COPING WITH PROJECT UNCERTAINTY IN CONSTRUCTION SUPPLY CHAINS

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Uncertainties affecting supply chain operations are recognised as significant obstacles to achieving value for customers. One strategy for coping with uncertainty is to build flexibility into the supply chain, but this has rarely been discussed in the context of construction. Two key research questions are considered: ‘what are the sources of supply chain uncertainty in construction supply chains?’ and ‘what types of flexibilities are required to mitigate these uncertainties?' These uncertainties are investigated via a case study of a main contractor including three projects and nine suppliers. A generic list of uncertainties is developed and grouped according to different sources of supply chain uncertainty. Flexibility types are then mapped onto these uncertainties to highlight which types of flexibility are needed to respond to different uncertainties.

Keywords: flexibility, risk, supply chain management, uncertainty.

INTRODUCTION

Uncertainties affecting supply chain operations are recognised as significant obstacles to achieving value for customers. As a result, researchers in the field of operations management and supply chain management have examined sources and types of supply chain uncertainty and strategies to cope with such uncertainties (Childerhouse and Towill, 2004; Mason-Jones and Towill, 1998; Prater *et al.*, 2001; van der Vorst and Beulens, 2002; Wilding, 1998), but this has rarely been discussed in the context of construction.

One strategy for coping with uncertainty is to build flexibility into the supply chain. Flexibility is generally perceived as an adaptive response to environmental uncertainty (Gerwin, 1993). More specifically, it is a reflection of the ability of a system to change or react with little penalty in time, effort, cost or performance (Upton, 1994). The link between uncertainty and flexibility is well established, with many researchers outlining the importance of flexibility in coping with uncertainty (Prater *et al.*, 2001; Tang and Tomlin, 2008). Flexibility has been researched in a number of different areas relating to operations management including manufacturing flexibility (Slack, 2005; Upton, 1994), supply chain flexibility (Vickery *et al.*, 1999) and transport flexibility (Rodrigues *et al.*, 2008).

Two key research questions are considered: ‘what are the sources of project uncertainty in construction supply chains?’ and ‘which flexibility types are required to mitigate these uncertainties?' The paper is structured as follows. In the next section a literature review focusing on supply chain uncertainty and project uncertainty and risk

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Gosling, J. and Naim, M.M. (2009) Coping with project uncertainty in construction supply chains. *In:* Dainty, A. (Ed) *Procs 25th Annual ARCOM Conference,* 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, 813-22.

is presented. Next a description of the method adopted is offered. A classification for the different flexibility types required for project uncertainty is then developed from the literature. The empirical findings of the case research are then presented and analysed. This is followed by a conclusion.

LITERATURE REVIEW

Davis (1993) suggest that the underlying problem when managing complex networks is "the uncertainty that plagues them". Understanding the sources of supply chain uncertainty and managing these uncertainties is clearly of interest to researchers and practitioners alike. A useful definition of supply chain uncertainty is offered by van der Vorst and Beulens (2002): supply chain uncertainty refers to "decision making situations in the supply chain in which the decision maker does not know definitely what to decide as he is indistinct about the objectives; lacks information about its environment or the supply chain; lacks information processing capacity; is unable to accurately predict the impact of possible control actions on supply chain behaviour; or, lacks effective control actions".

Uncertainty and risk are very often confused or used interchangeably. Raftery (1994) proposes a continuum with risks on one extreme, quantifiable, data driven and open to statistical testing, and uncertainties at the other, based on subjective probability and informed opinion. This is supported by Rodrigues *et al.* (2008) who argue that risk is a function of outcome and probability and hence it is something that can be estimated; uncertainty, on the other hand, occurs when decision makers cannot estimate the outcome of an event or the probability of its occurrence. The two concepts are clearly closely related and intertwined. Uncertainty increases risk and risk is a consequence of uncertainty.

Mason-Jones and Towill (1998), building on Davis (1993), developed the uncertainty circle model to conceptualise the different sources of uncertainty that affect supply chain performance. The uncertainty circle classifies supply chain uncertainty into four general types: process, supply, demand and control. Process uncertainty affects internal abilities to meet a target. Supply uncertainty results from poorly performing suppliers handicapping value adding processes. Demand uncertainty is associated with specific customers in relation to schedule variability and transparency of information flow. It also refers to the difference between the end marketplace demand and orders placed by customers. Control uncertainty affects the ability to transform customer orders into targets and supplier raw material requests. It has subsequently been refined and applied in a number of different ways (Rodrigues *et al.*, 2008) and, therefore, it is considered as a suitable basis for use in this paper and a convenient way to categorise the disturbances encountered in construction projects.

Project heterogeneity and the resulting uncertainty or risk is well documented. Differences such as location and the amount of projects within an overall programme and the amount of technological uncertainty have been described in the literature. (Evaristo and van Fenema, 1999) A considerable amount of published material relating to project risk analysis and assessment is available (Ackermann *et al.*, 2007; Mustafa and Al-Bahar, 1991). Risk management has also been a popular area for researchers (Al-Bahar and Crandall, 1990; Conroy and Soltan, 1998). Much of the risk management literature seeks to establish formal risk management processes, protocols and management tools and techniques.

A number of strategies have been proposed to cope with uncertainty. A possible solution is to reduce uncertainty. Childerhouse and Towill (2004) show how reduction of supply chain uncertainty can lead to benefits associated with inventory, cost, market share and profitability. Another strategy is to respond or mitigate uncertainty via building flexibility into a system. Tang and Tomlin (2008) develop models to demonstrate the power of flexibility to mitigate supply chain risks and uncertainties. They provide a convincing argument for firms to build a degree of flexibility into the supply chain. Other researchers have also highlighted the link between uncertainty and flexibility and have developed models and definitions (Prater *et al.*, 2001). This paper seeks to develop the notion of flexibility in the context of project orientated operations such as construction.

METHOD

The findings reported and discussed in this paper focus on the uncertainties experienced in a construction system. These findings are drawn from a larger in-depth study of two construction systems. A researcher was seconded to a “design-and-build” construction organisation, referred to as BuildUK in this paper, for ten weeks in order to undertake the research. BuildUK is a main contractor based in the South East of the UK and has a turnover of £65 million with a workforce of around 550 employees. Major clients include housing associations, care scheme operators, commercial and industrial concerns and schools.

While BuildUK is the focal organisation within the study, three units of analysis are specified: a network coordinator, projects and suppliers. The construction system in this paper is made up of one network co-ordinator (BuildUK), three projects and nine suppliers that feed into these projects. The projects were selected via ‘snowball sampling’ (Scarbrough *et al.*, 2004). This process includes using recommendations from key industrial contacts from the case company for further empirical research. Projects were selected based on the extent to which a project had entered the construction phase and pragmatic concerns such as the willingness of the project management team to engage with the researcher. Build characteristics such as value, time constraints, construction method, contractual arrangements and logistical challenges were also considered. Suppliers were also recruited via snowball sampling. Suppliers were approached according to two criteria: to represent the range of supply chain structures and a range of categories of supplier relationships with the network co-ordinator.

A range of data collection techniques were used in the study. These are summarised in table 1. Data was collected via interviews, different forms of observation and inspection of various document types. For the investigation of the network coordinator via industrial secondment, semi-structured interviews were carried out with major process teams, such as ‘technical’, ‘pre construction’ and ‘new business’ teams, and the researcher was granted permissions to sit in different team meetings. Supply chain managers, buyers, quantity surveyors, technical design staff and business improvement employees were all interviewed as part of the secondment. Access was also granted to internal systems and databases. For the investigation of projects, site managers and project managers were interviewed and regular visits and tours of the site were conducted as different sites progressed. Documents, such as project plans, requisition forms and bills of materials were provide to support other forms of data collection. A template was designed for interviewing and capturing data from project managers based on risks and uncertainties across all the stages of a project. Risks and uncertainties were probed against generic project stages as identified in the project protocol (Winch and Carr, 2001).

Table 1: Summary of data collection protocol

Unit of analysis	No.	Protocol	Interviews	Observation	Documents
Network Coordinator	1	Industrial Secondment	Major process teams	Inclusion in team meetings	Internal systems and databases
Projects	3	Uncertainty Identification	Site Management	Site visits	Project specific documents
Suppliers	9	Pipeline Survey	Recommended Contact	Factory visits	Websites, company reports

This paper also draws from the findings of supplier assessment, which was conducted with nine suppliers in the ETO system. This was developed in-house by the authors, and is described in greater detail in Gosling *et al.* (2007), so as to gather exploratory data about a supplier or subcontractor. This utilised a mix of open and closed questions under different headings relating to products and services, external environment, internal environment, production strategy, risk and uncertainty and lead time analysis. The lead time analysis section probed areas of variability and uncertainty across generic phases of a construction order-to-delivery pipeline.

For the analysis of project uncertainties, a risk and uncertainty register, in the form of a spreadsheet, was developed for each project based on the data collected from semi structured interviews with site management teams. The uncertainties for individual projects were then categorised to develop a more generic list of uncertainties. A final spreadsheet was developed listing the generic uncertainties, which was then grouped according to the sources of supply chain uncertainty described in Mason-Jones and Towill (1998). A literature review was conducted to develop a classification of flexibility types to respond to project uncertainties. These flexibility types are then mapped onto the generic list of uncertainties developed to show which flexibility types are required to respond to different uncertainties. A binary clustering technique is then used to identify whether uncertainties can be mitigated by different flexibility types, where a 0 indicates that a particular flexibility types is not required and a 1 that it would help respond to a specific uncertainty. These 0-1 matrices have previously been described as binary coding or 'bit maps' (Langley, 1999). In order to cluster the results, the columns were then sorted by uncertainties that require the most flexibility types and the flexibility types that appear most in the analysis.

FLEXIBILITY CLASSIFICATION FOR PROJECTS

Flexibility may be seen as having two distinct elements, those internal to the business that describe system behaviour, and those that are viewed externally by customers, which determine the actual or perceived performance of the company. The former may be seen as causal to the latter, where a combination of internal types may be needed to yield one or more of the external types (Oke, 2005). Synthesising the literature it is possible to identify the key flexibilities required to enable delivery of diverse project requirements and emerging circumstances. These are displayed in table 2. The first five external flexibility types are unchanged from those outlined in Naim *et al.* (2006). However, the definitions have been adjusted to reflect the requirements for project delivery, as opposed to manufacturing and logistics. A sixth external flexibility type has been added to those originally specified by Naim *et al.* (2006). Contract flexibility refers to the ability to accommodate different contract types and requirements. This includes the ability to offer different contract types, such as design and build or construction management, and contract changes to costs.

Table 2: Definitions of flexibility types for project uncertainty

Internal flexibility types	Definition	External flexibility types	Definition
Design and Development	The ability to design and develop a wide range of design requirements	Product	The range and ability to accommodate new projects
Process	Ability to structure the project process and deliver projects in different ways.	Mix	The range and ability to offer different project types in the company portfolio
Communication	Ability to manage a range of different information types	Volume	The range and ability to accommodate changes in project demand
Coordination	The ability to configure resources for project development and execution.	Delivery	The range and ability to change project due dates
Labour	Ability to accommodate changes in labour requirements.	Access	The ability to provide extensive geographical coverage for projects
Vendor	The combined flexibility offered by manufacturing warehousing and transport elements of the supply chain	Contract	The ability to accommodate different contract types and requirements
Sourcing	The ability to reconfigure the supply chain with little penalty in time, cost, effort and performance.		

Sources: (Gosling et al., 2008; Krishnan and Bhattacharya, 2002; Naim et al., 2006; Palani Rajan et al., 2005; Sanchez, 1995; Slack, 2005; Upton, 1994)

Seven internal flexibility types are proposed in this paper. The importance of design flexibility in dynamic uncertain environments is highlighted by Krishnan and Bhattacharya (2002). Rajan *et al.* (2005) suggest that design flexibility is part of product flexibility. While they focus on the flexibility of products themselves rather than the manufacturing system in which they are created they provide a useful classification. They discuss design flexibility with reference to a ranking scale. At one end is a completely new product and total redesign with limited reuse of parts and previous designs, and, at the other, minor changes in some of the components or previous designs or no change required at all. We refer to design flexibility as the ability to respond to design requirements across this spectrum. An organisation may be said to have high design flexibility if it can design and develop completely new, innovative projects with new technology and also very simple, standardised projects.

In a manufacturing context Naim *et al.* (2006) refer to process flexibility as the ability to produce the same parts in different ways. Gil *et al.* (2005) explore process flexibility in the context of challenging project deliveries and define process flexibility as the ability to structure the project process so that it can accommodate late changes in design criteria and intermediate schedule milestones The importance of information management in enabling customisation has long been recognised. Peppers and Rogers (1997) who describe the concept of communication flexibility, that is, the ability to manage a range of information types, their sources and receivers. In their synthesis

Naim *et al.* (2006) refer to communication flexibility as the ability to manage a range of information types. Sanchez (1995) suggests that in dynamic product markets where frequent adjustments in product strategies are required, flexibility in co-ordinating the uses of product creation resources are a premium. This, Sanchez (1995) argues, consists of flexibilities to redefine product strategies, reconfigure chains of resources, and the redeployment of resources. While the co-ordination of labour resources maybe partially covered in co-ordination flexibility, we have also singled out labour flexibility. Many of the seminal manufacturing flexibility papers, such as Slack (2005) and Upton (1994), include labour as a key flexibility consideration for a manufacturing system. Sourcing and vendor flexibility are both linked to supply chain flexibility, which is covered in greater depth in Gosling *et al.* (2008).

FINDINGS

This section presents the generic uncertainties identified in the case studies grouped by their supply chain source. They are presented across four tables, which are discussed in turn. Table 3 shows the control uncertainties identified in the study. The control system directs the site processes and their interaction with the supply and demand side. Control uncertainties, primarily, relate to information flows and project management activities. The binary clustering in the table shows that the uncertainties requiring the most flexibility types are achieving project milestones, fragmented decision making and timely and correct information from consultants. Communication and process flexibility types are the most frequently required types for control uncertainties. For the external flexibility types, contract flexibility is important for the control system. This includes the ability to respond to emerging contract requirements of the system, which may change as a project progresses or is being negotiated. Product, mix and delivery flexibility may be needed to adjust to changing due dates and design requirements, whereas volume and access flexibility are not important for the control system.

Table 3: Flexibility requirements for control uncertainties

Control uncertainties identified from case studies	Comm	Process	Contract*	Co-ord	Design	Labour	Vendor	Sourcing	Product*	Mix*	Delivery*	Volume*	Access*	Total
Achieving project milestones	0	1	0	0	1	1	1	1	1	0	1	0	0	6
Fragmented decision making	1	1	1	1	1	0	0	0	0	0	0	0	0	5
Timely/correct information from consultants	1	1	0	0	0	0	0	0	0	1	0	0	0	3
Effectiveness of contract arrangements	1	0	1	1	0	0	0	0	0	0	0	0	0	3
Permissions from regulators	1	0	1	1	0	0	0	0	0	0	0	0	0	3
Shared objectives	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Things not accounted for in planning	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Timely/correct information from clients	0	0	0	0	0	1	1	0	0	0	0	0	0	2
Total	6	5	3	3	2	2	2	1	1	1	1	0	0	

*External Flexibilities

Table 4 shows the demand uncertainties identified and Table 5 shows the process uncertainties. Demand uncertainties are primarily concerned with those derived from the clients and customers. Binary clustering in the table shows that late changes in specification, drawing approvals and new technologies require the most flexibility types.

Table 4: Flexibility requirements for demand uncertainties

Demand uncertainties identified from case studies	Design	Product*	Mix*	Process	Comm	Co-ord	Labour	Vendor	Sourcing	Volume*	Delivery*	Access*	Contract*	Total
Late changes in specification	1	1	0	1	1	1	0	1	1	0	0	0	0	7
Drawing approvals	1	1	0	1	1	0	0	0	0	0	0	0	0	4
New technology or technique	1	1	1	0	0	1	0	0	0	0	0	0	0	4
Appropriate/effective design	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Scheme viability long term	1	1	0	0	0	0	1	0	0	0	0	0	0	3
Design too rigid	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Client non payment	0	0	1	0	0	0	1	0	0	0	0	0	0	2
Total	6	6	4	2	2	2	2	1	1	0	0	0	0	

*External Flexibilities

Table 5: Flexibility requirements for process uncertainties

Process uncertainties identified from case studies	Co-ord	Labour	Process	Vendor	Delivery*	Comm	Sourcing	Design	Contract*	Product*	Mix*	Volume*	Access*	Total
Deliveries unable to access site	1	1	1	1	1	0	0	0	0	0	0	0	0	5
Speed of construction	1	1	0	1	1	1	0	0	0	0	0	0	0	5
Volatility of workflow	1	1	0	1	1	1	0	0	0	0	0	0	0	5
Accuracy of project plan	1	1	0	1	1	0	1	0	0	0	0	0	0	5
Delivery bottlenecks	1	1	1	1	0	0	0	0	0	0	0	0	0	4
Amount of storage space	1	1	1	1	0	0	0	0	0	0	0	0	0	4
Amount of work space available	1	1	1	1	0	0	0	0	0	0	0	0	0	4
Final cost	1	0	1	0	0	0	0	0	1	0	0	0	0	3
Desired equipment unavailable	1	0	0	1	0	0	1	0	0	0	0	0	0	3
Quality/Excessive snagging	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Labour resources	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Site impact on local community	0	0	1	0	0	0	0	1	0	0	0	0	0	2
Security	0	1	1	0	0	0	0	0	0	0	0	0	0	2
Site management competency	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Safety hazards	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Damages	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Total	11	11	9	8	4	2	2	1	1	0	0	0	0	

*External Flexibilities

Many of the uncertainties from the demand side relate to design changes. Consequently, external flexibility types most required in order to cope with such uncertainties. The other external flexibility types, volume, delivery, access and contract, are less important in coping with demand uncertainties identified in this study.

The process uncertainties identified in table 5 relate to site processes and affect the ability of the project team to meet site targets. The binary clustering shows that deliveries that are unable to access site, the speed of construction and the volatility of workflow required the most flexibility types. It also shows that co-ordination, labour and process flexibilities are the most frequently mapped types for mitigating process uncertainties. For the external flexibility types delivery was the most popular. This highlights the importance of the capability to adapt due dates on site. Product, mix, access and volume flexibilities are less important in responding to process uncertainty.

Table 6 presents the supply uncertainties identified. These relate to uncertainties that find their source in the supply side. According to the binary clustering bad performance, supplier capacity and consistency, as well as responsiveness of suppliers all required the most flexibility types. Vendor and sourcing flexibilities were the most important flexibility types for mitigating these uncertainties. These two flexibility types have both been identified as antecedents for supply chain flexibility. Delivery flexibility was the only external flexibility to be mapped. This may be because supply uncertainties are too far removed from the customer to be of concern unless they impact on the delivery date.

Table 6: Flexibility requirements for supply uncertainties

Supply uncertainties identified from case studies	Vendor	Sourcing	Delivery*	Comm	Process	Co-ord	Labour	Design	Mix*	Volume*	Product*	Access*	Contract*	Total
Bad performance from suppliers	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Capacity of subcontractors	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Consistency of suppliers	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Flexibility/Responsiveness of suppliers	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Early or late deliveries	1	0	1	0	0	0	0	0	0	0	0	0	0	2
Subcontractor bankruptcy	0	1	1	0	0	0	0	0	0	0	0	0	0	2
Timely/correct information from suppliers	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Total	5	5	5	1	0	0	0	0	0	0	0	0	0	

*External Flexibilities

Finally, table 7 shows a summary of the supply chain uncertainty types and their flexibility requirements. 8 control uncertainties, 7 demand uncertainties, 16 process uncertainties and 7 supply uncertainties are summarised. The table highlights that different flexibility types are required to cope with different sources. Co-ordination, process and vendor are the flexibility types that were mapped most often, closely followed by labour. The most popular external flexibility was delivery, with volume and access flexibility receiving no requirements for the uncertainties identified.

Table 7: Summary of flexibility requirements for different sources of supply chain uncertainty

Supply Chain Uncertainty Source	Co-ord	Process	Vendor	Labour	Delivery*	Comms	Sourcing	Design	Product*	Mix*	Contract*	Volume*	Access*	Total
Control	3	5	2	2	1	6	1	2	1	1	3	0	0	27
Demand	2	2	1	2	0	2	1	6	6	4	0	0	0	25
Process	11	9	8	11	4	2	2	1	0	0	1	0	0	49
Supply	0	0	5	0	5	1	5	0	0	0	1	0	0	17
Total	16	16	16	15	10	10	9	9	7	5	5	0	0	118

*External Flexibilities

CONCLUSIONS

The first research question posed was ‘what are the sources of supply chain uncertainty in construction supply chains?’ A generic list of uncertainties has been developed from the results of a case study protocol probing the uncertainties of three different projects in a construction system. This generic list of uncertainties has been grouped according to different sources of supply chain uncertainty. The second research question posed was ‘which types of flexibilities are required to mitigate these uncertainties?' A classification of flexibility types has been developed from the literature which was then mapped onto the generic list of uncertainties. Issues relating to 'how much flexibility is required?', 'which uncertainties are more important?' and ‘how are uncertainties related?’ are not addressed here. The extent to which uncertainties should be reduced or responded to has also not been resolved. These issues will be addressed in future research. The findings herein will be of interest to researchers and practitioners in the area of construction supply chain management who would like to better understand risk and uncertainty. Like many exploratory case-based studies, limitations such as small sample size, contextual bias and subjective criterion for variables have to be noted.

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