Combined use of a backcast scenario and cross-impact matrix analysis to identify causes of uncertainty in a nascent transport infrastructure project.

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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 quantifies the factors contributing to uncertainty, focussing on the early stages of the project lifecycle.

The method used a back-cast scenario to describe a future view of a transport project. The causal relationships between elements of the planning and decision processes that led to the scenarios were discussed in structured interviews with stakeholders, and each conversation was coded using qualitative analysis techniques to identify the active elements of the process. Causality between the elements was explored to evaluate their influences and dependencies with those elements found to be simultaneously both highly influential and highly dependent were identified as those driving uncertainty. The sensitivity of the analytical element of this process to its parameters was also examined to quantify their contribution to the uncertainty in the analysis and to establish robust values for these parameters.

The specific scenario presented here was based on a disused railway where several studies evaluating its re-opening have resulted in contradictory views on its mode of use and on the achievable benefits. In the scenario, the rail service is re-instated for light rail use in conjunction with a new sustainable urban area anchored on an existing small village. In this case, the results showed that local politics and leadership were the most influential factors in the project while the economic environment, the utility of the proposal, and planning policy contributed most to the uncertainties in the project.

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 the planning and decision process. Therefore, the integrated method has application in other areas of project inception and planning, much wider than in the transport application demonstrated here.

1. Introduction

Transport planning is largely evidence led and driven by long established, well documented, exhaustive processes to fully understand the implications of the proposed measures; their effect on travel demand, and on the transport network (DfT, 2016). Yet some transport projects appear to be discussed for long periods with no progress, or are implemented and fail to meet expectations (Flyvberg et al., 2003). Research by Laird and Venables (2017) finds that the results of Cost Benefit Analysis (CBA) assessment can have little impact on the decision to proceed and Naess (2013) quantifies and verifies that finding in examination of Scandinavian projects.

In 1959, and again in 1979, Lindblom(1979; 1959) described policy and planning in terms of an ecosystem of evolving actions with complex and sometimes unforeseen interactions. Subsequently others, (te Brömmelstroet et al., 2017; Worsley and Mackie, 2015; Glaister, 2006) have commented that transport planning is no longer well supported by a compartmentalised rational analytic process, it is a complex political decision process with multiple stakeholders and with evolving assessment criteria. Indeed the UK Department for Transport has instigated consultation (DfT, 2018) on the evolution of WebTAG (DfT, 2016), the globally accepted guidance and tool for transport assessment. This consultation concerns the introduction of criteria based in social welfare expressed as “people and places” and as “journey experience” extending the assessment beyond the previous more quantifiable measures of journey time and air pollution emissions.

There are many definitions of uncertainty in the transport planning literature and uncertainty is associated with all stages of a project from concept to delivery. The word “uncertainty “is often found to be synonymous with “risk”, specifically financial risk in the project construction stage Flyberg et al. (2003) or the design stage (Alumar et al., 2012). There are examples of large projects with significant cost overruns (Ferguson, 2011; Flyvberg et al., 2003).This level of implementation risk however is well understood in engineering disciplines (May and Haldane, 2011; Jeon and Amekudzi, 2007; Loosemore et al., 2006) with commercially available software and templates to quantify and manage it (Palisade, 2011). Therefore, in this research, a unique approach was designed and used to examine the intangible forms of uncertainty found in the assessment process as the project is conceived, as its viability assessed and as the decision made to proceed to implementation or otherwise.

Focussing on the field of transport planning and policy, various researchers have provided taxonomies and sets of approaches to handle uncertainty. Walker et al. (2003) classify uncertainty on three axes; the first axis is boundaries and completeness which is also described by Van Geenhuizen (2007) as a problem of understanding the structure of the system. The second axis ranges from that which is statistically quantifiable to that which is essentially unquantifiable and described qualitatively using scenarios (Lindgren and Bandhold, 2009; van der Heijden, 1996). The third is a more abstract axis and ranges from uncertainty which can be reduced by research to that which is inherent, unseen and irreducible. Rittel and Webber (1973) describe this latter level of uncertainty as “Wicked” problems, ones with incomplete, contradictory and varying requirements; Khisty (2000) discusses how complex transport planning problems fit into this category.

Much of the research into uncertainty in transport planning has focussed on the modelling and assessment process. Researchers describe general techniques in analysing model sensitivity (Duthie et al., 2010; Saltelli et al., 2008; Rodier, 2007; Cacuci et al., 2005), Refsgaard et al. (2005) examine the same problem of understanding uncertainty in models of water basins. Yang et al. (2013) examine travel demand predictions, specifically focussing on analysing uncertainty in the modelling process and both Wang et al. (2015) and Xiao et al. (2013) examine methods to mitigate uncertainty in specifically transport related applications.

However, as the project concept is formed, as well as in its assessment and subsequent approval, there is a social and a political dimension to decision making which complements the rational evaluation of the project benefits and further contributes to the uncertainty in the project (Vigar, 2017; Wachs, 1985). The DfT consultation (DfT, 2018) concerning the inclusion in transport assessment of more facets concerning social welfare and journey experience complemented by comments on how transport planning is evolving to become more oriented to improving communication and consensus building (Cascetta et al., 2015). When linked with observations of the complexity of the policy and infrastructure ecosystems (Marsden and Reardon, 2017) identify the growing level of uncertainty in the processes that surround rational analysis in assessment of a transport scheme and demonstrate that a methodology that seeks to find the drivers of uncertainty must include the wider system in which the project is positioned.

The primary goal of this research was therefore to devise a method to identify the uncertainty at the concept stage of a transport project; before plans are fully formed and when the questions still revolve around what the project encompasses and what facets of it should be prominent. The secondary goals are to investigate the sensitivity of the method to variation in its control parameters and to observe how uncertainty evolves as the number and combination of stakeholders engaging with the project as it grows.

This paper first reviews the techniques that are used to identify and manage uncertainty in this area. Next it describes how these have been brought together into a single method for this research. The scheme chosen for the study is one with a history of conflicting views in its proposed development. The results of applying the method are presented and further work is undertaken to examine the sensitivity of the conclusions to the parameters used in that analysis. The paper concludes with a review of the method, its applicability, its limitations and how it may be developed in future.

2. Review of Methods used to Identify and Manage Uncertainty

A comprehensive review was carried out to identify methods relevant to this research. These are:

a) Scenario Planning, which is used to describe multiple alternate views of the future to allow planners and managers to design strategies which are robust in different scenarios (Lindgren and Bandhold, 2009; van der Heijden, 1996).

b) Qualitative Analysis Techniques (Packer, 2011) combined with elements of Expert Elicitation (Cooke, 1991) to take the views of several individuals and combine them to a single result.

c) Strategic Models which are used to represent a physical or logical system and hence understand its dynamics (Vester, 2012; Godet, 2011; Gordon and Hayward, 2000; Checkland, 1999).

These are described in more detail below.

2.1 Scenario Planning

Scenario planning is a methodology used to describe one or more possible futures (Lindgren and Bandhold, 2009; van der Heijden, 1996). It uses a behavioural framing approach and van der Heijden describes scenarios as “interesting and enlightening” narratives of the future which link events in a consistent manner to construct a gestalt with which stakeholders, from varied backgrounds, can engage. However, the term “Scenario Planning” has multiple definitions and interpretations in both the literature and in practice. Borjeson (2006) differentiates between scenario planning techniques, classifying them as *Predictive* “What will happen” where the scenario is expressed in parameterised values; *Explorative* “What can happen” where multiple plausible futures are formed; and *Normative* “How to make this happen” where there is significant uncertainty, but a desirable future can be described.

Khisty (2000) when describing how to analyse a *wicked problem* states that these problems are best tackled by using a learning and communication approach to work towards a solution while gaining insight into the problem. Two techniques are identified to achieve this. The first *is a conventional inductive approach* to work forward from the present situation to reach a solution. The second, *an abductive inference approach* is preferred when uncertainty is such that it is impractical to work forward from the present and assumes the project planners have the ability to devise a solution based on backwards inference from an innovative goal which can bring new, previously unconsidered, factors into account.

In this latter approach, the concept of back casting is introduced. Back cast scenarios are described by Dreborg (1996) as a technique to deduce what had to happen to achieve a desired future and to examine the sensitivity of that future to the individually identified events. Examples of this approach are found in Tuominen et al. (2014) who used a pluralistic back cast approach to elicit multiple future scenarios and the pathways to them, then studied the interrelationship between the elements of the paths and in Hojer et al. (2011) who provide a detailed study of the use of back casting in sustainable development.

This research adopts the method of back casting from an innovative future to determine how that solution could be achieved as the core of the approach to identifying uncertainty in the sequence of events from the initial project concept to its completion

2.2 Cross-Impact Model

To quantify the uncertainty in the early stages of the transport planning process, a model is required. Models used in transport planning range from detailed microsimulation of individual vehicles (Barcelo, 2010) and agent based activity models of individual travellers (Miller and Salvini, 2002) through models of aggregated flows (Ortuzar and Willumsen, 2011) to system dynamics models set in the principles of system design (Checkland, 1999). Shepherd (2014) describes system dynamics models in detail with 54 examples of their use in transport related areas with a focus on soft changes and policy, and concludes that they have applications exploring the nature of a problem, and understanding its dynamic properties but should not be used for detailed analysis or precise forecasts.

Work by Gordon and Hayward (2000), Godet (2011) and Vester (2012) takes system dynamics models to a much more abstract level, studying the structure of the system rather than modelling the activity in the system. Their cross-impact model takes the variables that come into play to drive the system to a greater or lesser extent and examines the causal inter-relationships between them. These relationships are then used to establish which variables are “active” (or “influential” in Godet’s terminology) and which are “passive” (or “dependent”). The primary output to aid analysis is a plot of influence versus dependency as shown in the diagram taken from Vester (2012) in Figure 1.

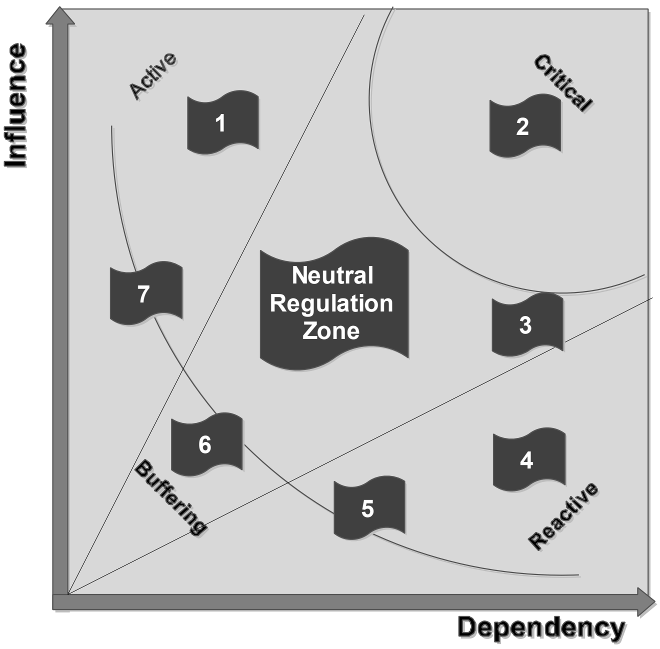

Figure 1 Cross-Impact Analysis adopted from Vester (2012)

In both Godet’s (2011) and Vester’s (2012) descriptions of the cross-impact matrix method, the analysis shows which of the variables in the system contribute to the instability of the system. In Vester’s (2012) diagram (Figure 1) 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 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 variables which regulate the system.

Gordon and Hayward's (2000) motivation was to develop a method that gave assurance that all influences in a Delphi exercise (Linstone and Turoff, 2002) had been accounted for and to model likely outcomes. Vester (2012) developed the methodology to use the cross-impact matrix to understand the system interrelationships rather than to understand the actual outcome and Godet (2011) developed it further by using both direct and indirect links between variables. Cole (2006) provides a review of the method and examples of its use in analysis of sustainability projects suggesting that with some further developments, it could yield valuable results.

All three versions of the cross-impact analysis method have the same assumptions and problems, namely that a comprehensive set of variables and causalities that describe the system can be found, and that the views of the multiple stakeholders in the system are included. The innovation in the method developed in this research, is that the opinions of the multiple stakeholders were held separately and systematically combined to form the overall view revealing the different beliefs that individuals have about the system and the inherent tensions within the decision process are identified.

2.3 Qualitative Analysis and Elicitation

The data used in the cross-impact method is derived from interviews conducted with stakeholders who have an interest in the scheme under study. Packer (2011) and Silverman (2006) discuss the qualitative research interview process in depth. Packer in particular is critical of the controlled interview with prescribed one-sided dialog and an emphasis on quantification, arguing that a qualitative interview should be based in conversation, albeit a conversation with a structure. Zimmerman et al. (2011) (2012) examined 15 back cast studies looking at the methods for scenario development where stakeholders were involved in either the development of the vision, the assessment of the vision, or both. The key problems identified were the lack of engagement of all participants if the exercise is conducted by a set of small working groups resulting in the *bandwagon*[1] effect or the *halo*[2] effect that is often seen in focus groups.

However, Zimmerman et al. (2011) found that , by using a set of semi structured interviews based around a back cast scenario they were able to maintain diversity of opinion from multiple stakeholders and elicit a broad view of the route to achieve the goal described in the scenario. Similarly, Scolobig and Lilliestam (2016) in reviewing stakeholder engagement methodologies in environmental decision making comment on the difficulties in representing the heterogeneity of stakeholders' perspectives when dealing with their value based issues, and ensuring all views are represented, rather than those of the dominant stakeholders.

In the research reported in this paper, a similar approach to that described by Zimmerman et al. (2011) was adopted using a normative back cast scenario in structured interviews with individual stakeholders and hence avoiding the issues identified with focus groups. The interviewees were each provided with the normative back cast scenario in which the realisation of the project was described including the route by which it was achieved. The goal of the interviews was to elicit the causality between the steps of the project from conception to completion through open ended conversations with multiple stakeholders and to query alternative outcomes for the project or alternative routes. This one-to-one approach to the interviews was intended to increase engagement and to avoid the pitfalls of focus groups.

2.4 Linked Techniques

The techniques reviewed above do not exist in isolation. Cascetta et al. (2015) formed 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. 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

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[1] In the bandwagon effect participants follow the group opinion and minority opinions are lost.

[2] In the halo effect a charismatic group member will lead and their minority opinion will dominate.

strategy within each scenario, and Usher and Strachan (2013) derived very similar diagrams while eliciting values of quantifiable variables. Tuominen et al. (2014) report a project which integrated a backcasting scenario approach with qualitative analysis methods applied to a Delphi exercise as well as multiple scenarios to examine the impact of the choice of policy packages and produce "*informed estimates on the direction and magnitude of the impacts"* using a table of synergies and conflicts. Usher and Strachan (2013) used an expert elicitation technique (Cooke, 2013; O'Hagan, 2011; Gossens and Cooke, 2008) to quantify estimates of key variables in climate change policy and in doing so also drew small causal diagrams to describe influences on the elicited measures, albeit with no further analysis of those diagrams.

These projects demonstrate benefits in integrating scenario planning techniques with analysis of the scenario narrative and serve as a guide for the research reported here which develops an integrated method specifically designed to identify uncertainty in a project at an early stage. The method described by Robinson (1990) forms the closest guide to the method proposed in this study; though the Robinson study is more analytical in evaluating the effect of multiple scenarios and using an impact analysis to identify the driving factors and less focussed on identifying the drivers of uncertainty which is the goal of the research reported in this paper.

3. Integrated Methodology to Identify Uncertainty

The scope of the method described here was to analyse the causes of uncertainty in the inception stages of a project, and in the assessment and decision process. 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 Rittel and Weber's definition of a "wicked problem", one which defies rational analysis (Rittel and Webber, 1973).

The strategy to develop the method to identify uncertainty had three steps:

- First, identify an appropriate type of model: This was the cross-impact matrix method (Vester, 2012; Godet, 2011; Gordon, 1968) which is designed for strategic analysis with a goal of determining which variables contribute most to uncertainty. This choice then determined the data requirements; a set of variables to describe the system and the influence matrix between them.
- Second, gather the data: The method was based on individual discussions with stakeholders about a back cast scenario followed by analysis of these interviews using qualitative analysis tools to identify the variables in the system and their causality relationships.
- Third, analyse the system: The variable and causalities were analysed and the robustness of the results investigated with sensitivity analysis.

While previous research has generally dealt with one of the individual steps of scenario planning, elicitation, qualitative analysis, and the cross-impact matrix method; the methodology developed here brought all components together to identify the drivers of uncertainty in a proposed transport development. The integrated method is shown conceptually in Figure 2 which provides an overview of the steps.

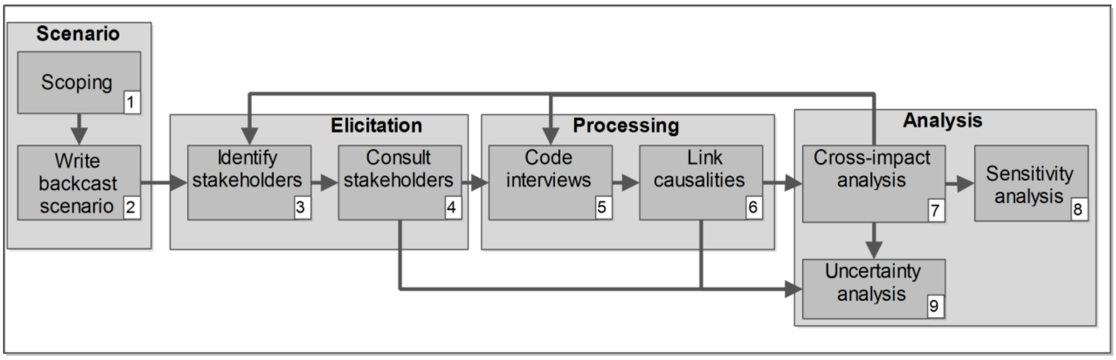

Figure 2 Method Overview

The method starts with a description of the problem to be studied, this is one which appears to be experiencing delays and difficulties in the decision process. In this research, a case study was identified through examination of Local Transport Plans in the North East of England to identify a suitable candidate.

The stages involved in the methodology were:

(1) The problem was scoped to derive an initial premise and the subject boundaries. These were used to prepare the briefing notes for the normative back cast scenario.

(2) An initial set of stakeholders who had an interest in the project, and a similar view of an ideal future were identified and consulted to prepare the scenario. These stakeholders were asked to describe an ideal view of that future and how it may be realised. 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.

(3) The set of stakeholders who would form the major part of the elicitation task were identified. These stakeholders were taken from the transport and planning communities of the area covering the case study using a targeted selection based sampling method. An alternate method of using social media or email groups to gather a self-selected group of respondents was rejected because the methodology employed here relied on open-ended interviews to explore the uncertainty in the case study. Using a closed set of questions for a larger group, or imposing a requirement to form a detailed response to a complex scenario, without offering the interviewer the opportunity to probe causality, would reduce the depth of inquiry available. The depth of inquiry achieved here is one of the strengths of this research.

(4) Open ended, one-to one interviews were conducted and recorded with this set of stakeholders to elicit their view of the scenario. The interviewer probed the causality between events described in the scenario or introduced by the interviewee.

(5) The recorded interviews were studied in depth to extract the noun and verb phrases that were the key elements and actions identified in the interviews (Miles et al., 2014; Packer, 2011; Silverman, 2006). These were coded as variables using the NVivo software (QSR,

2014). Variables were added as required and as the interviews progressed, the system was regarded as approaching completeness when no new variables were required (Packer, 2011).

(6) The causality between variables was coded separately for each stakeholder. This stage was unique in that it extended existing cross-impact matrix model by including the capability to hold the causality links for each stakeholder independently and subsequently combining them in investigative analysis of the causes of uncertainty.

(7) The cross-impact matrix method analysis was run to produce the Influence-Dependency graph. Coding of the interview transcripts and notes was reviewed to ensure consistency and the stakeholder recruitment was reviewed to ensure a representative sample of experts had been consulted. Variables were rationalised using both cluster analysis, where the similarity was measured through the number of common links, and text analysis, to identify those that represented similar concepts, and were merged if required.

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

(9) Uncertainty analysis, based on the Influence-Dependency graph from the cross-impact matrix analysis, was undertaken augmented with the notes from stakeholder interviews. The links between variables were 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 1.

There are two feedback paths in the methodology. First, after initial assessment of the results, the coding of variables was reviewed to ensure the coding exercise had captured the concepts expressed by the stakeholders consistently. Second, the selection of stakeholders was reviewed to ensure that no bias had been introduced towards any particular set of views and that a representative selection of interests was represented.

There are also two data paths identified, see Figure 2, in which the results of the cross-impact matrix method analysis are related back to the stakeholder interviews and the causality links. The output of the methodology is not restricted to the classification of variables by their status as shown in Figure 1, it is also the knowledge of how variables attain that status and which opinions from which group of stakeholders are most relevant to that status. Project owners would then be able to use these results through further engagement with interested parties to devise actions to address those uncertainties and mitigate those issues proving deleterious to the project progress.

3.1 Algorithms for Multi Stakeholder Cross- Impact Matrix Method

Bespoke software was written to implement a multiple stakeholder cross-impact matrix analysis. The basic requirements for the software were that it holds (a) a set of variables which represent the key elements and actions in the system being studied, (b) a set of stakeholders and,(c) for each stakeholder individually, a set of links which express causality between two variables. The software implements Godet's version of the cross-impact matrix method (Godet, 2011) which takes into account indirect causality where if *a* influences *b* and *b* influences *c*, then there is a causality link implied between *a* and *c.* This method is extended to progressively decrease the weight of a link with increasing depth of causality and also to infer the strength of a link from the number of stakeholders referring to it.

The software derives the Influence-Dependency graph for different combinations of stakeholders and can vary the depth of the causality link chains and the weighting of those links at increasing depths. It also computes measures of the stability for each configuration and makes comparisons between configurations.

Therefore the influence *I* and dependency *D* for each variable with indirect linking is:

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

$$s_{d,i,j}(k,l) = linked_d(o,k,l), o \in O \tag{2}$$

$$s_{d,i,j}(k,l) = \left(\sum_{o \in O} linked_d(o,k,l)\right)^p \tag{3}$$

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 (2) if *any* of the stakeholders *o* in the set *O* makes a link between variables *k,l* as intermediaries between variables *i,j* where $linked_d(o,k,l)$ is 0 or 1 if the link is present, or it is defined as in equation (3) the sum of the number of stakeholders making the same link between *k,l* raised to the power *p*:

The weight function is parameterised using λ as a depth weight parameter as:

$$w(d) = e^{-\lambda d} \tag{4}$$

Figure 3 illustrates the derivation of the $s_{d,l,j}()$ terms for the influence between variables *i* and *j* for the different steps on the chain *i,k,l,j.*

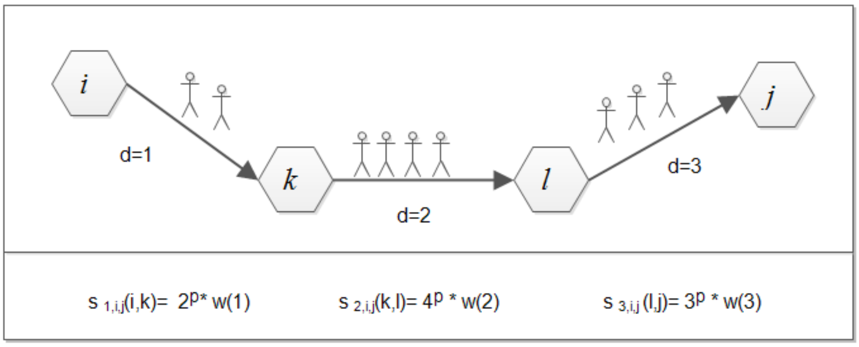

Figure 3 Summation Components

The output of the analysis software is an Influence-Dependency plot as described by Vester (2012) created from a selection of the views from combinations of stakeholders and with parameters to control depth of influence, weighting of depth, and the summation mode for the multiple stakeholders. A further output is obtained by summing the total causality passing through each link as it participates in multiple chains, for example if, in Figure 3, there was a chain between two other variables *m* and *n*,*m,k,l,n*, then the causality measure for the link *k,l* would be the sum of the causality in both chains.

4. The Leamside Line Case Study

The UK Transport Act 2000 requires each Local Transport Authority (LTA) to write, and update, a Local Transport Plan (LTP) to describe its transport strategy every five years (DfT, 2009). These LTPs for 2011 were analysed for the North East of England Region to identify differences in strategy, evaluation, and priority in the four adjacent LTAs (Northumberland County Council, 2011; Stockton on Tees Borough Council, 2011; Tyne and Wear Integrated Travel Authority, 2011; Durham CC, 2010). One transport initiative that was identified in three of the four LTPs and showed significant variation in the approach of each LTA was the potential re-opening of the Leamside Line, a disused rail line between Newcastle and Durham (Figure 4).

Figure 4 Leamside Line

The Leamside Line was opened in 1839 and superseded in 1872 by what now is the East Coast Main Line (ECML), the last passenger train ran in 1964 and the last coal freight train in 1991. Since that date, the line has deteriorated through theft and lack of maintenance although it still has the status of a railway having not been de-listed.

In the last ten years, as well as the comments in the LTPs, there have been several reports which assess the benefits of re-opening the Leamside Line (AECom, 2010; Network Rail, 2010; ATOC, 2009; AECom, 2007; Network Rail, 2007; AECom, 2006). The LTAs promote re-opening the line but cannot make a clear case for it. The Association of Train Operating Companies (ATOC, 2009) can justify it based on what appears to be smaller level of passenger traffic generation than the LTAs while the Rail Capacity Review (Network Rail, 2010) makes a case based on opening the line primarily for freight only. All propose very different uses for the same physical transport asset with significant differences in their justification for it. ATOC (2009) claim it ranks 10th out of the 35 schemes reviewed in England in justification for rail re-opening, while a consultant's report (AECom, 2006) states that it is the least cost effective option to provide better transport links in the North East.

The Leamside Line therefore presents a multi-faceted set of uncertainties including the economic environment, the mode of operation, the collaboration of multiple LTAs each with a different vision for the line, and the prediction of the type and volume of its use when constructed. Therefore, the Leamside Line lends itself as an appropriate case study.

4.1 Backcast Scenario: The Leamside Line in 2035

The normative scenario was the core of the elicitation exercise. It was written to describe a desirable outcome for the chosen case study and used to elicit opinions on the pathway to achieving that outcome. The scenario was developed through interviews with four stakeholders, each with knowledge of the Leamside Line or with an interest in sustainable transport in the North East of England. Generally, all stakeholders had a favourable opinion towards re-opening the line. The writing style for the scenario was an informal narrative, with vignettes to illustrate examples of trip behaviour and rail operation. The goal was to be able to use the scenario in a one hour interview with the second set of stakeholders to provoke discussion about the route to the desired outcome, the decisions that would need to be made, the conditions that would have to exist and the influences these conditions and decisions would have.

The scenario posited that in 20 years, the Leamside Line would be re-opened to local rail traffic and integrated with existing local public transport and lightweight freight as well as the national freight network. A sustainable small town aligned with the Leamside Line and anchored on the existing village of Fencehouses would also be developed. The main drivers for development were described in the scenario as congestion relief on local roads, alleviation of a rail bottleneck on the ECML, and sustainable urban development. In addition, the scenario included an assumption that there had been changes in the criteria and methods for transport assessment, recognising some shortcomings in existing methods. The three vignettes embedded in the scenario illustrated the use of the Leamside Line giving the point of view of a family living in Fencehouses, the issues facing the local Rail Manager, and the operation of an innovative lightweight local freight system.

As this research was co-located with the Self Conserving Urban Environment (SECURE) project (Bell, 2013), quantitative questions based in the elicitation methods described by Cooke (2013) and O'Hagan (2011), and illustrated in a database of 45 example studies (Gossens and Cooke, 2008) were appended to the scenario. The questions, in this case, concerned the size of Fencehouses, the initial ridership of the Leamside line and its potential growth, the year of “peak car” in the study area and the mode of operation of the line (freight, passenger or both). While these quantities were potentially of use to the SECURE (Bell, 2013) project; here, the goal was to use these questions to further discuss causality; as demonstrated in an elicitation exercise undertaken by Usher and Strachan (Usher and Strachan, 2013).

4.2 Stakeholder Elicitation Exercise

The goal of the elicitation exercise was to first identify those “variables” which control or are controlled in the decision process, and second the causality relationships between those variables. 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 range and depth of the stakeholder expertise required to cover local knowledge of planning and planning policy as well as expert knowledge in public transport provision and sustainability . 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 cohort of stakeholders was 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. Initially, eight interviews were conducted and after peer review at a SECURE project (Bell, 2013) internal conference, three more were identified to improve the stakeholder coverage of the scenario, specifically this added the views of transport users and transport activists. In total eleven individuals were interviewed with a wide range of experience and perspective. They included:

- Local urban planners, service providers, and transport planners
- Sustainable transport political activists
- Local authority sustainability officers
- Senior consultants in transport, accessibility, and policy strategy.

Interviews lasted between 1 to 2 hours during which time, notes were taken and causal diagram snippets drawn. The interviews were also recorded using a smartphone app. The interview notes and recordings were systematically analysed and coded to identify the elements and actions.

A set of 99 variables emerged from the interviews, classified by their functional group. After the initial coding exercise, a clustering exercise was undertaken based on the commonality of links between variables (where variables with similar sets of links were adjacent in the cluster) and variables also were examined by the research team for common concepts. As an example of this review, two variables "*Political Ambition and Foresight"* and "*Strong Political Driver*" both referred to the leadership required to instigate and carry out a transport project. The former was used to refer to institutional leadership, the latter to the need for a specific project champion, but the comments made by the stakeholders were similar and their causality links placed them close together in the cluster analysis. Therefore these two variables were merged to one "*Political Action Initiated*" variable. Post review, 68 variables remained to describe the Leamside Line project.

Links between variables were formed by searching the transcripts for link words and phrases between adjacent variables. It was not possible to imply causality from simple adjacency, instead a linking phrase had to be present. Typical examples include: "disconnected highway network" ***because*** "of the historical industrial development" and "not located on good *[public transport]* nodes and links" ***therefore*** "they use private cars". Similarly links were identified in the causal diagram snippets in the interviewer's notes using the lines drawn between each variable with verification from the interview recording where required.

In some cases, the causality may be agreed as plausible by several interviewees but can be refuted and lead to different causality by another. For example: When talking about the financial prosperity of Fencehouses, the scenario posits that as residents lived and worked locally, then low transport costs would mean they would have higher disposable income as transport fares were not incurred. Several interviewees agreed but did not go further, another interviewee argued that this was not the case, and instead it was the passenger service that helped create wealth and that saving disposable income through less travel was not the reason for increased prosperity. It was this case, and others that reinforced the decision to use a cross-impact analysis method as the debate over the true causality and contradictory opinions from different stakeholders, did not need to be resolved which would be a requirement if a systems dynamics model had been used. This problem is illustrated by research into the causality between economic development and transport development by Maparu and Mazumder (2017) with the conclusion that the relationship was complex, context dependent, and causality was not firmly determined to be in one direction or the other.

5. Results

This section first comments on the sensitivity of the method to the parameters used in the cross-impact analysis. It then reviews the results of the analysis, commenting on the drivers of uncertainty in the system and on the contributions made by variables in the functional sub groups.

5.1 Sensitivity Analysis of the Cross Impact Matrix Method

The primary goals of the analysis of the project presented in this paper were to identify the elements of the scenario that contribute most to the instability of the process by which it may be realised and to understand how the system depends on the combined opinions of the stakeholders. However, before these two goals could be realised, there was a prior need to study the sensitivity of the system to the parameters that aggregate and weight the views on the causality between variables. This analysis was conducted on a “One at A Time”(OAT) basis (Saltelli et al., 2008) as the goal was to understand how individual parameters control the results and not to seek any optimisation or calibration.

5.1.1 Measures

Measures of instability were developed to evaluate the uncertainty in the analysis. First a measure of the uncertainty driver value for each variable was derived corresponding to its position in the Influence-Dependency graph where values in the upper right quadrant score highly in the uncertainty measure.

Cole (2006) used the product of the influence and dependency $MS_i=I_i*D_i$ (Multiple Score) to determine if the variable is active (i.e. in the upper right quadrant) or passive in the lower left. Based on Vester’s (2012) classification of variables two further indices were developed. The City Block metric $CB_i=(I_i+D_i)/2$, the sum of the influence and dependency where a variable at (1,1) will have the maximum instability, and the Inverse Distance metric ID_i shown in equation 5, measuring the distance of variable *i* from the (1,1) maximum instability point, normalised to lie between 0 - 1 then inverted to match the same ordering as the Multiplier Score and the City Block metric.

$$ID_i = 1 - \sqrt{\frac{1}{2}\left((1-I_i)^2 + (1-D_i)^2\right)} \quad (5)$$

5.1.2 Sensitivity Analysis

The effect of the parameters used to combine the opinions of the stakeholders, the depth of links in the analysis, and the weighting by depth was analysed.

The reaction of the system to changes in how variables were weighted by the number of stakeholders was investigated, this is controlled by variable *p* in Equation 3. In Vester's (2012), and Godet's (2011) methodology, where there is only one composite stakeholder, the only mode available is that a link is either set or not set. Godet however does use a "weak, medium, strong" classification with weight values 1, 2, 3 respectively. Analysis showed that while there were changes in the ordering of variables ranked by their influence as *p* was varied, the set of the most influential variables was consistent. The primary effect was to increase their differentiation by influence, bringing the most influential variables up to zones 1 and 2 and depressing the majority to zones 4, 5, 6 and little significant difference was found when the selection of the group of the most influential and dependent variables is made as this is based on the order, not on their absolute values. There is little in previous work to guide the selection of a summation mode as previous work did not consider multiple stakeholders and the closest approximation to current practice is to mirror Godet's (2011) "weak, medium, strong" classification with values 1,2,3 respectively which, in this project with 11 stakeholders, is approximated with a value of p=0.5.

The measures of stability and the variation between the system and a reference set were evaluated for values of the weight, 1≤w ≤9 and depth 1≤d≤9, shown in Figure 5.

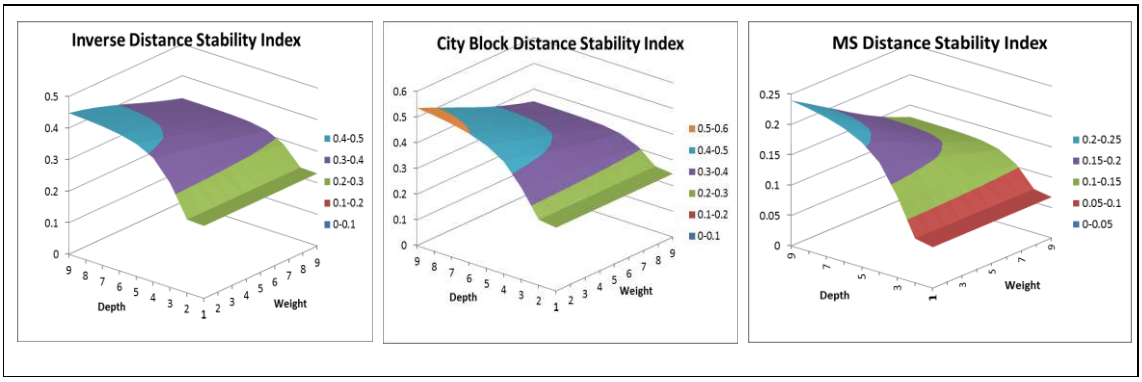

Figure 5 Stability Measures

Analysis of the stability measures showed that as depth increases and as the weight of the deeper connections increase, then instability also increases. This rate of increase slows above depth=5 apart from at low weight values (Note that low weight parameters give higher values to links at greater depth). All measures exhibit a similar shape with instability being constant at all weight values with depth = 1 and all showing rising instability with increasing depth and weight. Above weight = 5, and depth =5 the instability measures do not change significantly. This concurs with Godet's (2011) empirical observation that a depth of 4 to 5 is adequate but Godet provides no analytical evidence to support this claim. Therefore subsequent analysis was based on depth=5 and weight=5.

5.2 Influence-Dependency Analysis

The Influence-dependency analysis for all 11 stakeholders was conducted. The resulting Influence-Dependency graph emerging from the analysis of the interviews is shown in Figure 6 with the graph for each category of variables shown in Figure 7.

Table 1 then gives the list of variables, their category and the number of stakeholders mentioning each variable.

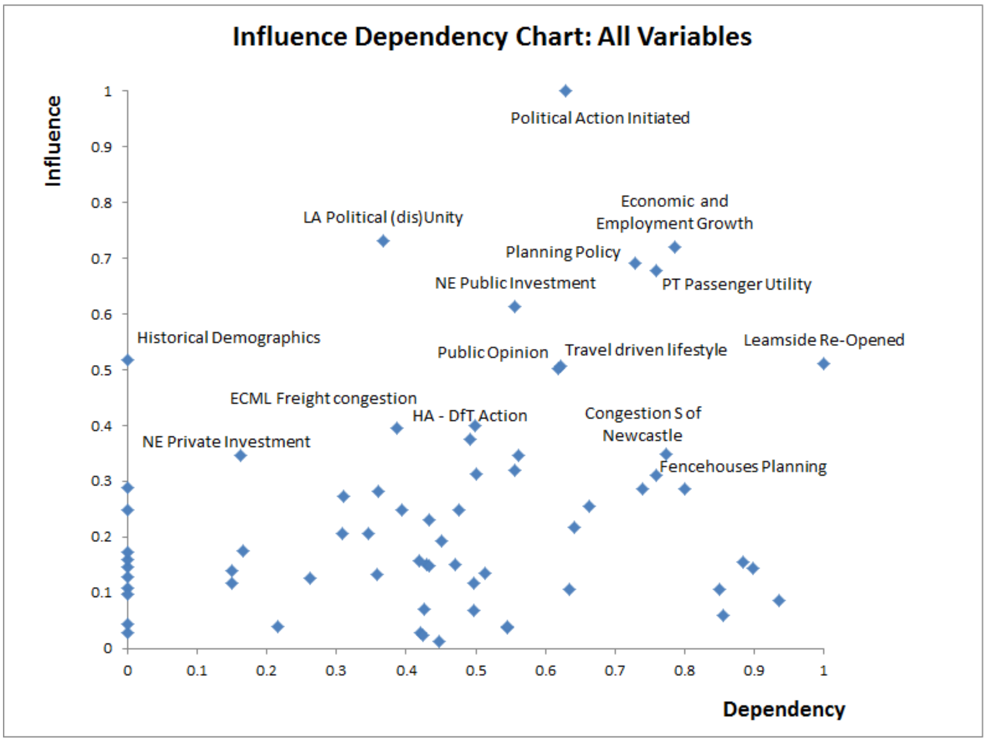

Figure 6 Influence Dependency Plot

Figure 7 Influence Dependency by Variable Class

The primary factors driving the uncertainty in the process of the Leamside Line planning are to be found in the “Politics” and the “Economics and Demographics” categories. A selection of the observations from the analysis is presented here:

Politics: This category holds the two most influential variables; the “*Local Authority Political (Dis)unity*” and the “*Political Action Initiated*” variables. The need for leadership identified in the latter variable was not evident in the normative scenario, but yet was found to be the most influential factor in driving the project to re-open the Leamside Line. In parallel as the research reported here progressed, political developments in the UK 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. Similarly, addressing the problem of lack of co-ordination between local transport authorities, supra-regional transport bodies have formed to integrate local transport authorities i.e. the West Midlands Combined Authority (WMCA, 2017). These initiatives by Government bode well for schemes such as the Leamside. However, while there was a proposal for a Combined Authority in the area covered by the case study, it was abandoned in 2016 (BBC, 2016) and at present, there is no Mayoral post covering the wider North East of England area. In effect, the findings in this research concerning the Leamside Line case study can be shown to be addressed in other areas, but remains unaddressed in the Local Authority areas involved in the Leamside Line.

Economy and Demographics: This category holds the variables most responsible for instability in the system as well as some of the least influential and least dependent. For example, the “Historical Demographics” variable has no dependencies, which is to be expected as it is established and unchangeable. The role of the “*Economic and Employment Growth*” variable is however found to be a significant uncertainty surrounding the Leamside Line project. Spending on national infrastructure during times of recession to promote economic growth is however one of the fundamental tenets of Keynesian economics (Keynes, 1936) but the view from the stakeholders was that the Leamside Line would not be funded until economic recovery was underway and the politics of austerity 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). 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.

Fencehouses: The Fencehouses variables are all of low influence with medium to high dependency. This indicates that development of Fencehouses would be dependent on the re-opening of the Leamside Line, but 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 on the local freight use proposed in the scenario but the local freight use does depend on the Leamside Line. The “*Political Action Initiated*” variable is however dependent on the “*ECML Freight Congestion*” variable and this could be regarded as one of the triggers to find leadership for the Leamside Line initiative.

Public Transport: The public transport nodes show similar behaviour with one exception. The "*Public Transport Passenger Utility*" variable, which encapsulates the passenger experience and principally influences "*Public Transport Ridership*". This in turn has many dependencies, which places it into the "instability" zone.

Road Transport: The key variable in the road transport nodes category is the "*Action of the DfT and H.E.".* This analysis places the DfT and Highways Emgland in the zone that Vester (2012) refers to as the "control" zone where 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 endorses that role in the view of the stakeholders.

Leamside Line: The Leamside Line nodes are also primarily in the lower quartile of influence and spread across the range of dependency. The two most influential nodes in this category are the "*Rail Planning Timescale*" and the "*Leamside Line Re-opened*" variable. The former has no outside influences, it is controlled by rigid, nationally set, planning cycles. The latter is the most dependent variable and also densely connected which is to be expected it is the target action of the project.

Sustainability: The sustainability nodes are low in influence. Sustainability is however influenced by *"Public Opinion*", revealing a chain where public pressure to move towards a sustainable transport network influences both planning policy and the gatekeepers of transport planning policy, but this is not a major influence on policy. The low emphasis of sustainability emerging in this analysis exposes a discrepancy between the factors deemed to be important by this cohort of stakeholders (which included a sustainability professional and a sustainability activist) and the factors held to be important in common understanding of contemporary transport scheme development priorities as noted in Peng et al. (2017) in describing a methodology for designing sustainable rail corridors which would merit further investigation in post analysis review workshops .

5.3 Stakeholder Analysis

A systematic exploratory analysis was conducted to understand the stability of the system with regards to the number of stakeholders included in the decision process. The analysis was conducted for all selections of "*N from M*" for values of N from 1 to 11, M=11. The results, for the ID measure of instability are illustrated in Figure 8 where in separate graphs the spread of the instability measure, the mean and the range versus the number of stakeholders (N) is shown. The other instability measures show a similar pattern and are therefore not reproduced here.

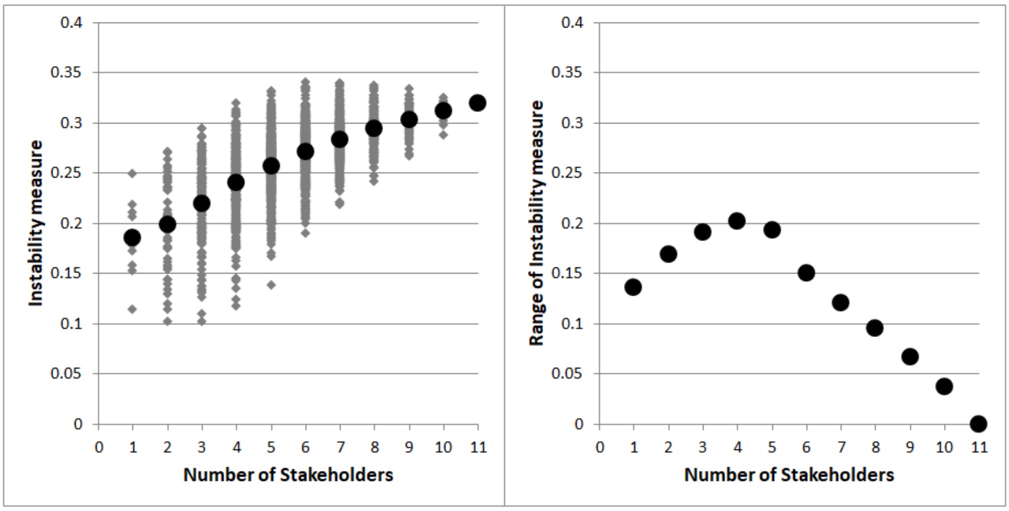

Figure 8 Stability Measures

The first observation from the shape of the graph is that in general, instability increases with the number of stakeholders indicating that each individual in isolation tends to understand the system as being relatively more stable than they do when their view of it is complicated by the opinions of others. However, with small numbers of stakeholders (2 to 4), there are cases where the system becomes more stable as stakeholders are combined and a lower stability measure results. Further examination shows this occurs when similar opinions are combined, such as planners with similar job descriptions from different administrations. The converse occurs when disparate stakeholders are included with the consultants contributing most to the increase in instability with small numbers of stakeholders. This could be attributed to the fact that their links tended not to be role specific and hence contrast with the more role oriented links from other stakeholders. The spread of the stability measure systematically decreases as more stakeholders are included beyond 4 stakeholders. Whether this value is an absolute value a relative value (as a fraction of M=11) or specific to the selection of stakeholders in this case study can only be resolved after more case studies have been undertaken. However, this result suggests that even with a relatively few (less than 10) stakeholders consistency in the results is shown to emerge.

6. Conclusions

The method described here merges scenario planning techniques, qualitative analysis and the cross-impact matrix method to identify the drivers of uncertainty surrounding a nascent transport development project. These drivers were identified to be the effects of politics, leadership, policy and economic environment, which should not come as a surprise to any observer of transport projects. This reinforces findings by Vigar (2017) that political influence and the need to act on the wider stage is a significant factor in project success. It also in agreement with a comment by 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".* Further credibility is also given to the findings in this case study concerning leadership and the cohesive actions of local authorities by the actions in other parts of the UK to elect Mayors with executive powers and to create supra-regional transport authorities (WMCA, 2017; Stevens, 2006; UK Parliament, 2000).

The most important contribution made by this research is that the factors leading to these uncertainties can be identified and hence offer project stakeholders the opportunity to reduce the criticality of those variables. The method is robust to the parameters and stability measures used in the analysis and the conclusions that emerge are similar under changing values of these parameters. However, this method is not a suitable technique for project assessment, it is not intended to quantify project related metrics such as time, cost, and distance, and it is not intended to provide the basis of the decision as to whether or not a transport development should proceed. It must also be recognised that the selection of stakeholders in the elicitation exercise can have a significant impact on the analysis. In the case study described here, the stakeholders are primarily "experts", with knowledge of the case study project or of the issues it addresses. Wider consultation at the elicitation stage with a more widely drawn cohort of stakeholders from different democratic groups, or at a subsequent project dissemination stage, with an audience who share different sets of values and beliefs about the project would be valuable to validate the findings for this case study.

The value of this approach is in its ability to shed light on the reasons why a project has difficulty to progress past the inception stage. By identifying the influences which drive the uncertainty in the project, a project owner may be placed in a better position to act, in conjunction with stakeholders, to rationalise those influences and in doing so, take mitigation action facilitating the project to proceed.

6.1 Recommendations

Further developments of the method in the opinions of the authors would focus on tighter integration between its analytical components. Commercial software was used to code the interview notes and recordings (QSR, 2014) and extract the variables while custom software was written to undertake the cross-impact matrix analysis. Charting an audit trail from input (the notes of the interviews) to output (the Influence Dependency graph) is consequently a manual task with time consuming stages which could be reduced by further technical integration, now that the principal has been investigated and demonstrated.

A further development could be to use the outputs of the analysis in a workshop environment to present the findings and to dynamically experiment with reinforcing or breaking links to understand the relevance of each facet of the system and to generate a set of actions; such as, in this example, reducing the parochial relationships between Local Authorities, to then realise the project.

6.2 Reflection

In the context of the test case, the Leamside Line, the method provided key findings which are highly plausible but more importantly reveal the source of the project blocks. The authors are unaware of other methods systematically able to achieve these goals.

Finally, it is sometimes said of transport models that a good model is one that principally confirms what is already known, but may be unstated, but then also provides new insights. On that measure, application of the method to the Leamside Line project shows it is a good model.

7. Funding

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Table 1 List of Variables by Category

Economy and Demographics			
Ageing Population	2	Economic and Employment Growth	10
Employment in of large urban areas	5	Historical Demographics	8
Travel driven lifestyle	6	Reluctance to mode shift	2
Knowledge Economy	4	Rising population	4
Heritage & Tourism	1	Urban Agglomeration	8
Commute Inertia	3		
Politics			
NE Private Investment	7	Electioneering	3
HA - DfT Action	4	NE Public Investment	10
Public Opinion	8	UK Funding	5
Council favours Leamside for freight	1	Bias to road spend	3
Planning Policy	11	LA Political (dis)Unity	11
Electric Vehicle Policy	7	Social Inclusion	3
Political Action Initiation	11		
Road Travel			
Car and Van Use	11	Road Network Connectivity	6
Road travel utility	2	Congestion S of Newcastle	8
Car Availability	8	Cost of road travel	8
Freight			
ECML Freight congestion	9	Local rail based freight network	11
Leamside Freight	9	Location of regional freight centre	3
Type of freight on Leamside	4	Local Freight Requirements	6
Public Transport			
PT Passenger Utility	11	Durham as city hub	3
ECML Passenger utility	4	Gateshead rail interchange	1
Metro Capacity	2	NE Travel Card	3
PT Network capacity	3	PT Co Competition	4
PT Running costs (Subsidy)	7	PT Integration	8
PT Route Profitabilty	2	PT Investment	10
PT Regulation	6	NE PT Ridership	10
Leamside Line			
Leamside business case	10	Leamside Mode Priority	6
Leamside engineering	4	Leamside priority in funding	3
Leamside ridership	9	Leamside Rail integration	10
Rail Planning Timescale	5	Leamside Re-Opened	11
Leamside Passenger Utility	4		
Sustainability			
Benefit in sustainability	5	Sustainable emphasis of Fencehouses	4
Walk Cycle Provision	2	Environmental Cost	3
Fencehouses			
Fencehouses Planning	9	Fencehouses is built	9
Fencehouses Prosperity	5		

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