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INFORMATION FLOWS IN HIGHWAY PROJECT DELIVERY

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Transport infrastructure projects involve many stakeholders sharing information across organisational and temporal boundaries. The growing use of Building Information Modelling requires closer alignment of processes for the creation, distribution and validation of project information across stakeholders, but this topic has had little scrutiny in the linear infrastructure sector and is poorly understood by clients or major suppliers. The aspiration of this paper is to understand the information flows from project inception to handover and surface some of the challenges in developing common or complementary protocols. This paper presents the results of a qualitative interpretivist study into the delivery of highway projects. Following 11 semi-structured interviews with members of different parts of the supply chain and the collation of published and unpublished project and corporate documentation which have been transcribed and coded, a conceptual IDEF0 model of the information flows associated with projects is presented. The outputs of this research highlight the challenges facing project teams in implementing information management practices and the paper and document based information exchange which pervades through standards, contracts, deliverables and quality management.

Keywords: information management, Building Information Modelling, organizational analysis

INTRODUCTION

The UK Government is pushing for innovation across the construction supply chain by requiring Building Information Modelling (BIM) Level 2 adoption on all its projects. BIM, as defined by the UK Government, requires asset owners to adopt a lifecycle approach to the creation, management and exchange of project and asset information, mandating that suppliers meet the requirements laid out in a suite of standards sponsored by the BIM Task Group.

There is emerging industrial and academic research into how BIM concepts can theoretically be applied to highway projects (Mawlana *et al*., 2015; e.g. Sibert 2013), but the slow and inconsistent rate of adoption within the sector shows that there is a misalignment between the BIM Utopia described by BIM Evangelists and the pragmatism required by practitioners who operate under tight time and budgetary constraints (Miettinen and Paavola 2014). If BIM is going to have the impact that

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people desire of it, the technologies and processes underpinning BIM will need to align to the real world challenge of delivering projects (Arayici *et al*., 2009; Sackey *et al*., 2014). This is particularly the case during the adoption phase where new and old processes will be operating simultaneously within teams.

Like any information system (IS) intervention, BIM will require an element of process re-engineering (Alfred 2011) to unlock its maximum benefits. An early activity of process change is to map the current process (Kettinger *et al*., 1997) in order to develop the requirements for the change. IDEF0 has been proposed as a suitable modelling language for conceptually modelling IS requirements (Lee *et al*., 2007) as it presents a functional view of the system without the detail of specific data structures, organisational structures or temporal issues (Giaglis 2001).

APPROACH

In conducting this research we used a systems approach, which involved examining guidance documentation and formal requirements from clients, designers and contractors, conducting interviews with stakeholders from various organisation types and carrying out ethnographic-type reflections by the lead researcher being embedded in a project information management team over a 42 month period. We use this multi-method approach for data collection to understand what the formally defined processes are and to test how these are actually implemented in practice.

When we refer to "Highways" in this paper we refer to major roads (Motorways and A-roads), those which are designed to the Design Manual for Roads and Bridges (DMRB). Such roads are characterised by high volumes of traffic, mixed use of freight, commuter and distance travel, have few junctions or crossings and will typically have a speed limit of 50 mph (80 km/h) or higher (Walsh *et al*., 2011). There are approximately 50,000 km of such major roads in the UK (O'Flaherty and Hughes 2016). By "project" we refer to capital investment and major projects, where expenditure can run into tens or hundreds of millions of pounds sterling. We bound the research area to the UK as these projects operate under the same regulatory frameworks and so comparisons can be drawn across organisations. As the BIM mandate falls onto Highways England, the owner and operator of England's strategic road network, we focus on its processes. Highways England's standards are generally also applied on local authority schemes, though often with some adaptation.

Thus this research aims to contribute to understanding of the effective application of BIM for Highways projects, which is to identify what information is required to be managed, who creates what, who the recipients are and how the process is currently undertaken. Through this research, we do not intend to make any value judgements on productivity or efficiency or how things could be improved, but instead to describe real world processes undertaken by practitioners. This represents a key gap in the information management literature, particularly in infrastructure delivery, where the thrust of research on the implementation of BIM is aimed at keeping pace with the theoretical and proof of technology concepts, rather than understanding the particular mechanisms of the phenomenon under study. Throughout this research we look at highways projects as socio-technical systems. Projects involve people working in cross-organisational teams, socially constructed through contracts, branding and organisational business processes. The engineering process is highly dependent on information, material and mechanical technologies to design and construct the outputs of projects.

METHODS

The opportunity to conduct this research arose from a practitioner-researcher approach in which the lead researcher has been seconded into design and client organisations over a 42 month period. Throughout the period the researcher has taken an active role in projects and has collected field notes and relevant documentation for later analysis. These were supplemented by conducting semi- and un-structured interviews with key project stakeholders. Such qualitative methods allow a much richer understanding of the phenomenon under study (Harty 2008) and the semi-structured interview gives the interviewed the opportunity to explore in more detail, challenge statements and get under the skin of the issue (Easterby-Smith *et al* ., 2008). The interviews would each last approximately 60-90 minutes and the subject was asked to describe his or her job role in detail, sometimes this would relate to a specific project so that the descriptions were more tangible. The interviewer would then focus on the processes for specific parts. Data collection followed a grounded theory approach, collecting evidence across different data until the entire process was captured and validated.

Altogether, the research findings are based on three sources of data:

> Published and unpublished materials from client, designer and contractor groups
> 11 semi-structured interviews with practitioners, which were transcribed:
> 1 x project director
> 3 x designer
> 5 x contractor
> 1 x client project manager
> 1 x lawyer
> Observations and reflections by the lead researcher being embedded within project teams.

The interview transcripts and documentation were coded using a cloud-based Computer Aided Qualitative Data Analysis Software, dedoose.com, as a process to identify the factors involved in delivering highways projects and to highlight the information flows between different functions. No predetermined coding schema was used, as an inductive exercise, the aim was to develop a grounded model (Easterby-Smith *et al*., 2008, 175) whereby functions were identified and the interfaces between them were highlighted. Having a practitioner-research approach gave the analysis a richer semantic understanding to the underlying assumptions and meanings of statements.

This was developed into a narrative which discussed the various aspects of the process under study. Modelling using IDEF0 was used as an interpretive tool to provide a conceptual description of the narrative. Systems modelling, using diagrams with a known syntax and notation, provides an alternative means of describing a system than prose (Kassem *et al*., 2011). By displaying the characteristics of a system in this structured way stakeholders are better able to learn about and understand the topic under study and make more informed decisions about system and process change (Blockley and Godfrey 2000).

In order to model the information flows we are using Integration Definition for Function Modelling (IDEF0). IDEF0 is a systems engineering modelling notation which "is used to show data flow, system control, and the functional flow of life cycle processes." (US Department of Defense Systems Management College 2001, 51). By

modelling the functions and flows it is possible to develop a conceptual model describing the information flows in project delivery. An advantage of IDEF0 is that the flows do not necessarily denote chronological continuity or sequence in the processes, which means that functions can be iterative, concurrent or temporally separated. Similarly it does not assign a role or a specific means. This is complements the varied procurement and commercial arrangements of highways projects which could range from in house delivery, a full Design Build Finance Operate contract, or separate contracts let for each project stage.

This follows Yung *et al.*, (2014) who used IDEF0 to model the process for MEP coordination with other designers' outputs through BIM and Kim and Jang (2002) who used IDEF0 to model the re-engineering the process television manufacture.

IDEF0 modelling

An IDEF0 model presents a top-down diagram where systems are defined in terms of functions. Within each function information is either created, consumed or modified.
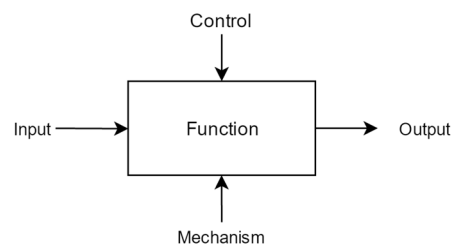
Each function is symbolised by a box and then the Inputs, Controls, Outputs and Mechanisms (ICOM) are denoted by labelled arrows (see Figure 1). Inputs and

Figure 1: IDEF0 Syntax

outputs can link functions to represent flow. Each function can then be divided into sub functions and a new diagram produced to display a higher granularity.

For this exercise we are producing the highest level diagram, the "top level context diagram", which gives an overview of the high level and most important flows in the system. In this way we can identify the relationships between lifecycle phases, each of which fulfil a separate function, with the other functions on which the project depends. Based on a further qualitative analysis, using the narrative as the data for this stage, we have identified the following top level functions; Ongoing Asset Management, Scheme/Project Assurance, Survey, Scheme Identification, Design, Construction Planning, Construction, Handover, Supplier Management, Departures from Standards, External Stakeholder Management.

For each function we reviewed the narrative to identify the inputs, outputs, controls and mechanisms which relate to the function. Then using a diagramming software we started to build the diagram. First we drew each function separately and then started connecting the outputs of one with the inputs to the recipient functions. The inputs and outputs include a range of information types ranging from a go/no-go decision to a defined deliverable in the form of a report or drawing.

Results of the modelling exercise are shown in Figure 2, for presentation purposes we have condensed the final model. The following sections discuss the various elements of the model that the researchers feel pertinent by following the structure of the ICOM syntax.

Flows (inputs and outputs)

In order to interpret the model and understand what the flows represent, two key concepts should be understood.
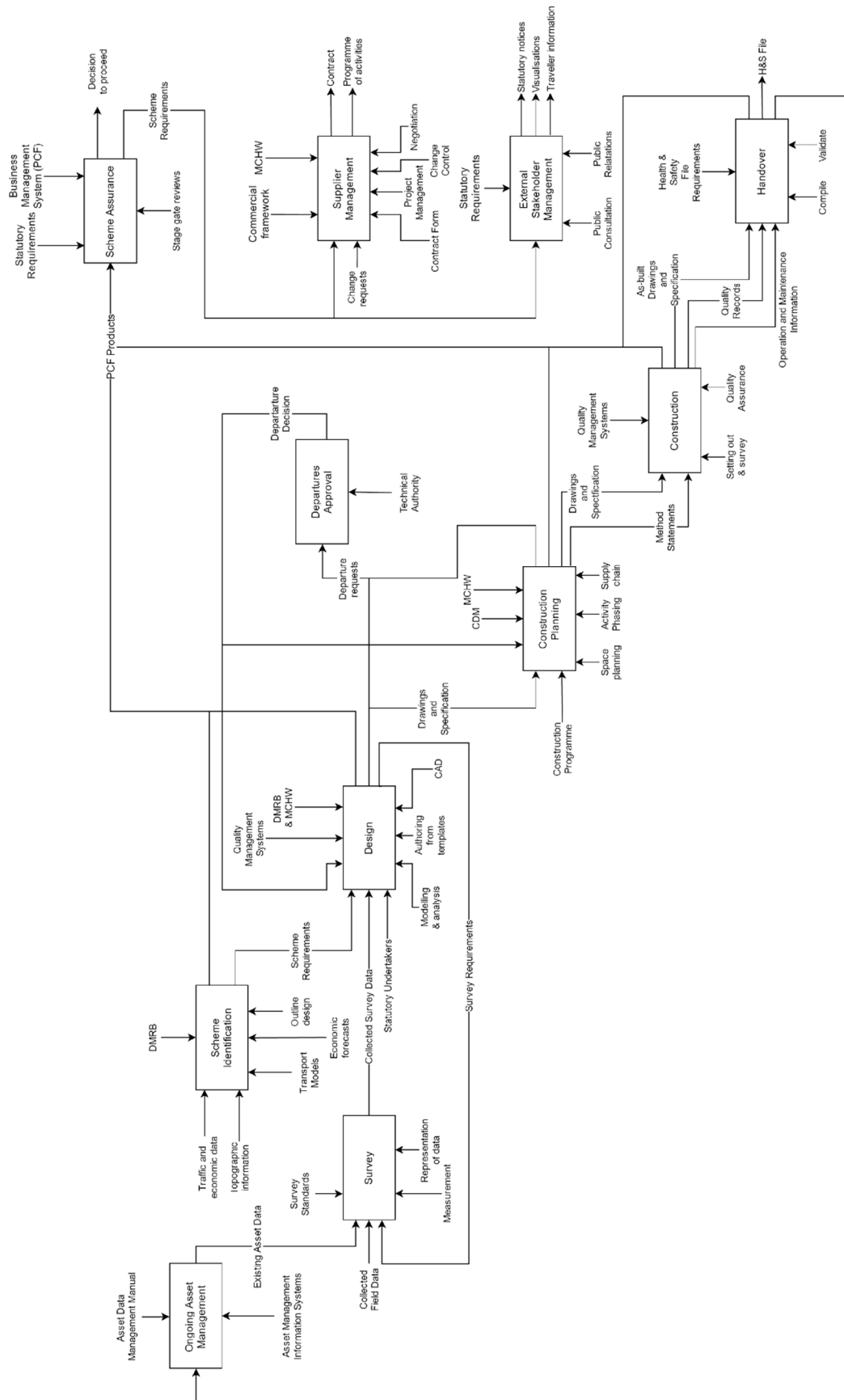
Figure 2: Context IDEF0 Model showing information flows across the highways project

- *Boundary Objects*

Boundary objects form the basis of collaboration in highway project delivery. The term "boundary object" was coined by Star and Greismann in (1989) and refers to documents and information artefacts which are transferred across functional or organisational boundaries as the basis of knowledge coordination (Whyte and Lobo 2010).

When we model the information flow we are modelling the transference of a boundary object to another function. We are not modelling the flow of materials or resources, the boundary object contains the information relating to those things. For instance a road scheme might require the placing of a man-hole. The man-hole and its associated activities exist in the real world, however not in the information system.

Data and documentation will inform the worker where to place it, what its specification will be and any method statements. The outputs are an as-built record and quality reports (Figure 3).

Such objects may be specific to an asset or activity, or be a report on a range of activities undertaken. For instance, Highways England's core deliverables (known as PCF products after the Project Control Framework project lifecycle) are created for the purpose of review, validation, approval and cross phase knowledge sharing. These are typically in the form of report, spreadsheet or drawing. Which may be shared in the native format, but are often converted to a stable PDF format so that it becomes a static record of the deliverable.
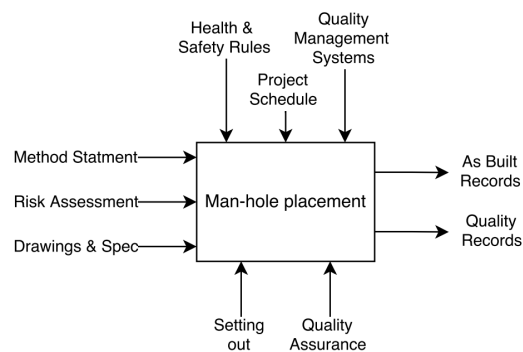
Figure 3: Example function demonstrating boundary objects

- *Document Management*

Document Management, though not represented in the model, is fundamental to how the flows are facilitated. We see in our data that a mix of formal and informal methods are used to share documentation and deliverables, both electronically and via paper. Procurement portals are common for supplier management prior to contract award and then the processes to be deployed during the project are agreed through negotiation.

BS 1192 (British Standards Institution 2007) is a core requirement of BIM Level 2, but and highways practitioners are struggling to accommodate it in their processes through deploying cross-organisational Electronic Document Management Systems (EDMS). However, at present, the multitude and haphazard deployment of these systems cause almost as much confusion as the problem they are supposed to solve.

The emergence of tablet and mobile computing has made electronic documentation more attractive, because they can be brought into the field and used for data collection as well as document display. It is good practice for suppliers to keep an archive of all project information for at least as long as the warranty stated in the contract, especially records relating to the quality management, sometimes referred to as an audit trail, of the activities undertaken and information produced. If there are incidents which require the project to enter arbitration or litigation, this archive provides the bulk of evidence.

Functions

The model broadly groups the functions into four categories.

- *Ongoing network and asset management*

Interview subjects were all keenly aware that a highway project is only part of the asset lifecycle. Few highway projects are building a road on green-field, many are, instead, major modification of an existing road and in all cases a project will connect with the existing network. The notion of "taking possession" of a road during projects and then handing back to the asset operator and maintainer, often also an outsourced role, was often articulated. The transfer of the as-built information to the operator is through the Health and Safety file, which should contain all information to support the safe operation of the asset.

- *Existing condition data*

The conceptual design (part of option selection), detailed design and construction planning all rely heavily on gathering data about the world and structuring it to support decision making. The first port of call is to look at data which is already available from the operator's asset management systems, topographic and mapping suppliers such as Ordnance Survey and the British Geological Survey and to look to economic data to model traffic growth. Once a corridor and site boundary has been identified further investigative and measured surveys can be undertaken.

Such surveys can are expensive, placing workers in potentially unsafe environments and causing inconvenience to road users, therefore they are only undertaken when absolutely required. A lack of robust survey and existing conditions data requires engineers to make assumptions through interpolation or referring to experience. Many argue that much survey work, aside from that to assess condition and deterioration, could be avoided if sufficient record keeping from previous interventions had been maintained.

- *Project Lifecycle*

Similar to all engineering environments, highway projects follow a lifecycle which includes stage-gate reviews and governance. Highways England's project lifecycle is defined through the Project Control Framework (PCF), which has eight stages: Strategy, Shaping and Prioritisation, Option Identification, Option Selection, Preliminary Design, Statutory Procedures and Powers, Construction Preparation, Construction, Commissioning and Handover, Closeout. There is a second version of the PCF, called the Single-Option PCF, which is for projects which will not have an option selection phase. The Single-Option PCF includes stages 0, 3, 5, 6 and 7.

At the end of each stage the supplier is required to produce a number of deliverables, documenting the activities undertaken. These deliverables are then used during stage gate reviews for assurance and as the basis for activity in the next stage. At Highways England deliverables are called PCF Products, at each stage there are up to 129 products in 23 categories, each could contain one or many documents. Local authorities operate a similar set of stage gates, but are not as prescriptive as to the information deliverables for each stage. We have, therefore, taken an abstraction of the PCF to group the activities as described through the functions they fulfil. These functions follow a diagonal spine through the model and relate to the technical delivery of projects.

- *Project Management and Assurance*

Aside from the technical delivery of projects there are a number of functions which run concurrently supporting the technical assurance and smooth running of the project. These include operating a stage review process, stakeholder management, giving permission to depart from standards, managing supply chains and project schedules.

These functions are often, though not always, undertaken by the client. For instance, contractors will often employ the designer to validate that what has been built meets the design, demonstrating that the work has been done to ensure the project will meet its objectives.

The information flowing through these functions are generally reports on activities, instructions and contractually related documentation.

Controls and Mechanisms

- *Standards*

The highways sector is beholden to standards, they provide the generic requirements of all highway project delivery and are relied up extensively by all stakeholders. The Design Manual for Roads and Bridges (DMRB) and Management Contracts for Highways Works (MCHW) are developed by Highways England and used extensively on local authority schemes. Both the DMRB and MCHW also signpost a great many other standards to which designs, processes and products must conform.

The DMRB, effectively, provides the template to which the ideal highway will be designed. Text contained within a black box is mandatory and must be followed. All other text is advice and guidance. There are a number of circumstances where it is acceptable not to conform to mandatory requirements, such as geometric constraints, economy, or conflicting requirements. In this case the project will need to seek permission for a Departure from Standard from the client's technical authority.

- *Contracts and specifications*

Typically all but the highest levels of project management and assurance are outsourced for the delivery of highway projects. The management of suppliers is through the use of contracts, which detail the work that the supplier will carry out, the requirements for quality and processes and the payment terms. Sub-contracts will typically mirror the main contract, apportioning packages to lower tiers of the supply chain. It is very rare that there are no changes to the contract after it has been signed. Any changes or negotiations must follow a strict change control process, which includes storing correspondence such as emails, meeting minutes and change notices. This is sometimes handled by an EDMS.

DISCUSSION

Highway projects principally deal concurrently with two types of information. Technical information relating to the configuration and implementation of the project and management information supporting technical assurance and stakeholder management. At current this is predominantly a paper based system (albeit functioning electronically), which is engrained through templates and requirements of standards, frameworks and contracts. There are attempts to automate and formalise document management through EDMS, but the research showed that this has yet to become engrained.

The role of standards cannot be understated. Project participants are accustomed to navigating great quantities of technical requirements, and much of the engineer's job is

to signpost the relevant clause, rather than design from first principles. Departures from standard are common and are the principle technical information flow between the client and supplier in between project stage gates. Interview subjects often raised the importance of getting a high quality existing condition survey early. Such information supports the design and planning of many aspects of projects.

CONCLUSION

In this paper, following qualitative analysis, we have described the information flows in prose and through the development of an IDEF0 model. The research came from the need to understand the current uses and flows of information on projects and, in future work, compare this to the requirements of BIM Level 2. Many argue that BIM Level 2 requires process re-engineering (Arayici *et al*., 2011; Mom *et al*., 2014; Sebastian 2011). The first stage of re-engineering is to understand how the system is currently configured, which is the contribution this paper makes.

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