology to review stakeholder engagement and variable coding.
- And finally, to examine the effects of breaking causality links in the system to examine what would be the effect of changing the beliefs of a set of stakeholders, potentially removing drivers of uncertainty in the project under study.

10.5 Transferability

10.5.1 Method

The requirements for this method to be applicable are that the project to be studied should show significant uncertainty; such that its progress is either being blocked or its decision making process is being queried. In the case study used in this research, an asset was apparently available and studies had been undertaken into its best use, but with no clear strategy for its use emerging and with no actions planned to develop it, despite a broad intention being evident that something should be done with the unused asset. Similar circumstances may be envisaged where multiple claims are made for the use of an asset or the design of a policy and the effect is a paralysis of action. In the case study used here, the different modes of use of the railway are evident in the consultant's reports and the local authority plans, and hence no clear plan has been devised for the Leamside Line.

There is, however, nothing unique to transport planning about these types of issues; the same can be stated concerning land use, infrastructure, economics, environmental management, product development, marketing, and politics. The requirements for this methodology to be applied are solely that the issue to be analysed must be identifiable and capable of being subjected to an initial scoping exercise. To initiate the analysis, there must be an organisation or person sufficiently engaged to commission the application of the methodology developed here to identify uncertainty in the project, and that other stakeholders may be engaged in developing the normative scenario and commenting on it. As already stated, these conditions are not the sole preserve of transport planning and hence, by induction, neither is the methodology developed here restricted to transport planning applications.

The methodology is therefore readily transferrable to other fields where uncertainty may be observed, and hence analysed, subject to the pre-requisites of scoping, incentive, and stakeholder availability.

10.5.2 Results

The results derived from the case study contained in this research should however not be regarded as transferable. This research was not intended to identify generic uncertainties in transport planning and indeed, the primary drivers of the Leamside Line project, those of leadership and political cohesion, are being addressed in other areas of the UK. Hence, it would be expected that results would be different if similar analysis was carried out in another context, perhaps where an executive Mayor and a unified Transport Authority were well established. The goal of this research was to devise and trial the method, and while the results of the case study are both interesting and highly plausible, their purpose in this research is not to pronounce facts on uncertainty in transport planning *per se*, but to comment on the results derived from the methodology for this particular case study.

10.6 Recommendations for Future Work

Recommendations for future work fall into two categories:

- Improvements to the process after the experience of applying it to the Leamside Line case study, and
- Further applications of the methodology to test its applicability in other areas, not necessarily in transport planning, and to carry those case studies through to a post investigation workshop stage.

10.6.1 Process improvements

The principal process improvements recommended by the researcher is to integrate the two main software tools used in the analysis. In this case study, NVivo (QSR, 2014) was used to code the stakeholder interview notes, transcripts and recordings, and the bespoke project software was written to implement the Cross Impact Matrix Method analysis (See Chapter 4). In the analysis of the case study, variables were manually copied from one to the other and causality linking was only applied in the latter software. This led to several traceability issues. For example: it was not possible, in the analysis software, to select a variable or a link and follow that back to the original interview notes. This had to be undertaken manually and the reason for the link between two variables re-inferred on examination of the notes. Similarly, in the investigation of the reasons why a variable was placed in a location in the Influence-Dependency space, which links were used to place it there were readily observed, but the reference back to the original sources of those links, the interview notes and media, was only available if undertaken manually.

In future case studies, it is recommended the bespoke analysis software is extended to include the necessary capabilities of NVivo (to identify and label areas of text, graphics or audio) and variables are linked to those objects in the original interview notes and recordings. This would provide a path back from a link or a variable directly to the sources of that link or variable. In a post analysis workshop situation, this would be essential to allow stakeholders to query the causality and then understand how it can be addressed.

The second recommendation concerns the software written for the project which suffers from being slow to run. A typical analysis in this project takes 2 minutes on an Intel Core I5 laptop with 8 GB memory. Primarily this is due to the coding techniques used to write the software and the use of associative arrays and unsophisticated search algorithms within the analysis. While this may be acceptable in a research mode, it would not be acceptable in a production system used in a workshop environment. In a project with more stakeholders and variables, the execution times for multi-stakeholder analysis, and the selection of sub-sets of stakeholders would require an improvement in the execution speed.

10.6.2 Case Studies

The researcher also recommends that the methodology be applied to other case studies, not necessarily in the field of transport planning, to verify the findings presented here in the parameters recommended after the sensitivity studies, in the comments on the plausibility of findings in other projects and to examine the transferability of the method to disciplines other than transport planning.

Primarily however, further case studies would ideally be conducted on live projects with a goal to resolve the uncertainties in the project in post study workshops which brought together stakeholders with a goal to use the findings derived from this methodology. The critical evaluation factor would then become:

> *Will stakeholders, on examining the findings of this methodology, be empowered to act to change their views, the views of others, or the organisational factors that contribute to the uncertainty in the project, and does this then allow the project to progress?*

If so, then the methodology will have achieved its goal.

Appendix A: Table of Variables

The Table of Variables contains the list of variables used in the analysis. It holds the consolidated variables which are formed by subsuming two or more variables, and their links into a single entity. The fields in the table give the name of the variable, its category, the number of stakeholders referencing it and the number of consolidated links from and to defining the causality measures of the variable.

Variable	Category	Stake-holders	Links	Description
Ageing Population	Economy and Demographics	2	0/1	The ageing population in the UK with an effect on housing supply, and transport requirements.
Benefit in sustainability	Sustainability	5	1 / 10	The perceived benefits of a sustainable policy.
NE Private Investment	Politics	7	1 / 16	Industry led investment in business and housing.
Car and Van Use	Road Travel	11	59 / 5	Use of private vehicles, cars and vans.
PT Passenger Utility	Public Transport	11	24 / 36	The desirability of public transport; a combination of fares, safety, environment, timetable, and network coverage.
Road Network Connectivity	Road Travel	6	2 / 11	The quality of the road network, specifically the main corridors and their ability to create links between residential and employment areas. This is a problem for the older towns in the NE.
Congestion S of Newcastle	Road Travel	8	15 / 14	The congestion in the road network, specifically in the area where it would be relieved by the Leamside Line.
Cost of road travel	Road Travel	8	0 / 16	Fuel costs and cost of car ownership.
Durham as city hub	Public Transport	3	12 / 7	The city of Durham's connection to the Public Transport network
ECML Freight congestion	Freight	9	1 / 18	The volume of freight on the ECML. This has a detrimental effect on the passenger services which use it, leading to a need for a diversion route.
ECML Passenger utility	Public Transport	4	4 / 5	The attractiveness of the ECML for passengers which has an effect on public transport use and is affected by the volume of freight and the Leamside Line re-opening.
Economic and Employment Growth	Economy and Demographics	10	26 / 35	The economic performance of the area.
Electioneering	Politics	3	0 / 4	Statements made with a view to winning votes for political power.
Fencehouses is built	Fencehouses	9	48 / 2	The action that Fencehouses is built as a small town with the sustainable characteristics described in the scenario.
Fencehouses Prosperity	Fencehouses	5	6 / 4	Availability of jobs in Fencehouses and that the sustainable attractiveness makes it a middle class dormitory town.

Gateshead rail interchange	Public Transport	1	2 / 1	Link to Leamside Line at Gateshead. This would be required to satisfy the need for Local Authority parity in investments.
HA - DfT Action	Politics	4	6 / 17	The assessment processes and actions of the DfT and Highways England when determining if transport projects are passed for funding.
Leamside business case	Leamside	10	53 / 9	The quantifiable aspects of the case made to re-open the Leamside Line, including the ownership model, the risk management, the capital requirements, and the subsidies needed.
Leamside engineering	Leamside	4	0 / 5	Technical issues in rebuilding the Leamside Line, which have an effect on risk and on the business case.
Leamside Freight	Freight	9	32 / 14	The use of the Leamside Line for freight (heavy rail) as well as the use for light weight local freight.
Leamside Mode Priority	Leamside	6	8 / 9	The mode choice (freight or passenger, local or national) made in the business case for re-opening.
Leamside priority in funding	Leamside	3	5 / 1	Regional funding priorities.
Leamside Rail integration	Leamside	10	7 /9	Integration with bus (Belmont Parkway) and the option for joint running of trams and passenger trains.
Leamside Re-Opened	Leamside	11	98 / 24	The action that the Leamside is re-opened.
Local rail based freight network	Freight	11	40 / 12	The Leamside Line is used for light, local freight.
Location of regional freight centre	Freight	3	4 / 5	Will there be a local freight distribution centre and if so will it be located on the Leamside Line?
Metro Capacity	Public Transport	2	0 / 2	Capacity of the Tyneside Metro system.
Leamside ridership	Leamside	9	30 /6	Number of passengers on the Leamside Line. Depends on mode choice and Leamside Line utility. Highly uncertain input to the business plan and to DfT considerations.
NE PT Ridership	Public Transport	10	56 / 2	Current and predicted numbers using public transport, specifically in the North East.
NE Public Investment	Politics	10	20 / 32	Investment in the North East region by public bodies i.e. National Govt.

NE Travel Card	Public Transport	3	6 / 6	Integrated ticketing for Public Transport.
PT Co Competition	Public Transport	4	3 / 5	Competition between providers, their attitude to new entrants and the tendency to chaos, if not regulated.
PT Integration	Public Transport	8	7 / 7	Integration between Public Transport modes and with Park and Ride.
PT Invest	Public Transport	10	24 / 11	Capital investment in Public Transport.
PT Network capacity	Public Transport	3	3 / 1	Public Transport network capacity.
PT Running costs (Subsidy)	Public Transport	7	12 / 10	Public Transport need for subsidy and revenue support, and its availability.
PT Route Profitability	Public Transport	2	1 / 1	Profit is in towns not on rural routes, which creates a need for subsidy and Public Transport regulation.
Public Opinion	Politics	8	10 / 22	Public attitude to change, sustainability, costs, and the establishment.
Rail Planning Timescale	Leamside	5	0 / 11	There are fixed planning periods of 5 year duration. These are influential in project funding and approval.
Reluctance to mode shift	Economy and Demographics	2	2 / 1	People are reluctant of change from car to Public Transport. Viewed as a strong influence in the North East Region by 2 stakeholders.
Rising population	Economy and Demographics	4	0 / 5	Increase in population in the area. Has an effect on transport and urban planning.
Sustainable emphasis of Fencehouses	Sustainability	4	4 / 3	Design of the town. Affects its attractiveness to new residents and affected by the council's ability to be innovative in design.
Travel driven lifestyle	Economy and Demographics	6	27 / 26	A lifestyle dependent on mobility and a view that, in this area, people commute long distances to work. This is proposed by some and denied by others - especially when referring to the historical pattern of pit villages and shipyard communities.
Type of freight on Leamside	Freight	4	4 / 6	Local or national freight, small scale or bulk.
UK Funding	Politics	5	2 / 10	Funding from national resources, i.e. the LSTF initiative.
Council Policy to Favour Leamside as ECML freight diversion	Politics	1	1 / 7	A strong policy decision in the most influential Council.

Knowledge Economy	Economy and Demographics	4	5 / 16	The evolution of the workplace and its effect on job location, commuting and freight.
Environmental Cost	Sustainability	3	1 / 7	Vehicle emissions and other environmental costs.
Bias to road spend	Politics	3	0 / 7	The perception that travel investment tends to favour road developments.
Walk Cycle Provision	Sustainability	2	6 / 1	Provision of sustainable transport options.
Heritage & Tourism	Economy and Demographics	1	4 / 2	Non work related travel attractors.
Road travel utility	Road Travel	2	2 / 13	The convenience of road travel (merged with car park availability).
Historical Demographics	Economy and Demographics	8	0 / 36	The distribution of employment and residential areas. In the NE this tends to be based on old colliery towns, which no longer have collieries or ship yards which have now closed. Replacement jobs are largely available in the public sector in different locations.
Planning Policy	Politics	11	38 / 56	Planned residential and employment distribution including a policy for incremental development and the planning timescales.
Urban Agglomeration	Economy and Demographics	8	8 / 18	The effect of transport on creating wider areas with greater employment opportunities. Specifically links between Newcastle and Middlesborough.
LA Political (dis)Unity	Politics	11	8 / 37	The tendency of the local authorities to compete for investment, or require parity in investment and the disjoint policy on Public Transport. Combined with their contradictory ability to collaborate in Local Enterprise Partnerships
Fencehouses Planning	Fencehouses	9	18 / 27	The location and size of Fencehouses, its style of development, and its links to transport.
Car Availability	Road Travel	8	10 / 9	The move to multi car households for some, and also to car clubs for others.
Electric Vehicle Policy	Politics	7	18 / 8	Policy to invest in Electric Vehicle production and in provision of charge points.
Leamside Passenger Utility	Leamside	4	2 / 4	The desirability of the Leamside Line A combination of fares and timetable and location of stops.
Local Freight Requirements	Freight	6	4 / 20	Industry's requirements from freight transport and their influence on its provision.

Social Inclusion	Politics	3	2 / 6	Refers to concessionary travel for the elderly, the need for affordable travel in poorer areas and planning for transport availability to areas with poor public transport links.
Commute Inertia	Economy and Demographics	3	0 / 7	Refers to a reluctance to commute long distances, or to move to find employment. In effect a requirement for local jobs.
PT Regulation	Public Transport	6	3 / 15	Regulation of public transport through competition legislation and Quality Bus Contracts.
Political Action Initiation		11	17 / 54	The need for motivation by the Local authority to bring stakeholders together and have ambition to push a project through, finding the funding for it and the need for a specific project champion.

Appendix B Table of Links

The Table of Links contains the list of links used in the analysis between two variables. The variables are the consolidated variables and may be composites of two or more of the originally coded variables, internal links between the components of a consolidated variable appear as self to self links. The columns are:

- The From and To variables for the link.
- A measure of strength of influence for the link as described in Equation 3.6 normalised to 100. The table is sorted on this measure to list the strongest links first.
- The change in stability in the ID measure as the link is broken.
- The change in RBO order for both Influence and Dependency as the link is broken.

From	To	Link Potency	ID Stability Diff * 100	RBO Diff Influence	RBO Diff Dependency
Political Action Initiated	Leamside Re-Opened	100	1.79	0.96	1.00
LA Political (dis)Unity	Leamside Re-Opened	95	0.01	0.89	1.00
Leamside business case	Leamside Re-Opened	88	0.24	0.94	0.98
NE Public Investment	Leamside Re-Opened	88	0.12	0.94	1.00
PT Passenger Utility	NE PT Ridership	82	-0.11	0.94	0.99
Political Action Initiated	NE Public Investment	76	1.13	1.00	0.99
Cost of road travel	Car Use	74	-0.08	0.96	1.00
Car Availability	Car Use	72	-0.13	1.00	1.00
PT Passenger Utility	Economic and Employment Growth	71	-0.18	0.94	0.98
Rail Planning Timescale	Leamside Re-Opened	68	-0.06	0.96	1.00
Public Opinion	Leamside Re-Opened	67	0.06	0.99	1.00
PT Invest	Leamside Re-Opened	67	0.20	0.96	1.00
Local Freight Requirements	Local rail based freight distrib network	66	-0.05	0.95	0.99
Planning Policy	Leamside Re-Opened	66	0.18	0.94	1.00
Economic and Employment Growth	Car Use	66	-0.09	0.95	1.00
Travel driven lifestyle	Car Use	66	-0.09	1.00	1.00
PT Passenger Utility	Car Use	66	-0.13	0.94	0.96
Public Opinion	Political Action Initiated	65	-0.12	0.99	0.99
Political Action Initiated	LA Political (dis)Unity	62	0.87	1.00	0.99
Road Network Connectivity	Economic and Employment Growth	62	-0.09	0.96	1.00
Leamside Re-Opened	Economic and Employment Growth	61	-0.46	0.94	0.97

ECML Freight congestion	Leamside Freight	60	-0.04	0.94	0.99
Electioneering	NE Public Investment	60	-0.06	0.96	0.99
Cost of road travel	NE PT Ridership	59	-0.06	0.96	1.00
UK Funding	NE Public Investment	59	-0.07	0.96	0.99
Planning Policy	Fencehouses is built	59	0.00	0.94	0.98
LA Political (dis)Unity	NE Public Investment	59	-0.02	0.91	0.99
Leamside engineering	Leamside Re-Opened	59	-0.06	0.96	1.00
NE Travel Card	PT Passenger Utility	58	-0.01	0.96	1.00
Historical Demographics	Travel driven lifestyle	58	-0.03	0.93	1.00
ECML Freight congestion	Leamside Re-Opened	58	-0.05	0.94	1.00
Knowledge Economy	Planning Policy	58	-0.06	0.94	0.99
PT Passenger Utility	Leamside Re-Opened	57	0.31	0.94	0.99
Economic and Employment Growth	Leamside Re-Opened	57	0.20	0.95	1.00
Electric Vehicle Policy	Electric Vehicle Policy	57	0.06	0.96	1.00
Urban Agglomeration	Travel driven lifestyle	57	-0.08	1.00	1.00
HA - DfT Action	Congestion S of Newcastle	55	-0.07	0.99	1.00
Congestion S of Newcastle	HA - DfT Action	55	-0.12	0.99	1.00
Fencehouses Planning	Fencehouses is built	55	-0.01	0.96	0.98
Political Action Initiated	Political Action Initiated	54	0.83	0.96	0.99
Benefit in sustainability	Political Action Initiated	54	-0.09	0.95	0.99
Knowledge Economy	Political Action Initiated	54	-0.10	0.94	0.99
Historical Demographics	PT Running costs (Subsidy)	53	-0.02	0.93	1.00
NE Public Investment	PT Running costs (Subsidy)	52	-0.04	0.96	1.00

Political Action Initiated	Leamside Freight	52	0.65	1.00	0.98
NE Public Investment	Leamside Freight	52	-0.02	0.96	0.99
Leamside Freight	Leamside business case	52	-0.01	0.96	0.97
NE Private Investment	Local rail based freight distrib network	52	-0.03	0.96	0.99
LA Political (dis)Unity	LA Political (dis)Unity	51	-0.03	0.91	0.99
Historical Demographics	Economic and Employment Growth	51	-0.04	0.93	1.00
Political Action Initiated	Local rail based freight distrib network	51	0.70	0.96	0.98
NE Public Investment	Local rail based freight distrib network	51	-0.02	0.96	0.99
Planning Policy	Car Use	51	-0.06	0.94	1.00
NE Public Investment	PT Invest	51	-0.03	0.96	1.00
Road travel utility	Car Use	51	-0.06	0.96	1.00
Political Action Initiated	PT Invest	51	0.70	0.96	1.00
Knowledge Economy	Economic and Employment Growth	51	-0.07	0.94	1.00
NE Public Investment	LA Political (dis)Unity	51	-0.08	1.00	0.99
Economic and Employment Growth	NE PT Ridership	50	-0.06	0.95	1.00
Local rail based freight distrib network	Economic and Employment Growth	50	-0.15	0.95	0.98
Political Action Initiated	Leamside Rail integration	49	0.63	1.00	1.00
Urban Agglomeration	Leamside ridership	48	-0.02	1.00	1.00
Commute Inertia	Planning Policy	48	-0.04	0.96	0.99
Rising population	Planning Policy	48	-0.04	0.96	0.99
Planning Policy	Planning Policy	48	-0.06	0.94	0.99
HA - DfT Action	NE Public Investment	48	-0.06	0.99	0.99
Fencehouses Planning	Leamside ridership	48	-0.04	0.96	1.00

PT Passenger Utility	Leamside ridership	48	-0.07	1.00	0.98
Economic and Employment Growth	NE Public Investment	48	-0.15	0.95	0.99
PT Co Competition	Leamside Re-Opened	48	-0.04	0.96	0.99
NE Public Investment	Planning Policy	48	-0.03	0.96	0.99
NE Private Investment	Planning Policy	48	-0.05	0.96	0.99
PT Integration	Leamside Re-Opened	47	0.05	0.96	1.00
Leamside Rail integration	Leamside Re-Opened	47	0.06	0.96	1.00
Political Action Initiated	Planning Policy	47	0.66	1.00	0.99
HA - DfT Action	Planning Policy	47	-0.06	0.99	0.99
UK Funding	Leamside Re-Opened	47	-0.03	0.96	1.00
Social Inclusion	Public Opinion	47	-0.06	1.00	1.00
NE Private Investment	Leamside Re-Opened	47	-0.03	0.96	1.00
HA - DfT Action	Leamside Re-Opened	47	0.01	0.99	1.00
Urban Agglomeration	Planning Policy	47	-0.07	1.00	0.99
PT Invest	PT Passenger Utility	47	-0.09	0.96	1.00
PT Running costs (Subsidy)	Leamside Re-Opened	47	0.03	0.96	0.99
Travel driven lifestyle	Leamside Re-Opened	47	0.12	1.00	1.00
Leamside Re-Opened	Planning Policy	47	-0.38	0.94	0.98
Environmental Cost	Public Opinion	47	-0.02	0.96	1.00
Leamside Freight	Leamside Re-Opened	47	0.27	0.96	1.00
Fencehouses Planning	Fencehouses Planning	46	-0.06	0.96	1.00
PT Regulation	PT Co Competition	46	-0.10	0.95	1.00
Planning Policy	Travel driven lifestyle	46	-0.05	0.94	1.00
LA Political (dis)Unity	Fencehouses is built	45	0.03	0.93	0.98

Leamside Freight	Congestion S of Newcastle	45	-0.07	0.96	0.99
Local rail based freight distrib network	Congestion S of Newcastle	45	-0.06	0.95	0.99
PT Regulation	NE Travel Card	45	-0.03	0.96	1.00
ECML Freight congestion	ECML Passenger utility	45	-0.02	0.95	1.00
Economic and Employment Growth	Car Availability	45	-0.13	0.97	1.00
Travel driven lifestyle	Car Availability	45	-0.09	1.00	1.00
Rail Planning Timescale	Leamside Freight	43	-0.02	0.96	0.99
Local Freight Requirements	Local Freight Requirements	43	-0.03	0.95	1.00
Metro Capacity	Local rail based freight distrib network	43	0.47	0.96	0.99
Type of freight on Leamside (Local or national)	Leamside Freight	43	-0.02	0.95	0.99
Rail Planning Timescale	Local rail based freight distrib network	43	-0.02	0.96	0.99
NE Private Investment	Leamside Freight	43	-0.03	0.96	0.99
Local Freight Requirements	Leamside Freight	43	-0.04	0.95	0.99
Planning Policy	Leamside Freight	43	-0.05	0.98	0.99
Bias to road spend	Car Use	43	-0.05	0.96	1.00
LA Political (dis)Unity	Local rail based freight distrib network	42	0.00	0.91	0.99
Leamside Re-Opened	Leamside Freight	42	-0.32	0.94	0.97
Historical Demographics	NE PT Ridership	42	-0.04	0.93	1.00
Planning Policy	Local rail based freight distrib network	42	-0.03	0.94	0.98
Benefit in sustainability	Car Use	42	-0.05	0.96	1.00
LA Political (dis)Unity	PT Invest	42	0.00	0.93	1.00

Local rail based freight distrib network	Car Use	42	-0.06	0.96	0.98
Congestion S of Newcastle	Local rail based freight distrib network	42	-0.04	0.99	0.99
Leamside Re-Opened	Car Use	42	-0.12	0.94	0.93
ECML Passenger utility	NE PT Ridership	42	-0.06	0.96	1.00
Economic and Employment Growth	Local rail based freight distrib network	42	-0.04	0.97	0.98
Social Inclusion	NE PT Ridership	41	-0.05	1.00	1.00
Congestion S of Newcastle	NE PT Ridership	41	-0.06	0.99	1.00
Planning Policy	PT Invest	41	-0.05	0.94	1.00
Planning Policy	Urban Agglomeration	41	-0.06	0.94	1.00
PT Regulation	NE PT Ridership	41	-0.02	0.96	1.00
NE Travel Card	NE PT Ridership	41	-0.03	0.96	1.00
PT Invest	NE PT Ridership	41	-0.08	0.96	1.00
PT Integration	NE PT Ridership	41	-0.04	0.96	1.00
Travel driven lifestyle	NE PT Ridership	41	-0.06	1.00	1.00
Car Use	NE PT Ridership	41	-0.08	1.00	1.00
Public Opinion	NE PT Ridership	41	-0.05	0.99	1.00
Urban Agglomeration	NE PT Ridership	41	-0.05	1.00	1.00
Planning Policy	NE PT Ridership	41	-0.05	0.94	1.00
ECML Freight congestion	Leamside business case	40	0.00	0.95	1.00
Local rail based freight distrib network	Leamside business case	40	-0.01	0.96	0.97
Political Action Initiated	PT Regulation	40	0.22	1.00	1.00
Leamside ridership	Leamside business case	40	-0.03	0.96	0.97
Leamside Re-Opened	Fencehouses Prosperity	40	-0.19	0.94	1.00
Economic and Employment Growth	Fencehouses is built	39	-0.01	0.97	0.98
Durham as city hub	Durham as city hub	38	-0.07	0.96	1.00
PT Running costs (Subsidy)	Durham as city hub	38	-0.05	0.96	1.00

Congestion S of Newcastle	Political Action Initiated	38	-0.18	0.99	0.99
ECML Freight congestion	Political Action Initiated	38	-0.06	0.95	0.99
Car Use	Political Action Initiated	38	-0.65	0.99	0.98
LA Political (dis)Unity	Political Action Initiated	38	-0.02	0.91	0.99
NE PT Ridership	Political Action Initiated	38	-0.65	0.99	0.98
Economic and Employment Growth	Political Action Initiated	38	-0.18	0.96	0.99
Leamside Re-Opened	Fencehouses Planning	37	-0.17	0.94	0.99
Road Network Connectivity	Heritage & Tourism	37	-0.05	0.96	1.00
Cost of road travel	Electric Vehicle Policy	36	0.00	0.96	1.00
Commute Inertia	Economic and Employment Growth	36	-0.04	0.96	1.00
Benefit in sustainability	Electric Vehicle Policy	36	-0.01	0.96	1.00
ECML Freight congestion	Economic and Employment Growth	36	-0.05	0.95	1.00
Heritage & Tourism	Economic and Employment Growth	36	-0.09	0.94	1.00
Leamside Freight	Economic and Employment Growth	36	-0.10	0.96	0.99
PT Running costs (Subsidy)	Economic and Employment Growth	36	-0.08	0.96	1.00
Durham as city hub	Economic and Employment Growth	36	-0.22	0.95	1.00
NE Public Investment	Economic and Employment Growth	35	-0.02	0.96	1.00
Political Action Initiated	Economic and Employment Growth	35	0.50	0.95	0.98
Leamside Rail integration	Leamside ridership	35	0.01	0.96	1.00

Local Freight Requirements	Location of regional freight centre	35	-0.06	0.95	0.99
Historical Demographics	PT Passenger Utility	34	-0.02	0.93	1.00
Rail Management technology	PT Passenger Utility	34	-0.03	0.96	1.00
Leamside Passenger Utility	PT Passenger Utility	34	-0.06	0.96	1.00
Electioneering	Leamside Re-Opened	34	-0.03	0.96	1.00
Rail Management technology	Leamside Re-Opened	34	-0.03	0.96	1.00
Public Opinion	NE Public Investment	34	-0.05	0.99	0.99
Leamside Mode Priority	NE Public Investment	34	-0.14	0.96	0.99
Leamside Mode Priority	Leamside ridership	34	-0.02	0.96	1.00
Gateshead rail interchange	PT Passenger Utility	34	-0.06	0.96	1.00
LA Political (dis)Unity	Planning Policy	34	0.00	0.93	0.99
ECML Freight congestion	PT Passenger Utility	34	-0.04	0.95	1.00
Environmental Cost	PT Passenger Utility	34	0.00	0.96	1.00
Leamside engineering	Leamside business case	34	0.00	0.96	1.00
Leamside Re-Opened	Leamside ridership	34	-0.10	0.94	0.98
Leamside Rail integration	PT Passenger Utility	34	0.02	0.96	1.00
HA - DfT Action	PT Passenger Utility	34	-0.05	0.99	1.00
PT Regulation	Leamside Re-Opened	34	0.07	0.96	0.99
Economic and Employment Growth	Planning Policy	34	-0.10	0.97	0.99
PT Integration	PT Passenger Utility	34	-0.02	0.96	1.00
PT Running costs (Subsidy)	PT Passenger Utility	34	-0.06	0.96	1.00
Local Freight Requirements	PT Passenger Utility	34	-0.06	0.95	1.00
Leamside Freight	ECML Freight congestion	34	-0.57	0.95	1.00

ECML Passenger utility	Leamside Re-Opened	34	-0.01	0.96	0.99
Council Policy - Favour Leamside as ECML freight diversion	Leamside Re-Opened	34	-0.03	0.96	1.00
Travel driven lifestyle	Public Opinion	34	-0.12	1.00	1.00
Road travel utility	PT Passenger Utility	34	-0.05	0.95	1.00
Environmen tal Cost	Leamside Re-Opened	34	0.01	0.96	0.99
Car Availability	PT Passenger Utility	34	-0.08	1.00	1.00
Social Inclusion	PT Passenger Utility	34	-0.05	1.00	1.00
Walk Cycle Provision	PT Passenger Utility	34	-0.12	0.95	1.00
LA Political (dis)Unity	Leamside business case	33	0.02	0.93	1.00
PT Regulation	Leamside business case	33	0.01	0.96	1.00
Leamside Mode Priority	Leamside Re-Opened	33	0.06	0.96	1.00
Leamside priority in funding	Leamside Re-Opened	33	0.14	0.95	1.00
Leamside Re-Opened	PT Passenger Utility	33	-0.35	0.94	0.98
Type of freight on Leamside (Local or national)	Leamside Re-Opened	33	0.06	0.95	1.00
Location of regional freight centre	Leamside Re-Opened	33	0.05	0.95	1.00
Local Freight Requirements	Leamside Re-Opened	33	-0.01	0.95	1.00
Congestion S of Newcastle	Public Opinion	33	-0.08	0.99	1.00
Electric Vehicle Policy	Leamside Re-Opened	33	0.10	0.96	1.00
Travel driven lifestyle	Planning Policy	33	-0.11	1.00	0.99
Travel driven lifestyle	PT Passenger Utility	33	-0.08	1.00	1.00
Economic and Employment Growth	Public Opinion	33	-0.09	0.97	1.00

NE PT Ridership	PT Passenger Utility	33	-0.29	0.99	0.99
Road travel utility	Public Opinion	33	-0.05	0.96	1.00
PT Passenger Utility	Public Opinion	33	-0.11	0.95	0.99
Leamside ridership	Leamside Re-Opened	33	-0.01	0.95	1.00
Travel driven lifestyle	Travel driven lifestyle	33	-0.04	0.96	1.00
Local rail based freight distrib network	Leamside Re-Opened	33	0.33	0.95	1.00
Congestion S of Newcastle	Leamside Re-Opened	33	0.10	0.99	1.00
Fencehouses is built	Leamside Re-Opened	33	0.12	0.93	0.99
Political Action Initiated	Public Opinion	33	0.50	0.96	1.00
HA - DfT Action	Leamside business case	33	-0.01	0.99	1.00
Urban Agglomeration	Leamside business case	33	-0.01	1.00	1.00
Political Action Initiated	Leamside business case	33	0.42	0.96	1.00
Type of freight on Leamside (Local or national)	Leamside business case	33	0.00	0.95	1.00
PT Running costs (Subsidy)	Leamside business case	33	0.00	0.96	1.00
PT Passenger Utility	Knowledge Economy	33	-0.11	0.95	0.99
Urban Agglomeration	Knowledge Economy	33	-0.08	1.00	1.00
Congestion S of Newcastle	Leamside business case	33	-0.02	0.99	1.00
Leamside Mode Priority	Leamside business case	33	-0.02	0.96	0.97
Economic and Employment Growth	Leamside business case	33	-0.01	0.97	0.97
Economic and Employment Growth	Travel driven lifestyle	33	-0.07	0.97	1.00
Fencehouses Prosperity	Travel driven lifestyle	33	-0.08	0.94	1.00
Cost of road travel	Congestion S of Newcastle	33	-0.02	0.96	1.00

Knowledge Economy	Travel driven lifestyle	33	-0.04	0.95	1.00
Road travel utility	Travel driven lifestyle	33	-0.07	1.00	1.00
Planning Policy	Knowledge Economy	33	-0.05	0.94	1.00
PT Passenger Utility	Travel driven lifestyle	32	-0.08	0.95	0.99
Fencehouses Planning	Travel driven lifestyle	32	-0.11	0.95	1.00
Commute Inertia	Fencehouses is built	32	0.00	0.96	1.00
UK Funding	HA - DfT Action	32	-0.03	0.96	1.00
Benefit in sustainability	HA - DfT Action	32	-0.03	0.96	1.00
Fencehouses Planning	Fencehouses Prosperity	32	-0.07	0.96	1.00
NE Private Investment	Fencehouses is built	32	0.00	0.96	1.00
Economic and Employment Growth	Congestion S of Newcastle	32	-0.05	0.97	0.99
Planning Policy	Congestion S of Newcastle	32	-0.04	0.94	0.99
Car Use	Congestion S of Newcastle	32	-0.11	1.00	0.98
Travel driven lifestyle	Congestion S of Newcastle	32	-0.05	1.00	0.99
Type of freight on Leamside (Local or national)	Congestion S of Newcastle	32	-0.01	0.95	1.00
Economic and Employment Growth	HA - DfT Action	32	-0.11	0.97	1.00
Political Action Initiated	Fencehouses is built	32	0.40	0.96	0.98
NE Public Investment	Fencehouses is built	32	0.01	0.96	0.98
Public Opinion	Fencehouses is built	32	0.00	0.99	0.98
Leamside Re-Opened	Congestion S of Newcastle	32	-0.16	0.94	0.97
Leamside Re-Opened	Fencehouses is built	31	-0.07	0.94	0.94
Cost of road travel	Leamside Freight	31	-0.02	0.96	0.99
Congestion S of Newcastle	Road travel utility	31	-0.11	0.99	1.00

Rail Management technology	Leamside Freight	31	-0.02	0.96	0.99
Car Use	Road travel utility	31	-0.22	1.00	1.00
NE Private Investment	PT Running costs (Subsidy)	31	-0.02	0.96	1.00
LA Political (dis)Unity	Local Freight Requirements	30	0.00	0.93	1.00
Rising population	Local rail based freight distrib network	30	-0.02	0.96	0.99
Location of regional freight centre	Leamside Freight	30	-0.01	0.95	0.99
PT Regulation	PT Running costs (Subsidy)	30	0.01	0.96	1.00
Cost of road travel	Local rail based freight distrib network	30	-0.01	0.96	0.99
Council Policy - Favour Leamside as ECML freight diversion	Leamside Freight	30	-0.02	0.96	0.99
LA Political (dis)Unity	Leamside Freight	30	0.01	0.93	0.99
UK Funding	Leamside Freight	30	-0.03	0.96	0.99
UK Funding	PT Running costs (Subsidy)	30	-0.02	0.96	1.00
Leamside Rail integration	Leamside Freight	30	0.00	0.96	0.99
Bias to road spend	UK Funding	30	-0.02	0.96	0.99
Bias to road spend	Local rail based freight distrib network	30	-0.02	0.96	0.99
Rail Management technology	Local rail based freight distrib network	30	-0.02	0.96	0.99
Local rail based freight distrib network	Local rail based freight distrib network	30	-0.02	0.96	0.99
Historical Demographics	Car Use	30	-0.03	0.93	1.00
Historical Demographics	Urban Agglomeration	30	-0.03	0.93	1.00
HA - DfT Action	Leamside Freight	30	-0.03	0.99	0.99
Rail Planning Timescale	Car Use	30	-0.03	0.96	1.00
Rising population	Car Use	30	-0.03	0.96	1.00

Location of regional freight centre	Local rail based freight distrib network	30	-0.02	0.96	0.99
PT Passenger Utility	PT Running costs (Subsidy)	30	-0.16	0.95	0.99
Historical Demographics	PT Invest	30	-0.01	0.93	1.00
Local rail based freight distrib network	Leamside Freight	30	-0.08	0.95	0.99
Knowledge Economy	Local rail based freight distrib network	30	-0.02	0.95	0.99
Political Action Initiated	Environmen tal Cost	30	0.14	1.00	1.00
Leamside Rail integration	Local rail based freight distrib network	30	-0.01	0.96	0.99
Leamside Re-Opened	Local Freight Requirements	30	-0.44	0.94	1.00
Public Opinion	UK Funding	30	-0.28	0.99	0.99
Bias to road spend	PT Invest	30	-0.02	0.96	1.00
Fencehouses Planning	Car Use	30	-0.05	0.96	1.00
Road Network Connectivity	Car Use	30	-0.04	0.96	1.00
Electric Vehicle Policy	Car Use	30	-0.10	0.96	1.00
PT Co Competition	PT Invest	30	0.00	0.96	1.00
Local Freight Requirements	Car Use	30	-0.05	0.95	1.00
Public Opinion	Local rail based freight distrib network	30	-0.02	0.99	0.99
PT Running costs (Subsidy)	Car Use	30	-0.05	0.96	1.00
Leamside Mode Priority	Car Use	30	-0.05	0.96	1.00
Knowledge Economy	Car Use	30	-0.04	0.95	1.00
Rail Planning Timescale	NE PT Ridership	30	-0.03	0.96	1.00
Rising population	NE PT Ridership	30	-0.03	0.96	1.00
NE Private Investment	PT Invest	30	-0.02	0.96	1.00
HA - DfT Action	PT Invest	29	-0.03	0.99	1.00

PT Passenger Utility	Urban Agglomeration	29	-0.10	0.95	0.99
Economic and Employment Growth	Urban Agglomeration	29	-0.09	0.97	1.00
UK Funding	PT Invest	29	-0.02	0.96	1.00
Public Opinion	Benefit in sustainability	29	-0.28	0.99	1.00
Public Opinion	Car Use	29	-0.03	0.99	1.00
PT Integration	Car Use	29	-0.03	0.96	1.00
Leamside Freight	Local rail based freight distrib network	29	-0.03	0.96	0.99
Leamside Re-Opened	Local rail based freight distrib network	29	-0.11	0.94	0.96
Road travel utility	PT Invest	29	-0.03	0.96	1.00
Economic and Employment Growth	PT Invest	29	-0.05	0.97	0.99
Historical Demographics	Road Network Connectivity	29	-0.02	0.93	1.00
Road Network Connectivity	NE PT Ridership	29	-0.04	0.96	1.00
Historical Demographics	PT Integration	29	-0.01	0.93	1.00
PT Co Competition	NE PT Ridership	29	-0.04	0.96	1.00
Public Opinion	PT Invest	29	-0.02	0.99	1.00
Road travel utility	NE PT Ridership	29	-0.04	0.96	1.00
Knowledge Economy	PT Invest	29	-0.02	0.95	1.00
Fencehouses Planning	NE PT Ridership	29	-0.04	0.96	1.00
PT Network capacity	NE PT Ridership	29	0.08	0.96	1.00
Leamside Re-Opened	NE PT Ridership	29	-0.08	0.94	0.89
Political Action Initiated	NE PT Ridership	29	0.37	0.96	1.00
Leamside Mode Priority	NE PT Ridership	29	-0.04	0.96	1.00
Knowledge Economy	NE PT Ridership	29	-0.04	0.95	1.00
Environmental Cost	NE PT Ridership	29	-0.03	0.96	1.00
LA Political (dis)Unity	NE PT Ridership	29	-0.01	0.93	1.00

PT Passenger Utility	PT Invest	29	-0.08	0.95	0.99
Leamside Passenger Utility	Leamside Mode Priority	29	-0.01	0.96	1.00
PT Regulation	PT Integration	29	0.00	0.96	1.00
NE Public Investment	PT Integration	29	-0.02	0.96	1.00
Council Policy - Favour Leamside as ECML freight diversion	Leamside Mode Priority	29	-0.02	0.96	1.00
Benefit in sustainability	Leamside Mode Priority	29	-0.02	0.96	1.00
Rail Management technology	Leamside Rail integration	29	-0.01	0.96	1.00
LA Political (dis)Unity	PT Integration	29	0.00	0.93	1.00
ECML Freight congestion	NE Private Investment	29	-0.14	0.95	0.99
Public Opinion	Leamside Mode Priority	29	-0.03	0.99	1.00
Knowledge Economy	Leamside Mode Priority	29	-0.02	0.95	1.00
Planning Policy	Road Network Connectivity	29	-0.34	0.94	1.00
PT Invest	PT Integration	29	-0.05	0.96	1.00
Political Action Initiated	PT Integration	29	0.32	1.00	1.00
LA Political (dis)Unity	PT Regulation	28	0.01	0.93	1.00
PT Integration	Leamside Rail integration	28	-0.01	0.96	1.00
PT Passenger Utility	Leamside Mode Priority	28	-0.07	0.96	0.99
Leamside Freight	Leamside Mode Priority	28	-0.03	0.95	1.00
Location of regional freight centre	Type of freight on Leamside (Local or national)	28	-0.01	0.96	0.99
Council Policy - Favour Leamside as ECML freight diversion	Type of freight on Leamside (Local or national)	28	-0.01	0.96	0.99
Leamside ridership	Leamside Mode Priority	28	-0.13	0.95	1.00
PT Invest	Leamside Rail integration	28	-0.07	0.96	1.00

Ageing Population	Social Inclusion	28	0.46	0.96	1.00
Local Freight Requirements	Type of freight on Leamside (Local or national)	28	-0.06	0.95	0.99
Political Action Initiated	Type of freight on Leamside (Local or national)	28	0.28	1.00	0.99
Council Policy - Favour Leamside as ECML freight diversion	Durham as city hub	27	-0.03	0.96	1.00
Economic and Employment Growth	Social Inclusion	27	-0.34	1.00	1.00
Historical Demographics	Durham as city hub	27	-0.02	0.93	1.00
Historical Demographics	Fencehouses Planning	27	-0.02	0.93	1.00
Heritage & Tourism	Durham as city hub	27	-0.05	0.96	1.00
Urban Agglomeration	Fencehouses Planning	27	-0.04	1.00	1.00
Durham as city hub	Fencehouses Planning	27	-0.05	0.96	1.00
LA Political (dis)Unity	Fencehouses Planning	27	-0.01	0.96	1.00
Planning Policy	Durham as city hub	27	-0.12	0.94	1.00
Sustainable emphasis of Fencehouses	Fencehouses Planning	27	0.01	0.96	1.00
PT Invest	Durham as city hub	27	-0.05	0.96	1.00
Road Network Connectivity	Fencehouses Planning	27	-0.03	0.96	1.00
Planning Policy	Fencehouses Planning	26	-0.03	0.94	1.00
ECML Passenger utility	Durham as city hub	26	-0.03	0.96	1.00
PT Passenger Utility	Fencehouses Planning	26	-0.07	1.00	0.99
Historical Demographics	Heritage & Tourism	26	-0.02	0.93	1.00
Fencehouses Prosperity	Fencehouses Planning	26	-0.04	0.96	1.00
Travel driven lifestyle	Fencehouses Planning	26	-0.04	1.00	1.00

PT Co Competition	NE Travel Card	26	-0.02	0.96	1.00
Car Availability	Car Availability	26	-0.03	1.00	1.00
PT Passenger Utility	Heritage & Tourism	26	-0.20	1.00	0.99
ECML Freight congestion	Council Policy - Favour Leamside as ECML freight diversion	26	-0.12	0.95	0.99
Durham as city hub	ECML Passenger utility	26	-0.09	0.96	1.00
Political Action Initiated	NE Travel Card	26	0.16	1.00	1.00
Bias to road spend	Electric Vehicle Policy	26	0.00	0.96	1.00
Road travel utility	Car Availability	26	-0.05	1.00	1.00
Public Opinion	Electric Vehicle Policy	25	-0.01	0.99	1.00
Travel driven lifestyle	Electric Vehicle Policy	25	-0.03	0.96	1.00
Environmental Cost	Electric Vehicle Policy	25	0.00	0.96	1.00
NE Public Investment	Electric Vehicle Policy	25	0.00	0.96	1.00
Leamside Passenger Utility	Leamside Passenger Utility	25	-0.02	0.96	1.00
Planning Policy	Electric Vehicle Policy	25	-0.05	0.94	1.00
PT Regulation	Leamside Passenger Utility	25	-0.11	0.95	1.00
Leamside Passenger Utility	Leamside ridership	25	-0.01	0.96	1.00
NE Private Investment	Location of regional freight centre	25	0.00	0.96	0.99
Political Action Initiated	Location of regional freight centre	25	0.22	1.00	0.99
Cost of road travel	Leamside ridership	25	0.00	0.96	1.00
NE Travel Card	Leamside ridership	24	0.00	0.96	1.00
Environmental Cost	Leamside ridership	24	0.01	0.96	1.00
Travel driven lifestyle	Leamside ridership	24	-0.02	1.00	1.00
Road Network Connectivity	Leamside ridership	24	-0.01	0.96	1.00

Road travel utility	Leamside ridership	24	-0.03	1.00	1.00
Reluctance to mode shift	Leamside ridership	24	0.00	0.96	0.99
LA Political (dis)Unity	Leamside ridership	24	0.02	0.96	1.00
Fencehouses Prosperity	Leamside ridership	24	-0.02	0.96	1.00
Leamside Freight	Leamside ridership	24	-0.02	0.96	1.00
Historical Demographics	Leamside business case	24	0.01	0.93	1.00
Rail Planning Timescale	Leamside business case	24	0.00	0.96	1.00
Leamside business case	Leamside ridership	24	-0.07	0.96	1.00
Leamside business case	Leamside business case	24	-0.01	0.96	1.00
ECML Passenger utility	Leamside business case	24	0.02	0.96	1.00
Leamside Rail integration	Leamside business case	24	0.01	0.96	1.00
Council Policy - Favour Leamside as ECML freight diversion	Leamside business case	24	0.00	0.96	1.00
UK Funding	Leamside business case	24	0.00	0.96	1.00
NE Private Investment	Leamside business case	24	0.00	0.96	1.00
Durham as city hub	Leamside business case	23	-0.01	0.96	1.00
Location of regional freight centre	Leamside business case	23	0.00	0.96	1.00
NE Public Investment	Leamside business case	23	0.01	0.96	1.00
Social Inclusion	Leamside business case	23	0.00	1.00	1.00
PT Passenger Utility	Leamside business case	23	-0.02	1.00	0.97
Fencehouses is built	Leamside business case	23	0.40	0.96	0.97
Fencehouses Prosperity	Leamside business case	23	-0.01	0.96	1.00
Fencehouses Planning	Leamside business case	23	-0.01	0.96	0.97

Local Freight Requirements	Leamside business case	23	0.00	0.95	1.00
Urban Agglomeration	Fencehouses is built	23	0.00	1.00	1.00
Leamside Mode Priority	Fencehouses is built	23	-0.01	0.96	0.98
Road Network Connectivity	Fencehouses is built	23	0.00	0.96	1.00
Sustainable emphasis of Fencehouses	Fencehouses is built	23	0.04	0.96	0.99
Knowledge Economy	Fencehouses is built	23	0.00	0.95	1.00
Travel driven lifestyle	Fencehouses is built	23	-0.01	1.00	0.98
Road travel utility	Fencehouses is built	23	0.00	0.96	1.00
LA Political (dis)Unity	Gateshead rail interchange	22	0.00	0.96	1.00
PT Passenger Utility	Fencehouses is built	22	-0.02	0.95	0.98
Leamside Rail integration	Gateshead rail interchange	22	-0.03	0.96	1.00
Sustainable emphasis of Fencehouses	Walk Cycle Provision	22	0.00	0.96	1.00
LA Political (dis)Unity	Leamside priority in funding	22	0.00	0.96	1.00
Road travel utility	Walk Cycle Provision	22	-0.02	0.96	1.00
Congestion S of Newcastle	Walk Cycle Provision	22	-0.07	0.95	1.00
NE Public Investment	Walk Cycle Provision	22	-0.01	0.96	1.00
Political Action Initiated	Leamside priority in funding	22	0.21	1.00	1.00
Travel driven lifestyle	Walk Cycle Provision	22	-0.04	1.00	1.00
Public Opinion	Leamside priority in funding	22	-0.02	0.99	1.00
Public Opinion	Walk Cycle Provision	22	-0.01	0.99	1.00
HA - DfT Action	Leamside priority in funding	22	-0.02	1.00	1.00
Economic and Employment Growth	Leamside priority in funding	21	-0.09	1.00	1.00

NE Public Investment	Sustainable emphasis of Fencehouses	19	-0.01	0.96	1.00
Political Action Initiated	Sustainable emphasis of Fencehouses	19	0.18	1.00	1.00
Planning Policy	Sustainable emphasis of Fencehouses	19	-0.06	0.94	1.00
PT Route Profitability	PT Network capacity	18	-0.05	0.96	1.00
PT Running costs (Subsidy)	PT Network capacity	17	-0.04	0.96	1.00
Political Action Initiated	PT Network capacity	17	0.08	1.00	1.00
Road Network Connectivity	Reluctance to mode shift	13	-0.01	0.96	1.00
PT Passenger Utility	Reluctance to mode shift	13	-0.17	1.00	0.99
Leamside ridership	PT Route Profitability	7	-0.35	0.96	1.00

Appendix C: Qualitative Data Analysis Software Evaluation

Qualitative Data Analysis Software was required to support coding of the stakeholder interviews. Twelve QDA systems were evaluated, the list taken from (Miles et al., 2014). Evaluation was undertaken by examining web site information and in three cases, downloading and running the demo software. The criteria for assessment were:

- *Range of media*: The types of media the software can handle, i.e. text files, social media feeds, PDFs and audio and video media files.
- *Local file solution*: Some software solutions offer cloud based data storage and the ability for multiple researchers to work on the same data. Here, in this project, much of the work is done while the researcher is travelling and not well connected to the cloud. Hence a single user, local file resource option, is preferred in this case.
- *Cost:* Cost varied from free (open source), through low cost academic licence to full commercial licence, prohibitive in the context of this project.
- *Services:* Services such as real time data feeds (i.e. from social media), data storage backup, multiple researcher support, or in-app purchase of transcription services. These are valuable features of QDA software but not necessarily required in this project.

The media used in this project that form the requirements for the software are:

- Text files of interview transcripts. The software must be able to label blocks of text
- Audio files. The raw untranscribed audio.
- PDF files. The scanned notes from interviews. In effect these are multi page collections of images of the interviewer's notes and the requirement is to capture and label areas of those images.

The products evaluated are listed below:

Answr	
Info Source	http://www.cdc.gov/hiv/library/software/answr/index.html
Summary	Originates in in disease control applications. Organises topics across multiple documents, but restricted to text only, no images or PDFs.
Cost	Open source, free.
Decision	Restriction to text based analysis only is a block. No further action.

Atlasti	
Info Source	www.atlasti.com
Summary	Strength is in video and sound.
Cost	£65 student licence for 2 yrs, £1380 commercial.
Decision	Download demo.

CAT	
Info Source	http://cat.ucsur.pitt.edu/
Summary	Cloud package based in Pittsburgh University. Basic, single text file analysis using a common set of codes. Assumes pre –existing set of codes so not oriented to generating that list. Key capability is having multiple coders labelling a semi-structured text dataset.
Cost	Free
Decision	Cloud access only is a problem given the researcher's work patterns. Lack of functionality for this project. No further action.

Dedoose	
Info Source	www.dedoose.com
Summary	Cloud based and emphasises multi user projects Tags areas of documents and has more flexibility over generating and using tags than CAT. Works on quantitative data.
Cost	$11 per month
Decision	Cloud access only, given the researcher's work patterns, and cost for a multi-year project are a problem. No further action.

Discovertext	
Info Source	www. discovertext.com
Summary	Cloud based, emphasises automation and analytics and includes live data feeds from social media specifically Facebook and Twitter. This is a big CRM package for commercial applications designed for automated data analysis of large data flows.
Cost	$24 per month student rate
Decision	Cloud access only given the researcher's work patterns and cost for a multi year project are a problem. Software is intended for a different application to this project. No further action

HyperResearch	
Info Source	www.researchware.com
Summary	Conventional data storage (no cloud) Text encoding plus audio & video tagging with options to purchase transcription services.
Cost	$199 single student license
Decision	No area based PDF support – requires text only from PDF files. No further action

maxQDA	
Info Source	www.maxqda.com
Summary	Non cloud based, Strong on output options and UI. Codes text, audio, video and areas of PDF files.
Cost	$99 single student license
Decision	Downloaded demo.

QDA Miner	
Info	https://provalisresearch.com/products/qualitative-data-analysis-software/
Summary	Overpriced.
Cost	£1300
Decision	Overpriced. No further action.

Nvivo	
Info Summary	www.qsrinternational.com/products_nvivo.aspx
Summary	Auto-coding and import from survey monkey, twitter, etc. In App purchase for transcription. Text and audio support, can select regions of a PDF page. Extensive output options.
Cost	£78 per yr student license, also available at no cost through Newcastle University.
Decision	Downloaded demo.

Qualrus	
Info	www.qualrus.com
Summary	Standard set of functions including learning mode to autosuggest coding.
Cost	$179
Decision	No ability for image area selection in PDF. No further action.

Transana	
Info	www.transana.org
Summary	Very video and audio oriented – almost to the exclusion of text.
Cost	$75
Decision	Media supported inappropriate to this project. No further action.

Weft QDA	
Info	www.pressure.to/qda
Summary	Open source but now deprecated and website admits to software having many unaddressed bugs. Text only, no PDF or audio.
Cost	Free
Decision	Low quality open source code. No further action.

Three products were evaluated further after downloading the demo. Atlasti was removed from the list after evaluation showed it emphasised coding of audio-visual media, was not well suited to text analysis and was therefore not suitable for this project. MaxQDA ,and NVivo from QSR were both well suited to the project with the functions to support both the coding task and the researcher’s work patterns. NVivo was also available in Newcastle University as a supported product and this final criteria meant NVivo was selected for this project.

References

Adonis, A., Mottram, H., Curry, D., Hutton, W., Rosewell, B. and Ruffer, J. (2013) *North East Independent Economic Review Report April 2013*. Available at: http://www.nelep.co.uk/wp-content/uploads/2014/11/North-East-Independent-Economic-Review-April-2013.pdf (Accessed: 01/06/2013).

AECom. (2006) 'Tees Tyne Connectivity Study Final Report', [Online]. Available at: www.strategyintegrationne.co.uk/displaypagedoc.asp?id=644 (Accessed: 25/09/2012).

AECom. (2007) *Leamside Final Report (V3),* November 2007 in Nexus.

AECom. (2009) 'Tyne and Wear Freight Partnership: Rail Freight Assessment Report ', [Online]. Available at: http://www.northeastfreightpartnership.info/reports_meetings/reports/pdf/RailFreightAssessment_Final.pdf (Accessed: 23/09/2012).

AECom. (2010) 'Rail Freight Review 2010', [Online]. Available at: http://www.tyneandwearfreight.info/rail_freight/pdf/Rail Freight Review 2010.pdf. (Accessed: 25/09/2012).

AladdinSoft (2016) *XLStat*. Available at: https://www.xlstat.com/en/ (Accessed: 01/05/2016).

Alumar, S. A., Nickel, S. and Saldanha-da-Gama, F. (2012) 'Hub location under uncertainty', *Transportation Research Part B,* 46, pp. 529-543.

Amaya Moreno, L., Defterli, O., Fügenschuh, A. and Weber, G. (2014) 'Vester's Sensitivity Model for Genetic Networks with Time-Discrete Dynamics', in *Lecture Notes in Computer Science.* Vol. 8542.

Annema, J. A. and De Jong, M. (2011) 'The History of the Transport Future—Evaluating Dutch Transport Scenarios of the Past', *Transport Reviews,* 31, (3), pp. 341-356.

Argote, L. (1982) 'Input Uncertainty and Organizational Coordination in Hospital Emergency Units.', *Administrative Science Quarterly,* 27, pp. 420-434.

ATOC. (2009) 'Connecting Communities Expanding Access to the Rail Network', [Online]. Available at: www.atoc.org/clientfiles/.../ConnectingCommunitiesReport_S10.pdf (Accessed: 18/09/2012).

Austroads. (2010) 'Guidelines for Selecting Techniques for the Modelling of Network Operations', (AP-R350/10), [Online]. Available at:

https://www.onlinepublications.austroads.com.au/items/AP-R350-10 (Accessed: 01/11/2011).

Avineri, E. (2005) 'Soft Computing Applications in Travel and Transport Systems: A Review', in Hoffman, F., Koppen, M., Klawonn, F. and Roy, R.(eds) *Soft Computing: Methodologies and Applications* Berlin: Springer Verlag,pp 17 - 25.

Bain, R. (2009) 'Error and optimism bias in toll road traffic forecasts', *Transportation,* 36, (5).

Bain, R. (2011) 'On the reasonableness of traffic forecasts', *T.E.C.,* 52, (5), pp. 213,217.

Bamber, J. L. and Aspinall, W. (2013) 'An expert judgement assessment of future sea level rise from the ice sheets', *Nature Climate Change,* 3, pp. 424-427.

Bamford, C. G. (2006) *Transport Economics.*4 ed Essex: Heineman.

Banister, D. and Berechman, J. (2000) *Transport Investment and Economic Development.* Routledge.

Barcelo, J. (ed.) (2010) *Fundamentals of Traffic Simulation.* Springer Verlag.

Barfod, M. B. and Saling, K. B. (2015) 'A new composite decision support framework for strategic and sustainable transport appraisals', *Transportation Research Part A,* 72, (1), pp. 1-15.

Bartholomew, K. (2007) 'Land use-transportation scenario planning: promise and reality', *Transportation,* 34, (4), pp. 397-412.

Bartholomew, K. and Ewing, R. (2010) 'Integrated Transportation Scenario Planning ', [Online]. Available at: http://faculty.arch.utah.edu/bartholomew/Integrated_Transp_Scenario_Planning.html (Accessed: 20/04/2011).

Bastian, M., Heymann, S. and Jacomy, M. (2009) *Gephi: An open source software for exploring and manipulating networks,* in *International AAAI Conference on Weblogs and Social Media*, San Jose.

BBC (2016) *Sajid Javid ends North East devolution deal*. Available at: http://www.bbc.co.uk/news/uk-england-37312978 (Accessed: 12/03/2018).

Beeching, R. (1963) 'The Reshaping of British Railways', in British Railways Board(ed), London.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A. and Aghdasi, M. (2010) 'Decision Support: PROMETHEE: A comprehensive literature review on methodologies and applications', *European Journal of Operational Research,* 200, pp. 198-215.

Bell, M. C. (2013) *SECURE (SElf Conserving URban Environments)*. Available at: https://www.secure-project.org/ (Accessed: 17/05/2013).

Belton, V. and Stewart, T. (2002) *Multiple Criteria Decision Analysis: An Integrated Approach.* Springer.

Berechman, J. (2009) *The Evaluation of Transportation Investment Projects.* Routledge.

Beser Hugosson, M. B. (2005) 'Quantifying Uncertainties in a National Forecasting Model', *Transportation Research Part A: Policy and Practice,* 39, (6), pp. 531-547.

Birtchnell, T., Urry, J., Cook, C. and Cook, A. (2012) ' Freight Miles The Impacts of 3D Printing on Transport and Society. Scenarios workshop report: Examination of future scenarios for the ESRC project 'Technologies and Travel'', [Online]. Available at: http://www.academia.edu/3628536/Freight_Miles_The_Impacts_of_3D_Printing_on_Transport_and_Society (Accessed: 31/01/2013).

Booker, J. M. and McNamara, L. L. (2004) 'Solving black box computation problems using expert knowledge theory and methods', *Reliability Engineering and System Safety* 85, pp. 331–340.

Borjeson, L., Hojer, M., Dreborg, K., Ekvall, T. and Finnveden, G. (2006) 'Scenario types and techniques: Towards a user's guide', *Futures,* 38, pp. 723 - 739.

Borzacchiello, M. T., Nijkamp, P. and Scholten, H. (2013) 'Mobile phone data from GSM networks for traffic parameter and urban spatial pattern assessment: a review of applications and opportunities', *Geojournal,* 78, (2), pp. 223-243.

Brans, J. P., Mareschal, B. and Vincke, P. (1986) 'How to select and how to rank projects: The PROMETHEE method ', *European Journal of Operational Research,* 24, pp. 228-238.

Brinkman, A. P. (2003) *The Ethical Challenges and Professional Responses of Travel Demand Forecasters.* thesis. University of California.

Cacuci, D., Ionescu-Bujor, M. and Navon, I. (2005) *Sensitivity and Uncertainty Analysis: Applications to large-scale systems.* Boca Raton: Chapman & Hall.

Cadoret, M., Le, S., Le Poder, F., Bouche, J., Fournier, G. and Fournier, O. (2008) *EnQuireR: Exploration of Questionaires with R*. Available at: http://enquirer.free.fr/index.html (Accessed: 7 May 2016).

Cairney, P. (2012) 'Complexity Theory in Political Science and Public Policy', *Political Studies Review,* 10, pp. 346-358.

Calman, L. (2011) *What is Grounded Theory?* Available at: http://www.methods.manchester.ac.uk/medialibrary/docs/gt.pdf (Accessed: 12/11/2015).

Carlson, M., Antoniuk, T., Farr, D., Francis, S., Manuel, K., Nishi, J., Stelfox, B., Sutherland, M., Yarmoloy, C., Aumann, C. and Pan, D. (2010) *Informing Regional Planning in Alberta's Oilsands Region with a Land-use Simulation Model,* in *International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting,*, Ottowa.

Cascetta, E., Carteni, A., Pagliara, F. and Montanino, M. (2015) 'A new look at planning and designing transportation systems: A decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods', *Transport Policy,* 38, pp. 27-39.

Castellanos-Nieves, D., Masegosa-Arredondo, A. D., Villacorta-Iglesias, P. J., NovoaHernández , P. and Pelta, D. A. (2011) *Improving scenario method for technology foresight by Soft Computing techniques,* in *The 4th International Seville Conference on Future-Oriented Technology Analysis (FTA)*, Seville.

Centre for Advanced Automotive Technology (2018) *Connected and Automated Vehicles*. Available at: http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/ (Accessed: 11/02/2018).

Chakraborty, A. (2011) 'Enhancing the role of participatory scenario planning processes: Lessons from Reality Check exercises ', *Futures,* 43, (4).

Chambers. (2008) *The Chambers Dictionary.* Chambers.

Chatterjee, K. and Gordon, A. (2006) 'Planning for an unpredictable future: Transport in Great Britain in 2030', *Journal of Transport Policy,* 13, (3), pp. 254-264.

Checkland, P. (1999) *Systems Thinking, Systems Practice.* Wiley.

Chen, C., Shao, L., Xu, L. and Shang, J. (2009) 'A case study predicting environmental impacts of urban transport planning in China', *Environmental Monitoring and Assessment,* 157, (1-4), pp. 169-177.

Chen, H.-C. and Liu, S.-M. (2016) 'Should ports expand their facilities under congestion and uncertainty?', *Transportation Research Part B,* 85, pp. 109-131.

Chermack, T. J., Lynham, S. A. and Ruona, W. E. A. (2001) 'A review of Scenario Planning Literature', *Future Research Quarterly,* Summer 2001, pp. 7-31.

Cheung, K. and Polak, J. (2010) *A Bayesian Approach to Modelling Uncertainty in Transport Infrastructure Project Forecasts,* 2010 in *TRB 2010*, Washington DC.

Clay, M. J. and Johnston, R. A. (2006) *Multivariate Uncertainty Analysis of an Integrated Land Use and Transportation Model: MEPLAN,* in *TRB 2010*, Washington DC.

Colander, D. and Kupers, R. (2014) *Complexity and the Art of Public Policy: Solving Society's Problems from the Bottom up.* Princeton: Princeton University Press.

Cole, A. (2006) 'The Influence Matrix Methodology: A Technical Report', [Online]. Available at: http://icm.landcareresearch.co.nz/knowledgebase/publications/public/iMatrix_Tech_Report.pdf (Accessed: 05/09/2015).

Cook, C., Curry, A., Hubers, C. and Lyons, G. (2012) 'Care miles - Scenarios workshop report: Examination of future scenarios for the ESRC project 'Technologies and Travel'', [Online]. Available at: http://eprints.uwe.ac.uk/19929/ (Accessed: 31/01/2013).

Cooke, R. M. (1991) *Experts in Uncertainty: Opinion and Subjective Probability in Science.* New York: O.U.P.

Cooke, R. M. (2013) 'Validating Expert Judgment with the Classical Model', in Martini, C. and Boumans, M.(eds) *Experts and Consensus in Social Science - Critical Perspectives from Economics, Sociology, Politics, and Philosophy.* Springer.

Coombs, D. (2009) *Regional and Local Strategic Modelling and Appraisal Capability: Final Report.* Department for Transport

Courtney, H. (2001) *20/20 Foresight: Crafting Strategy in an Uncertain World* Harvard Business School Press.

Courtney, H. (2008) 'A fresh look at strategy under uncertainty: An interview ', *McKinsey Quarterley*, [Online]. Available at: https://www.mckinseyquarterly.com/fresh_look_at_strategy_under_uncertainty_2256 (Accessed: 01/07/2011).

Daniels, S. and Walker, G. (1996) 'Collaborative Learning: Improving public deliberation in ecosystem based management', *Environmental Impact Assessment Review,* 16, (2), pp. 71-102.

Davidson, P. (2007) *Visual-TM*. Available at: http://www.peter-davidson.com/software/pdvtm_home.htm (Accessed: 10/9/2017).

de Jong, G., Daly, A., Pieters, M., Miller, S., Plasmeijer, R. and Hofman, F. (2007) 'Uncertainty in traffic forecasts: literature review and new results for The Netherlands', *Transportation,* 34, (4), pp. 375-395.

De Neufville, R. (2003) 'Real Options: Dealing With Uncertainty in Systems Planning and Design', *Integrated Assessment* 4, (1), pp. 26-34.

DfT. (2007) 'Scenario Planning Toolkit', [Online]. Available at: http://www.dft.gov.uk/pgr/scienceresearch/futures/secsceniss/ (Accessed: 20/04/2011).

DfT. (2009) 'Guidance on Local Transport Plans', [Online]. Available at: http://webarchive.nationalarchives.gov.uk/tna/20100210180753/http://www.dft.gov.uk/pgr/regional/ltp/guidance/localtransportsplans/ (Accessed: 08/07/2012).

DfT. (2010) 'TAG Unit 3.15.5:The Treatment of Uncertainty in Model Forecasting ', *WebTAG*, 3.15.5, (d), [Online]. Available at: http://www.dft.gov.uk/webtag/documents/expert/unit3.15.5.php (Accessed: 4/07/2011).

DfT. (2014a) 'TAG unit M3-1 Highway Assignment Modelling', *WebTAG*, 3,1, [Online]. Available at: https://www.gov.uk/government/publications/webtag-tag-unit-m3-1-highway-assignment-modelling (Accessed: 05/04/2015).

DfT. (2014b) 'WebTAG: TAG unit A1-1 Cost-Benefit Analysis,' *WebTAG*, A1-1, [Online]. Available at: https://www.gov.uk/government/publications/webtag-tag-unit-a1-1-cost-benefit-analysis-november-2014 (Accessed: 01/08/2015).

DfT (2016) *Transport analysis guidance: WebTAG*. Available at: https://www.gov.uk/guidance/transport-analysis-guidance-webtag (Accessed: 19/02/2017).

DfT. (2017a) 'Connecting People: A Strategic Vision for Rail', [Online]. Available at: https://www.gov.uk/government/publications/a-strategic-vision-for-rail (Accessed: 02/01/2018).

DfT (2017b) *Tempro*. Available at: https://data.gov.uk/dataset/national-trip-end-model-ntem (Accessed: 31/04/2017).

Divall, C. (2017) 'High speed 2 where? A historical perspective on the 'strategic case' for HS2', in *Transport Policy: Learning Lessons From History.* pp. 97-114.

Do, H. and Rothermel, G. (2008) 'Using Sensitivity Analysis to Create Simplified Economic Models for Regression Testing', *ISSTA 08*, [Online]. Available at: cs.ndsu.edu/~hdo/pdf_files/issta-08.pdf (Accessed: July 20 - 24 2008).

Downey, H. K. and Slocum, J. (1975) 'Characteristics of organizational environments and perceived environmental uncertainty.', *Administrative Science Quarterly,* 17, (313-327).

Dreborg, H. K. (1996) 'Essence of Backcasting', *Futures,* 28, (9), pp. 813-828.

Durham CC. (2010) 'Local Transport Plan 3', [Online]. Available at: http://www.durham.gov.uk/Pages/Service.aspx?ServiceId=5685 (Accessed: 30/05/2012).

Duthie, J., Voruganti, A., Kockelman, K. and Waller, S. T. (2010) 'Uncertainty Analysis and its Impacts on Decision Making in an Integrated Transportation and Gravity Based Land Use Model', *Journal of Urban Planning and Development,* 136, (4), pp. 294-302.

Emberger, G., Pfaffenbichler, P., Jaensirisak, S. and Timms, P. (2008) '"Ideal" decision-making processes for transport planning: A comparison between Europe and South East Asia', *Transport Policy,* 15, (6), pp. 341-349.

Ettema, D. F. and Timmermans, H. J. P. (eds.) (1997) *Activity Based Approaches to Travel Analysis.* Pergamon.

EU. (2003) 'PROSPECTS: Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems', [Online]. Available at: https://trimis.ec.europa.eu/project/procedures-recommending-optimal-sustainable-planning-european-city-transport-systems (Accessed: 01/11/2017).

Ferguson, A. (2011) 'Backers sue on toll-road forecast use', *Brisbane Times*, [Online]. Available at: http://www.brisbanetimes.com.au/business/backers-sue-on-tollroad-forecast-use-20110414-1dfxd.html (Accessed: 26/07/2011).

FHWA. (2004a) 'Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools', (FHWA-HRT-04-039), [Online]. Available at: http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol2/Vol2_Methodology.pdf (Accessed: 04/02/2013).

FHWA. (2004b) 'Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software', (FHWA-HRT-04-040), [Online]. Available at: http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/Vol3_Guidelines.pdf (Accessed: 04/02/2013).

Figueria, J. R., Greco, S., Roy, B. and Slowinski, R. (2010) 'ELECTRE Methods: Main Features and Recent Developments', in *Handbook of Multicriteria Analysis.* Springer.

Fiorello, D., Fermi, F. and Bielanska, D. (2010) 'The ASTRA model for strategic assessment of transport policies', *System Dynamics Review,* 26, (3), pp. 283-290.

Flood, R. L. and Carson, E. R. (1993) *Dealing with Complexity. An Introduction to the Theory and Application of Systems Science.*2nd ed New York: Plenum.

Flyvberg, B., Bruzelius, N. and Rothengatter, W. (2003) *Megaprojects and Risk.* Cambridge University Press.

Forgie, V. and Richardson, E. (2008) 'The community outcomes process and mediated modelling', *Expert Environmental*, [Online]. Available at: https://www.environmental-expert.com/articles/the-community-outcomes-process-and-mediated-modelling-85476 (Accessed: 10/09/2017).

Forster, A. (1995) *The contribution of integrated transport studies to the process of urban planning.* thesis. Leeds.

Funtowicz, S. and Ravetz, J. (1990) *Uncertainty and Quality in Science for Policy.* Dordrecht: Kluwer.

Giaoutzi, M., Stratigea, A., van Leeuwen, E. and Nijkamp, P. (2011) 'Scenario Analysis as a Foresight tool in Agriculture', *Unpublished, In preparation*.

GMCA (2017) *Mayor of Greater Manchester: Andy Burnham*. Available at: https://www.greatermanchester-ca.gov.uk/themayor (Accessed: 02/01/2018).

GNU (2015) *Gnu Octave*. Available at: https://www.gnu.org/software/octave/ (Accessed: 06/09/2015).

Godet, M. (2000) 'The Art of Scenarios and Strategic Planning: Tools and Pitfalls. ', *Technological Forecasting and Social Change* 65, pp. 3-22.

Godet, M. (2011) *Methods of prospective: Micmac: Structural Analysis*. Available at: http://en.laprospective.fr/methods-of-prospective/softwares/59-micmac.html (Accessed: 31/10/2011).

Godet, M., Durance, P. and Gerber, A. (2009) *Strategic Foresight: La Prospective: Use and Misuse of Scenario Building*. [Online]. Available at: http://en.laprospective.fr/dyn/anglais/ouvrages/sr10veng.pdf (Accessed: 05/09/2015).

Gordon, T. J. (1968) 'Initial Experiments with the Cross-Impact Matrix Method of Forecasting', *Futures,* 1, (2), pp. 100-116.

Gordon, T. J. and Hayward, H. (2000) 'Initial Experiments with the Cross Impact Matrix Method of Forecasting', in Miyakawa, T.(ed), *The Science of Public Policy: Policy Analysis II.* Vol. IV Routledge, pp. 468- 487.

Gossens, L., H,J. and Cooke, R. M. (2008) *TU Delft Expert Judgment Data Base*. Available at: http://www.rff.org/Events/Documents/Cooke_Goossens.pdf (Accessed: 25/07/2015).

Govindan, K. and Jepsen, M. B. (2016) 'ELECTRE: A comprehensive literature review on methodologies and applications', *European Journal of Operational Research,* 250, (1), pp. 1-29.

Gray, D. and Begg, D. (2001) 'Transport Policy Under the Scottish Parliament', *Scottish Affairs,* 35, (Spring).

Grekos, M. (2014) 'Airports commission: Interim report', *Journal of Planning and Environment Law*, (4), pp. 420-422.

Gudmundsson, H. (2011) 'Analysing Models as a Knowledge Technology in Transport Planning', *Transport Reviews,* 31, (2), pp. 145-159.

Guimarães Pereira, Â. and Corral, S. (2009) '3 Pillars and 1 Beam: Quality of River Basin Governance Processes', *Ecological Economics,* 68, (4), pp. 940-954.

Hammersley, J. M. and Handscomb, D. C. (1964) *Monte Carlo Methods.* Methuen.

Harries, C. (2003) 'Correspondence to what? Coherence to what? What is good scenario-based decision making?', *Technological Forecasting & Social Change,* 70, pp. 797-817.

Hensher, D. A., Ho, C. and Mulley, C. (2015) 'Identifying preferences for public transport investments under a constrained budget', *Transportation Research Part A,* 72, pp. 27-46.

Hickman, R., Ashiri, O. and Banister, D. (2009) ' Achieving carbon efficient transport: backcasting from London.', *Transportation Research Record,* 2139, pp. 172-182.

Highways England. (2016) 'Post-opening project evaluation (POPE) of major schemes: meta report', [Online]. Available at: https://www.gov.uk/government/publications/post-opening-project-evaluation-pope-of-major-schemes-meta-report (Accessed: 04/09/2017).

HM Treasury (2016) *Infrastructure at heart of Spending Review as Chancellor launches National Infrastructure Commission*. Available at: https://www.gov.uk/government/news/infrastructure-at-heart-of-spending-review-as-chancellor-launches-national-infrastructure-commission (Accessed: 02/01/2018).

Hojer, M. (1998) 'Transport telematics in urban systems—a backcasting Delphi study', *Transportation Research Part D: Transport and Environment* 3, (6), pp. 445-463.

Holland, J. H. (2014) *Complexity. A Very Short Introduction.* Oxford: OUP.

Hollway, W. and Jefferson, T. (2000) *Doing qualitative research differently.* SAGE.

Huang, I. B., Keisler, J. and Linkov, I. (2011) 'Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends', *Science of The Total Environment,* 409, (19), pp. 3578-3594.

Hyde, K., Maier, H. R. and Colby, C. (2003) 'Incorporating uncertainty in the PROMETHEE MCDA method', *Journal of Multi-Criteria Decision Analysis,* 12, (4-5), pp. 245-259.

ISEE Systems, L. (2012) *STELLA*. Available at: www.iseesystems.com (Accessed: 05/09/2011).

Jeon, C. M. and Amekudzi, A. A. (2007) *Risk Management for Public Private Partnerships (PPP): Using Scenario Planning and Valuation Methods,* in *TRB 2007*, Washington DC.

Jeon, C. M., Chang, Y. and Amekudzi, A. A. (2010) 'Incorporating Uncertainty into Transportation Decision Making: A Sustainability Oriented Approach*', TRB.* Washington DC, pp.

Jorgenson, S. E. and Fath, B. D. (2011) *Fundamentals of Ecological Modelling: Applications in Environmental Management and Research.*4 ed Amsterdam: Elsevier.

Kahneman, D. and Tversky, A. (1979) 'Prospect Theory, An Analysis of Decision under Risk', *Econometrica,* 47, (2), pp. 263-292.

Kaplan, A. (1998) *The Conduct of Inquiry: Methodology for Behavioural Science.*2nd ed New Brunswick: Transaction

Keynes, J. M. (1936) *The General Theory of Employment, Interest, and Money.* London: McMillan.

Khisty, C. J. (2000) 'Can wicked problems be tackled through abductive inferencing?', *Journal of Urban Planning and Development,* 126, (3).

Khisty, C. J. and Arslan, T. (2005) 'Possibilities of steering the transportation planning process in the face of bounded rationality and unbounded uncertainty', *Transportation Research* C, (13).

Khisty, C. J. and Leleur, S. (1997a) 'Societal Planning: Identifying a New Role for the Transport Planner - Part 1', *Innovation,* 10, (1), pp. 17 - 25.

Khisty, C. J. and Leleur, S. (1997b) 'Societal Planning: Identifying a New Role for the Transport Planner - Part 2', *Innovation,* 10, (1), pp. 27 - 36.

Kikuchi, S. (2005) 'Study of Transportation and Uncertainty', in Attoh-Okine, N. O. and Ayyub, B. M.(eds) *Applied Research in Uncertainty Modeling and Analysis.* Springer, pp. 303-319.

Kloprogge, P., van der Sluijs, J. P. and Petersen, A. C. (2009) 'A method for the analysis of assumptions in model-based environmental assessments', *Environmental Modelling and Software,* 26, pp. 289-301.

Koh, A. and Shepherd, S. (2009) *MARS-SATURN link. Report to DfT on Task 3,* in Leeds.

Kruskal, W. H. (1958) 'Ordinal Measures of Association', *Journal of the American Statistical Association,* 53, (284), pp. 814-861.

Laird, J. J. and Venables, A. J. (2017) 'Transport investment and economic performance: A framework for project appraisal', *Transport Policy* 56, pp. 1-11.

Lami, I. M. (2014) 'Evaluation Tools to Support Decision-Making Process Related to European Corridors', in Lami, I. M.(ed), *Analytical decision-making methods for evaluating sustainable transport in European corridors.* Springer, pp. 85-102.

Lemp, J. D. and Kockelman, K. (2009) *Understanding and Accomodating Risk and Uncertainty in Toll Road Projects: A Review of the Literature,* Jan 2009 in *TRB 2009*, Washington DC.

Lewins, A. and Silver, C. (2008) *Using Software in Qualitative Research.* SAGE.

Lighttwist (2016) *EXCALIBUR*. Available at: http://www.lighttwist.net/wp/excalibur (Accessed: 11/06/2016).

Lindblom, C. (1959) 'The Science of Muddling Through', *Public Administration Review* 19, (2), pp. 79-88.

Lindblom, C. (1979) 'Still Muddling, Not Yet Through', *Public Administration Review, ,* 39, (6), pp. 517 - 526.

Lindgren, M. and Bandhold, H. (2009) *Scenario Planning .* UK: Palgrave MacMillan.

Linstone, H. and Turoff, M. (2002) *The Delphi Method: Techniques and Applications.* [Online]. Available at: http://is.njt.edu/pubs/delphibook (Accessed: 03/03/2011).

Lipshitz, R. and Strauss, O. (1997) 'Coping with Uncertainty: A Naturalistic Decision Making Analysis', *Organizational Behaviour and Human Decision Processes,* 69, (2).

Loosemore, M., Raftery, J., Reilly, C. and Higgon, D. (2006) *Risk Management in Projects.*2nd ed London: Taylor and Francis.

MaaS Alliance (2018) *The Mobility as a Service (MaaS) Alliance* Available at: https://maas-alliance.eu/ (Accessed: 11/02/2018).

Mackie, P. and Preston, J. (1998) 'Twenty-one Sources of Error and Bias in Transport Project Appraisal', *Transport Policy,* 5, pp. 1-7.

Maldonado, J. (1990) *Strategic Planning: An Approach to Improving Airport Planning Under Uncertainty. Master of Science Thesis, Technology and Policy*

Program. Cambridge, USA.: M.I.T.

Manson, S. M., Sun, S. and Bonsal, D. (2012) 'Agent-Based Modeling and Complexity', in Heppenstall, A. J., Crooks, A. T., See, L. M. and Batty, M.(eds) *Agent-Based Models of Geographical Systems.* Springer Science+Business Media.

Manzo, S., Nielson, A. and Prato, C. G. (2013) *Uncertainty in large-scale transport models forecasts,* September 2013 in *UNITE*, Copenhagen.

Maparu, T. S. and Mazumder, T. N. (2017) 'Transport infrastructure, economic development and urbanization in India (1990–2011): Is there any causal relationship?', *Transportation Research Part A,* 100, pp. 319-336.

Marchais-Roubelat, A. and Roubelat, F. (2008) 'Designing action based scenarios', *Futures,* 40, (1), pp. 25-33.

Marchau, V. A. W. J. and van der Heijden, R. E. C. M. (2003) 'Innovative methodologies for exploring the future of automated vehicle guidance', *Journal of Forecasting,* 22, (2-3), pp. 257-276.

Marsden, G. and Reardon, L. (2017) 'Questions of governance: Rethinking the study of transportation policy', *Transportation Research Part A,* 101, pp. 238-251.

Mattot, L. S., Babendrier, J. E. and Purucker, S. T. (2009) 'Evaluating uncertainty in integrated environmental models', *Water Resources Research,* 45.

May, A. D., Karlstrom, A., Marler, N., Matthews, B., Minken, H., Monzon, A., Oage, M., Pfaffenbichler, P. and Shepherd, S. (2005) *Developing Sustainable Urban Land Use and Transport Strategies: A Decision Makers Guidebook*. Available at: http://www.ivv.tuwien.ac.at/uploads/media/DMG_English_Version_2005_02.pdf (Accessed: 01/10/2017).

May, R. and Haldane, A. (2011) 'Systemic risk in banking ecosystems', *Nature,* 469, pp. 351-355.

McAdams, M. A. (2008) 'Complexity Theory and Urban Planning ', *Urban Affairs and Public Policy,* 9.

Microsoft (2010) *Visual Studio 2010*. Available at: https://www.visualstudio.com/ (Accessed: 06/09/2015).

Miles, M. B., Huberman, M. A. and Saldana, J. (2014) *Qualitative Data Analysis.* Sage.

Miller, E. J. and Salvini, P. (2002) 'Activity-based Travel Behaviour, Modeling in a Microsimulation Framework', in Mahmassani, H.(ed), *In Perpetual Motion: Travel Behaviour Research Opportunities and Application Challenges.* Pergamon, pp. 533-582.

Morgan, M. G. and Henrion, M. (1990) *UNCERTAINTY. A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge University Press.

Morris, M., D. (1991) 'Factorial Sampling Plans for Preliminary Computational Experiments', *Technometrics,* 33, (2), pp. 161-174.

MOTOS (2007) *Transport Modelling: Towards Operational Standards in Europe: MOTOS/M2.1/PU/v1.0*. Available at: http://www.transport-research.info/web/projects/project_details.cfm?id=11064 (Accessed: 28/10/2013).

MUCM (2011) *MUCM: Managing Uncertainty in Complex Models*. Available at: http://www.mucm.ac.uk/Pages/About.html (Accessed: 29 Nov 2011).

Muric, G., Macura, D., Gospic. N and Bogojevic, D. (2013) *An Approach to Assess Criticality of Elements in the Process of Information Infrastructure Protection.,* in *Telsiks 2013 11th International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services*, Nis, Serbia.

Naess, P. (2011) 'The Third Limfjord Crossing: A Case of Pessimism Bias and Knowledge Filtering', *Transport Reviews,* 31, (2), pp. 231-249.

Naess, P. (2013) *Forecasting inaccuracies: a result of unexpected events, optimism bias, technical problems, or strategic misrepresentation?,* in *International Conference on Uncertainties in Transport Project Evaluation (UNITE) 2013* Copenhagen.

Network Rail. (2007) 'Freight Route Utilisation Strategy (Archived)', [Online]. Available at: http://archive.nr.co.uk/aspx/4449.aspx (Accessed: 25/03/2018).

Network Rail. (2010) 'East Coast Main Line 2016 Capacity Review', [Online]. Available at: ttp://www.networkrail.co.uk/browse documents/rus documents/route utilisation strategies/east coast main line/east coast main line 2016 capacity review/east coast main line 2016 capacity review.pdf (Accessed: 01/10/2012).

Nijkamp, P., Rienstra, S. A. and Vleugel, J. M. (1998) *Transportation Planning and the Future.* Wiley.

Norman, D. A. (1999) 'Affordance, conventions, and design', *Interactions,* 6, (3), pp. 38-43.

Northumberland County Council. (2011) 'Local Transport Plan 2011-2026', [Online]. Available at: http://www.northumberland.gov.uk/default.aspx?page=7846 (Accessed: 30/05/2012).

O'Hagan, A. (2011a) *MUCM Toolkit, Managing Uncertainty in Complex Models*. Available at: http://mucm.aston.ac.uk (Accessed: 23 Sept 2011).

O'Hagan, A. (2011b) *SHELF: the Sheffield Elicitation Framework*. Available at: http://www.tonyohagan.co.uk/shelf/ (Accessed: 2/10/2011).

Ortuzar, J. D. and Willumsen, L. G. (2011) *Modelling Transport (4th Edition)* 4 ed London: Wiley.

Packer, M. (2011) *The Science of Qualitative Research.* Cambridge University Press.

Palisade (2011) *@Risk*. Available at: www.palisade.com/risk (Accessed: 5 Sept 2011).

Parish, D. (2009) 'The 1973-1975 Energy Crisis and its Impact on Transport', (09/107), [Online]. Available at: http://www.racfoundation.org/assets/rac_foundation/content/downloadables/energy%20crisis%20-%20parish%20-%20161009%20-%20report.pdf (Accessed: 03/07/2017).

Patching, D. (1990) *Practical Soft Systems Analysis.* London: Pitman.

Pentaho (2011) *Pentaho*. Available at: www.pentaho.com (Accessed: 13 Feb 2011).

Peterson, G. D., Cummimg, G. S. and Carpenter, S. R. (2003) 'Scenario Planning: a Tool for Conservation in an Uncertain World', *Conservation Biology* 17, (2), pp. 358–366.

Pfaffenbichler, P. (2011) 'Modelling with Systems Dynamics as a Method to Bridge the Gap between Politics, Planning and Science? Lessons Learnt from the Development of the Land Use and Transport Model MARS', *Transport Reviews,* 31, (2), pp. 267-289.

Pfaffenbichler, P., Emberger, G. and Shepherd, S. (2010) 'A system dynamics approach to land use transport interaction modelling: the strategic model MARS and its application', *System Dynamics Review,* 26, (3), pp. 262-282.

Porter, M. (1980) *Competitive Strategy.*: Macmillan.

Powersim Software, A. (2012) *POWERSIM STUDIO*. Available at: www.powersim.com (Accessed: 19/04/2012).

Priemus, H., Flybjerg, B. and van Wee, B. (2014) *Decision Making on Mega-Projects: Cost Benefit Anlysis, Planning and Innovation.* Cheltenham UK: Elgar.

Proust, K., Newell, B., Brown, H., Capon, A., C., B., Burton, A., Dixon, J., Mu, L. and Zarafu, M. (2012) 'Human health and climate change: leverage points for adaptation in urban environments.', *International Journal of Environmental Research and Public Health,* 9, (6), pp. 2134 - 2158.

QSR, I. (2014) *NVivo*. Available at: http://www.qsrinternational.com/products_nvivo.aspx (Accessed: 18/12/2014).

Rasouli, S. and Timmermans, H. (2012) 'Uncertainty in travel demand forecasting models: literature review and research agenda', *Transportation Letters,* 4, (1), pp. 55-73.

Refsgaard, J. C., van der Sluijs, J. P., Hojberg, A. L. and Vanrolleghem, P. (2005) 'Hamoni-CA Guidance: Uncertainty Analysis', pp. 46. [Online]. Available at: www.harmoni-ca.info/toolbox/Model_Uncertainty/index.php (Accessed: 10 April 2012).

Refsgaard, J. C., van der Sluijs, J. P., Højberg, A. L. and Vanrolleghem, P. A. (2007) 'Uncertainty in the environmental modelling process. A framework and guidance', *Environmental Modelling & Software* 22, pp. 1543-1556.

Reissner, S. (2013) Memo from phone conversation: Writing styles for technical storytelling, 28/07/2013.

Reissner, S. and Pagan, V. (2012) 'Story listeners in management practice'.

Rittel, H. W. J. and Webber, M. M. (1973) 'Dilemmas in a General Theory of Planning ', *Policy Sciences,* 4, pp. 155-169.

Road and Maritime Services NSW. (2013) 'Traffic Modelling Guidelines. V1.0. Roads and Maritime Services, NSW, Australia', [Online]. Available at: http://www.rta.nsw.gov.au/doingbusinesswithus/downloads/technicalmanuals/modellingguidelines.pdf. (Accessed: 14/08/2013).

Robert, C. and Casella, G. (2004) *Monte Carlo Statistical Methods.* Springer.

Robinson, J. (1990) 'Futures Under Glass. A recipe for people who hate to predict.', *Futures,* 22, (8), pp. 820-842.

Robinson, J. (2003) 'Future subjunctive: backcasting as social learning', *Futures,* 35, (8), pp. 839-856.

Rodier, C. J. (2007) 'Beyond Uncertainty: Modeling Transportation, Land Use, and Air Quality in Planning', [Online]. Available at: http://transweb.sjsu.edu/mtiportal/research/publications/summary/0701.html (Accessed: 30/08/2011).

Rodier, C. J. and Johnston, R. A. (2002) 'Uncertain socioeconomic projections used in travel demand and emissions models: could plausible errors result in air quality nonconformity?', *Transportation Research Part A* 36, (7), pp. 613 - 631.

Rowe, W. D. (2001) 'Managing Uncertainty', [Online]. Available at: http://rowe-res.com/Managing%20Uncertainty.pdf (Accessed: 27/03/2011).

Rumsfeld, D. (2002) *Nato Speeches: Press Conference*. Available at: http://www.nato.int/docu/speech/2002/s020606g.htm (Accessed: 26/02/2017).

Ruth, M. (2015) *Handbook of Research methods and Applications in Environmental Studies.* Edward Elgar Publishing.

Saaty, T. L. (2000) *Fundamentals of Decision Making and Priority Theory With the Analytic Hierarchy Process.* RWS.

Saltelli, A., Chan, K. and Scott, E. M. (2008) *Sensitivity Analysis.* Wiley.

Schade, B. and Schade, W. (2005) 'Evaluating Economic Feasibility and Technical Progress of Environmentally Sustainable Transport Scenarios by a Backcasting Approach with ESCOT', *Transport Reviews,* 25, (6), pp. 647-668.

Schwarz, N., Haase, D. and Seppelt, R. (2010) 'Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage', *Environment and Planning B: Planning and Design,* 37, pp. 265-283.

Scolobig, A. and Lilliestam, J. (2016) 'Comparing Approaches for the Integration of Stakeholder Perspectives in Environmental Decision Making', *Resources,* 5, (4).

Scottish Government (2017) *Edinburgh Tram Inquiry*. Available at: http://www.edinburghtraminquiry.org/ (Accessed: 14/10/2017).

Scourse, E., Aspinall, W. P. and Chapman, N. (2015) 'Using expert elicitation to characterise long-term tectonic risks to radioactive waste repositories in Japan', *Journal of Risk Research,* 18, (3), pp. 364-377.

Shen, Q., Chen, Q., Tang, B., Yeung, S., Hu, Y. and Cheung, G. (2009) 'A system dynamics model for the sustainable land use planning and development', *Habitat International,* 33, pp. 15-25.

Shepherd, S. P. (2014) 'A review of system dynamics models applied in transportation', *Transportmetrica B: Transport Dynamics,,* 2, (2), pp. 83-105.

Silverman, D. (2006) *Interpreting Qualitative Data.*3rd ed: Sage.

Simulistics, L. (2012) *Simile*. Available at: www.simulistics.com/ (Accessed: 19/04/2012).

Sobol, I. M. (2001) 'Global Sensitivity Indices for Nonlinear Mathematical Models and their Monte Carlo Estimates', *Mathematics and Computers in Simulation,* 55, pp. 271-280.

Sterman, J. D. (2000) *Business Dynamics: Systems Thinking and Modeling for a Complex World.* Boston: Irwin McGraw Hill.

Sterman, J. D. (2002) 'All Models are Wrong: Reflections on Becoming a Systems Scientist.', *System Dynamics Review,* 18, (4), pp. 501-531.

Stevanovic, A., Dakic, I. and Zlatkovic, M. (2017) 'Comparison of adaptive traffic control benefits for recurring and non-recurring traffic conditions', *IET Intelligent Transport Systems,* 11, (3), pp. 142-151.

Stevens, A. (2006) *White Paper proposes stronger mayors and more power to English communities*. Available at: http://www.citymayors.com/politics/uk_whitepaper06.html (Accessed: 02/01/2018).

Stockton on Tees Borough Council. (2011) 'Local Transport Plan 2011-2016 (LTP3)', [Online]. Available at: http://www.stockton.gov.uk/citizenservices/transport/ltp/ltp3/ (Accessed: 30/05/2012).

Strachan, N., Pye, S. and Hughes, N. (2008) 'The role of international drivers on UK scenarios of a low carbon society', in Strachan, N., Foxon, T. and Fujino, J.(eds) *Modelling Long-term Scenarios for Low Carbon Societies*. Vol. Climate Policy 8 (2) London: pp 125 - 139.

Svenfelt, A., Engström, R. and Svane, O. (2010) 'Decreasing energy use in buildings by 50% by 2050 — A backcasting study using stakeholder groups', *Technological Forecasting & Social Change,* 78, (5), pp. 785-796.

te Brommelstroet, M. and Bertolini, L. (2008) 'Developing land use and transport PSS: Meaningful information through a dialogue between modelers and planners', *Transport Policy,* 15, pp. 251-259.

TfL. (2010) 'Traffic Modelling Guidelines: TfL Traffic Manager and Network Performance Best Practice', [Online]. Available at: http://www.tfl.gov.uk/assets/downloads/traffic-modelling-guidelines.pdf (Accessed: 14/02/2013).

Thompson, J. L., Forster, C. B., Werner, C. and Peterson, T. R. (2015) 'Mediated Modeling: Using Collaborative Processes to Integrate Scientist and Stakeholder Knowledge about Greenhouse Gas Emissions in an Urban Ecosystem. ', *Society and Natural Resources,,* 23, (8), pp. 742-757.

Traffic Simulation Committee Japan Society of Traffic Engineers. (2002) 'Standard Verification Process for Traffic Flow Simulation Model.', [Online]. Available at: (Accessed: 14/08/2013).

Transport Scotland (2017) *Aberdeen Western Peripheral Route / Balmedie to Tipperty*. Available at: https://www.transport.gov.scot/projects/aberdeen-western-peripheral-route-balmedie-to-tipperty/ (Accessed: 15/08/2017).

Tuominen, A., Tapio, P., Varho, V., Jarvi, T. and Banister, D. (2014) 'Pluralistic backcasting: Integrating multiple visions with policy packages for transport climate policy', *Futures,* 6, pp. 41-58.

Turoff, M. (2002) 'The Policy Delphi', in Linstone, H. and Turoff, M.(eds) *The Delphi Method: Techniques and Applications.*

Tversky, A. and Kahneman, D. (1974) 'Judgment under Uncertainty: Heuristics and Biases', *Science,* 185, pp. 1124-1131.

Tyler, S. (2009) 'Multi-Stakeholder Deliberation', in Swanson, D. and Bhadwal, S.(eds) *Creating Adaptive Policies.* New Delhi: Sage.

Tyne and Wear Integrated Travel Authority. (2011) 'Keep Tyne and Wear Moving LTP3: The Third Local Transport Plan for Tyne and Wear Strategy 2011 - 2021', [Online]. Available at: http://www.tyneandwearltp.gov.uk/ (Accessed: 30/05/2012).

UK Parliament. (2000) *Local Government Act 2000* http://www.legislation.gov.uk/ukpga/2000/22/contents.

UK Transport Systems Catapult (2015) *Sentiment Mapping*. Available at: https://ts.catapult.org.uk/sentiment-mapping (Accessed: 14/11/2015).

UNITE (2013) *International Conference on Uncertainties in Transport Project Evaluation.* Copenhagen:DTU.

Usher, W. and Strachan, N. (2013) 'An expert elicitation of climate energy and economic uncertainties', *Energy Policy,* 61, pp. 811-821.

van den Belt, M. (2004) *Mediated Modeling; A systems dynamics approach to environmental consensus building.* Washington DC: Island Press.

van Den Belt, M., McCallion, A., Wairepo, S., Hardy, D., Bidois, C. and Hale, L. (2012) 'Mediated Modelling of Coastal Ecosystem Services: A Case Study of Te Awanui Tauranga Harbour', [Online]. Available at: https://www.mtm.ac.nz/wp-content/uploads/2017/03/report-4.pdf (Accessed: 14/03/2015).

van den Brink, M. (2009) *Rijkwaterstaadt On the horns of a dilemma*. [Online]. Available at: http://books.google.com/books?id=UUV_Nyjf0H4C&pg=PA93&lpg=PA93&dq=scenarios+rijkswaterstaat&source=bl&ots=j5APbcJx5w&sig=xuAcqNX3SOmdREiHIEgNJJiu13I&hl=en&ei=iOF5TYOeMsLKhAea2PDlBg&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEcQ6AEwBw#v=onepage&q=scenarios%20rijkswaterstaat&f=false (Accessed: 05/05/2011).

van der Heijden, K. (1996) *Scenarios, the art of strategic conversation.* Wiley.

van der Sluijs, J. P., Craye, M., Funtowicz, S., Kloprogge, P., Ravetz, J. and Risbey, J. (2005) 'Combining Quantitative and Qualitative Measures of Uncertainty in Model Based Environmental Assessment: The NUSAP System', *Risk Analysis,* 25, (2), pp. 481-491.

van Geenhuizen, M. and Thissen, W. (2007) 'A Framework for Identifying and Qualifying Uncertainty in Policy Making: The Case of Intelligent Transport Systems.', in van Geenhuizen, M.(ed), *Policy Analysis of Transport Networks.* Ashgate.

van Wee, B. and Tavasszy, L. (2014) 'Ex Ante Evaluation of Mega-projects: Methodological Issue and Cost-benefit Analysis', in Priemus, H.(ed), *Decision Making on Mega-Projects.* Cheltenham: Edward Elgar.

Ventana Systems, L. (2012) *Vensim*. Available at: www.vensim.com (Accessed: 19/04/2012).

Vester, F. (2012) *The Art of Interconnected Thinking: Tools and concepts for a new approach to tackling complexity.*2nd ed Munich: MCB.

Vigar, G. (2017) 'The four knowledges of transport planning: Enacting a more communicative, trans-disciplinary policy and decision-making', *Transport Policy,* 58, pp. 39-45.

Wachs, M. (1985) 'Planning, Organizations and Decision Making: A Research Agenda', *Transportation Research A,* 19A, (5/6), pp. 521-531.

Walker, W. E., Harremoes, P., Rotmans, J., Van der Sluijs, J. P., Van Asselt, M. B. A., Janssen, P. and Krayer Von Krauss, M. P. (2003) 'A Conceptual Basis for Uncertainty Management in Model-Based Decision Support ', *Integrated Assessment,* 4, (1).

Wang, X., Lim, M. K. and Ouyang, Y. (2015) 'Infrastructure deployment under uncertainties and competition: The biofuel industry case', *Transportation Research Part B,* 78, pp. 1-15.

Weaver, W. (1948) 'Science and Complexity', *American Science,* 36, pp. 536-544.

Webber, W., Moffat, A. and Zobel, J. (2010) 'A Similarity Measure for Indefinite Rankings', *ACM Transactions on Information Systems,* 28, (4).

Welde, M., Eliasson, J., Odeck, J. and Borjesson, M. (2013) 'The Use of Cost-Benefit Analyses in Norway and Sweden: A Comparison*', European Transport Conference.* Frankfurt, AET, pp. 1-13.

WMCA (2017) *Transport for the West Midlands*. Available at: https://www.tfwm.org.uk/ (Accessed: 12/07/2016).

Worsley, T. and Mackie, P. (2015) 'Transport Policy, Appraisal and Decision-Making', [Online]. Available at: http://www.racfoundation.org/assets/rac_foundation/content/downloadables/Transport_policy_appraisal_decision_making_worsley_mackie_May_2015_final_report.pdf (Accessed: 12/06/2016).

Wright, G., van Der Heijden, K., Burt, G., Bradfield, R. and Cairns, G. (2008) 'Scenario planning interventions in organizations: An analysis of the causes of success and failure', *Futures,* 40, pp. 218-236.

Xiao, Y., Fu, X. and Zhang, A. (2013) 'Demand uncertainty and airport capacity choice', *Transportation Research Part B,* 57, pp. 91-104.

XJ Technologies, C. (2012) *AnyLogic*. Available at: www.xjtek.com (Accessed: 19/04/2012).

Zhao, Y. and Kockelman, K. M. (2002) 'The propagation of uncertainty through travel demand models: An exploratory analysis', *Annals of Regional Science,* 36, (1), pp. 145.

Zheng, H., Son, Y.-J., Chiu, Y.-C., Head, L., Yiheng, F., Sojung, K., H,X. and Hickman, M. (2013) 'A Primer for Agent-Based Simulation and Modeling in Transportation Applications', *The Exploratory Advanced Research Program*, [Online]. Available at: https://www.fhwa.dot.gov/advancedresearch/pubs/13054/index.cfm (Accessed: 02/09/2017).

Zimmerman, M., Darkow, I.-L. and von der Gracht, H. A. (2012) 'Integrating Delphi and participatory backcasting in pursuit of trustworthiness — The case of electric mobility in Germany', *Technological Forecasting and Social Change,* 79, (9), pp. 1605-1621.

Zimmerman, M., Warth, J., Von der Gracht, H. A. and Darkow, I.-L. (2011) 'Developing a backcasting approach for systematic transformations towards sustaianable mobility - The case of the automotive industry in Germany.', *4th International Seville Conference on Future-Oriented Technology Analysis (FTA) FTA and Grand Societal Challenges – Shaping and Driving Structural and Systemic Transformations* Seville, pp.