A Systems-Based Approach to the Identification of User/Infrastructure Interdependencies as a Precursor to Identifying Opportunities to Improve Infrastructure Project Value/Cost Ratios

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Introduction

The United Kingdom's (UK's) infrastructure is in need of significant investment[1], which might benefit from the opportunities afforded by interdependencies between the various infrastructure systems, although such interdependencies also bring risks. The UK Government has recognised the potential to encourage private investment through improvements in infrastructure project value/cost ratios[1]. In spite of these opportunities, it remains difficult for investors to be sure of an adequate return on their investment, or that they will capture their fair share of the value their investment helped to generate. New business models are required to help overcome these problems.

The *iBUILD* research consortium, with funding from the UK Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC), is studying the development of new infrastructure business models to support local infrastructure delivery[1]. It is pursuing three research themes: the business of interdependence; re-thinking infrastructure value; and, issues of scale in local delivery. These are being brought together in a number of integrative case studies that have been co-created with commercial and public project partners.

The new business models must take account not only of infrastructure-centred interdependencies (interdependencies between infrastructures themselves), but also user-centred interdependencies (interdependencies between users and the infrastructures that support them). This paper describes *iBUILD*'s development of a methodology for modelling the interdependencies between users and infrastructure as a necessary precursor to identifying opportunities to improve infrastructure project value/cost ratios. The methodology is based on model-based systems engineering (MBSE) techniques and involves: identifying the suite of policy, strategy and operational documents relating to the activity-of-interest; eliciting system data from the documents and integrating it using CORE 9, a powerful system modelling tool produced by Vitech Corporation, to create an activity system model; and, finally, generating N^2 diagrams from the model to identify the interdependencies.

Infrastructure Interdependence

Infrastructure interdependence is the term commonly used to refer to both dependencies and interdependencies between infrastructures. This is a somewhat limited viewpoint, because it fails to acknowledge that infrastructure is not an end in itself, but is created to facilitate the activities that generate value for civilised society. The 'real' value of infrastructure arises from the various uses to which it is put.

A new viewpoint therefore, is required: one that identifies the interdependencies between infrastructure and the value that users generate with it – in short, a 'user-centred' viewpoint. From

1. HM Treasury, 2011, 'National Infrastructure Plan 2011', Her Majesty's Treasury and Infrastructure UK, PU1208, The Stationery Office, London, United Kingdom.

this viewpoint it will be easier to see how any given infrastructure contributes to user value generation, and easier to allocate, and hence capture, that value for the relevant infrastructure, thus resulting in improvements to the value/cost ratio.

'Broadband for the Rural North' (B4RN): an Example of 'User-Centred' Infrastructure

The UK Government is rolling out 'Next Generation Broadband' (NGB), but current infrastructure-centred business models do not support installation in remote, rural areas.

To overcome this problem, a community company (B4RN) has been established to undertake the supply, installation and operation of a full fibre network, starting with eight rural parishes in the north-west of England[2]. It uses a novel business model to improve value/cost ratios. Cost reduction is achieved by: laying optical fibre cables across land owned by members of the co-operative, rather than in the public highway; members carrying out much of the installation work themselves; and, members who invest in the scheme receiving tax relief through the Government's Enterprise Investment Scheme. Value capture comes from members having access to the benefits arising from access to online services. It is difficult to make an objective assessment of monetary value for some of the services, such as access to a variety of news and entertainment services, but that does not matter because people are very good at making 'fuzzy' assessments of value, which they convert into a willingness to make a monetary payment for access. B4RN is, therefore, an example of the benefit that can come from adopting a user-centred viewpoint.

Identifying Interdependencies: A Model-Based Systems Engineering Approach

The interfaces between users and the infrastructures they use are often complex, which makes it difficult to identify user/infrastructure interdependencies. Creating models of user-centred systems can help overcome this problem. However, current methods of interdependence modelling rely on the input of domain experts, with the risk of subjective and variable outputs. *iBUILD* is exploring the feasibility of using a model-based systems engineering (MBSE) methodology, developed on an earlier EPSRC-funded project[3], to create objective and repeatable models of existing user/infrastructure systems.

MBSE is defined as the "formalised application of modelling to support (system development)"[4] – it joins modelling with systems engineering techniques to create an integrated view of the system of interest[5]. Within MBSE, *iBUILD* is using a so-called 'middle-out' approach to create models of existing user-centred systems, which requires: clear definition of the system boundary; elicitation of system data, ideally from an objective source; and integration of those data to create the model.

The *iBUILD* modelling methodology defines the boundary of the system of interest in terms of the suite of related policy, strategy and operational/procedural documents, identified using the repeatable search method shown indicatively in the diagram of Figure 1. The process starts with high-level policy documents and works down through increasing levels of detail to user operating processes and procedures. The National Infrastructure Plan 2013[6], which was used as the starting point (referred to as 'key policy' document in Figure 1), makes reference to a number of documents,

2. Forde, B., 2013, 'Broadband for the Rural North Limited: Business Plan v5.2', Broadband for the Rural North Limited, Lancaster, United Kingdom.
3. Bouch, C., Roberts, C., 2013, 'Developing System Models to Help Great Britain's Railways Embrace Innovative Technologies with Confidence', Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transport, Volume 227, Number 6, p. 677-684, Sage Publications, London, United Kingdom.
4. INCOSE, 2007, 'Systems Engineering Vision 2020', INCOSE-TP-2004-004-02 version/revision 2.03, INCOSE, San Diego, CA, USA.
5. Long, D., Scott, Z., 2011, 'A Primer for Model-Based Systems Engineering', 2nd Edition, pp 14, Vitech Corporation, Blacksburg, VA, USA

shown in the diagram as second level references; those documents in turn have references (third level references), and so on to produce an expanding tree diagram. The diagram does not, however, branch indefinitely: some documents start to repeat (shown grey), some do not have any references (shown blue) and some are deemed not relevant to the system of interest (shown red). The process continues until the circle at the end of every branch is grey, blue or red. The documents signified by the green circles then form the suite of documents for the system.

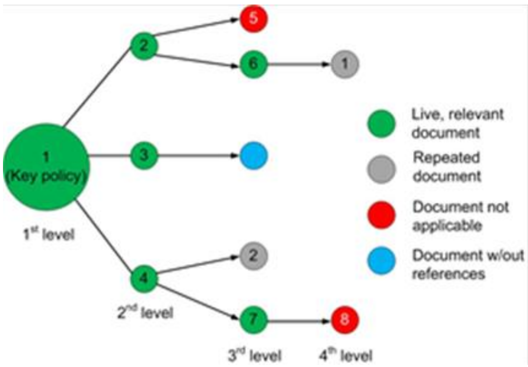

Figure 1: Indicative Diagram of the Document Search Method

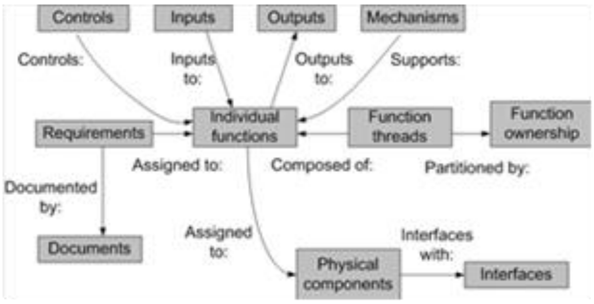

Figure 2: Indicative Diagram of an Entity-Attribute-Relationship Database Schema

Data integration and model creation is achieved using CORE 9[7]. Essentially, CORE 9 is an entity/relationship/attribute database, where the system entities (functions, components, data items, etc.), together with their attributes, are linked together by relationships. System data elicitation involves reading through the documents identified by the search method and picking out the entities that taken together describe a system. The entities include: requirements, which describe what the system should do; functions, which describe what the system does; components, which are the physical parts of the system; and items, which include flows of information between functions and components. A high-level outline of the CORE 9 schema is shown in Figure 2.

Example of User/Infrastructure System Model: Hypothetical Port

Work is currently underway to develop user/infrastructure system models using the methodology described above. Two iterations of the document search process, with the National Infrastructure Plan 2013[6] as the key policy document, have identified 107 relevant reference documents. System data are being elicited from these and integrated using CORE 9, but work has not yet advanced to the stage where a complete model has been developed. In the light of this, a hypothetical, outline model for a maritime port system has been created to illustrate how models will be able to assist with identification of user/infrastructure interdependencies.

The diagram in Figure 3 shows an assumed set of high level functions describing the operation of the port. The functions are shown on the diagonal running from top left to bottom right. All other boxes on the diagram show events (event boxes) that trigger the functions: for example, in the top left, arrival of the train triggers the function ‘Port unload train’. The event boxes also indicate interdependencies between the port and its supporting infrastructure: for example, the train arrival event indicates that there is an interdependence between the port and the railway system. Similarly, the ‘berth booking’ and ‘berth confirmation’ events indicate interdependencies between the port and the ICT system. These are, perhaps, obvious examples, which could be identified

6. HM Treasury, 2013, ‘National Infrastructure Plan 2013’, PU1576, Her Majesty’s Treasury, London, United Kingdom.
7. Vitech, 2012, ‘CORE® Delivers Project Success Through Integrated Modelling’, http://www.vitechcorp.com/products/core.shtml, accessed 29th August 2012.

without the help of a model; however, as the model is developed to greater levels of detail and complexity, it will help to identify interdependencies that might otherwise have remained hidden.

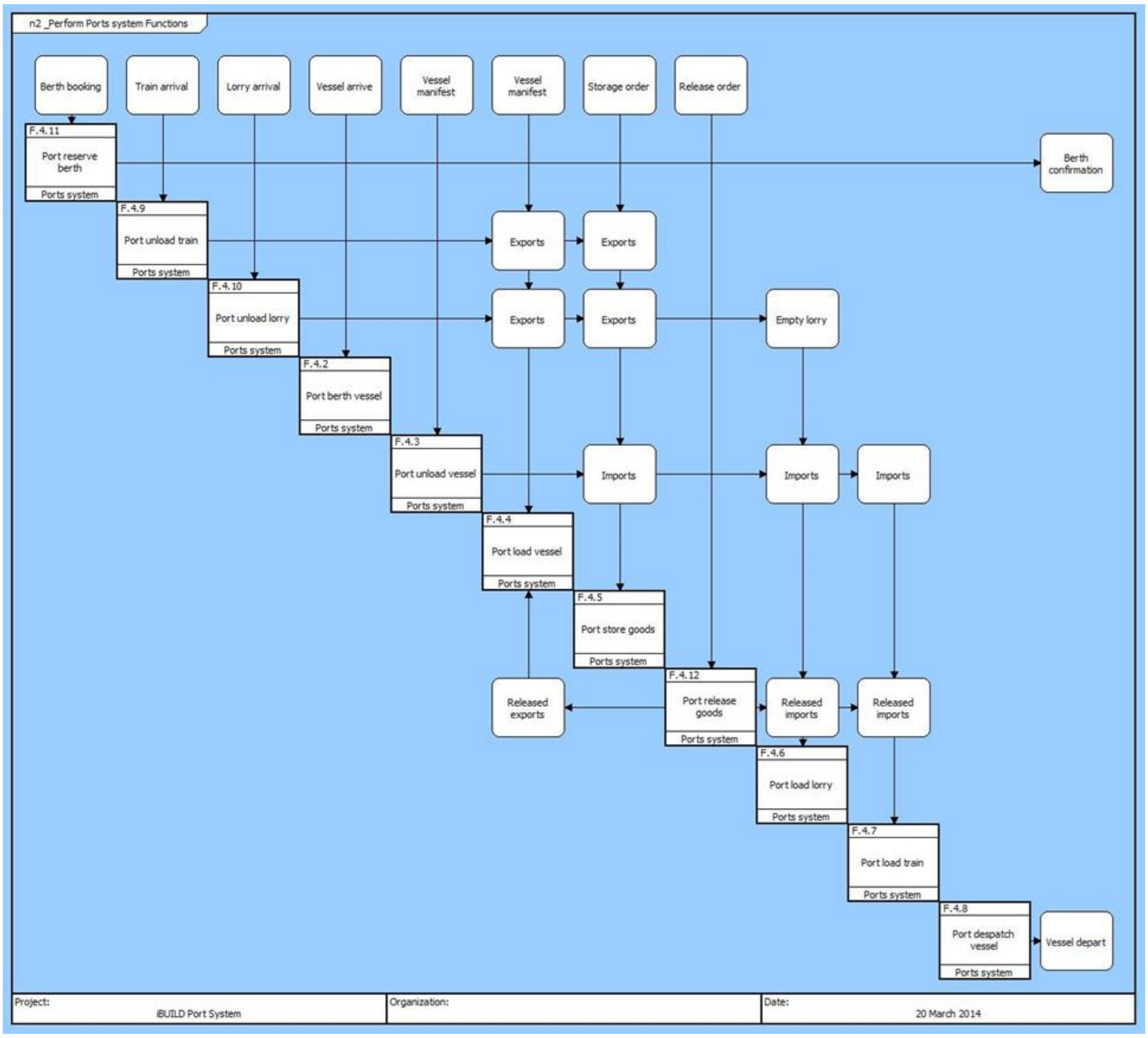

Figure 3: N^2 Diagram for a Hypothetical Port with Principal Functions and Related Interdependencies

Conclusions

This paper shows in outline that model-based systems engineering can be used to identify interdependencies between users and their supporting infrastructure. It suggests a repeatable method for identifying the suite of documents describing the system of interest. Moreover, it shows how objective data elicited from the documents can be integrated using CORE 9 to create a system model. The N^2 diagram derived from the model can help to identify the interdependencies.

Work is underway to develop further the model-based systems engineering approach and prove its efficacy. A current *iBUILD* case study concerns local business opportunities deriving from the arrival of the new high-speed train line (HS2) into Birmingham – business functions define (broadly-interpreted) infrastructure needs, hence opportunities to create and capture additional (again broadly-interpreted) value from their interdependencies, both now and into the far future, and thus propose novel business models that will deliver local and regional infrastructure to the greatest benefit to all. This is thus an ‘enabler’ in the complex, multiply-conflicting future city agendas.