A FRAMEWORK FOR CATEGORISING ENGINEER-TO-ORDER CONSTRUCTION PROJECTS

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Using the decoupling point concept, supply chains can be classified to cover a variety of different structures, ranging from very repetitive make-to-stock supply chains to very customized ‘engineer-to-order’ (ETO) industries. The purpose of this research is to add more clarity to the ETO category by addressing engineering sub-categories and their implications. A collaborative form of inquiry as the means for producing knowledge is adopted. This includes academics and practitioners co-operating throughout the research process. A single ETO category is found to be too broad, and eight sub-categories are proposed, which are used to highlight the need for appropriate procurement routes. By introducing a richer understanding of the ETO marketplace, the paper opens the way to effective procurement strategies depending on the sub-categories that construction organisations choose to engage with. It adds to the overall body of knowledge suggesting a ‘one-size-fits-all’ approach to strategy is not suitable.

Keywords: civil engineering, procurement, risk, supply chain.

INTRODUCTION

The decoupling point, which can be defined as the point at which strategic stock is held as a buffer between fluctuating customer orders and smooth production output, provides a useful classification system for supply chains, and helps to distinguish between stock driven and order driven systems (Hoekstra and Romme, 1992). Using this concept, a range of structures can be defined ranging from very repetitive make-to-stock supply chains to very customized ‘engineer-to-order’ (ETO) industries (Gosling *et al.*, 2007, Hoekstra and Romme, 1992, Olhager, 2003). In the latter, each item, or project, is to a degree unique, and the client will often engage with the design process (Gosling and Naim, 2009). Within this framework, much of the supply chain research has focused on high volume and repetitive manufacturing. The uncertainties faced in ETO industries, such as civil engineering and infrastructure, are markedly different from those in more stable environments. This mix of uncertainties will be affected by the degree of original or novel engineering required of each project. Hence, the ETO structure, as described by the literature, is found to be too broad. Furthermore, an important oversight in such classifications of supply chains is the extent to which any research might have to be undertaken as part of an ETO project.

The research in this paper is rooted in the ‘no-one size fits all’ perspective (Bask, 2001; Shenhar, 2001), which has been described elsewhere as the demand

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contingency model (Sanderson and Cox, 2008). The fundamental proposition is that some kind of alignment should be conducted between supply strategy and the product type. If procurement decisions are made based on a 'one size fits all' approach, then serious problems can ensue. Suboptimal procurement strategy and contractual arrangements can lead to payment conflict, delays, quality conflict and administrative conflict, and contract disputes can culminate in expensive litigation or arbitration activities (Conlin *et al.*, 1996, Fenn *et al.*, 1997). It is also possible that an unsuitable procurement approach does not adequately allocate risk among the supply chain (Barnes, 1983).

High profile case studies of contractual disputes and conflict, such as those encountered during the construction of Wembley stadium, are well publicised (Eaglesham, 2004). The industrial context of this paper is set within the civil engineering sector in the UK. It also focuses on 'habitual', as opposed to one off clients (Barnes, 1983). The purpose of this paper is to add more clarity to the ETO supply chain type by identifying any engineering sub-categories and determining their implications on procurement forms and hence risk mitigation. The specific research objectives are specified as, firstly, to develop a framework to rationalise the range of ETO projects, and secondly, to consider the contractual implications of the framework.

LITERATURE REVIEW

Extending the family of supply chain structures

Gosling *et al*. (2007) define six different supply chain structures: engineer-to-order (ETO), buy-to-order (BTO), make-to-order (MTO), assemble-to-order (ATO), make-to-stock (MTS) and ship-to-stock (STS). The particular structure that is of interest in this paper is the ETO supply chain. Many authors agree that all production dimensions in the ETO supply chain are customised for each order, that the decoupling point is located at the design stage, and that they operate in project specific environments. The lack of agreement is found in the extent to which existing designs are modified to order, or whether completely new designs are developed for each order (Gosling and Naim, 2009).

Wikner and Rudberg (2005) propose a framework to consider the design aspect of ETO supply chains. They decouple the engineering and production related activities of the supply chain and propose a non linear approach. An engineering dimension and production dimension are advocated with the engineering dimension ranging from ETO, where a new product is designed, and engineer to stock (ETS), where a design is already 'in stock'. Between ETO and ETS engineering modifications to existing product designs are used in varying degrees. This paper examines the potential subclasses of ETO that may lie along this spectrum, and considers a new set of subclasses that involve 'research-to-order' activities.

Figure 1 shows the extended family of supply chain structures, including the new 'research-to-order' structure. The level of standardisation and customisation that takes place before a customer order is indicated in each of the different supply chain structures. The shaded cells indicate that the activity is customised and the cells that are not shaded indicate standardisation. The line that runs through the different structures is the decoupling point, and shows the point at which the customer order enters the supply chain. The customer, in this case, is taken to be the next direct receiver of the material in the supply chain as opposed to the ultimate end user.

Figure 1: The extended family of supply chain structures; adapted from (Gosling et al., 2007)

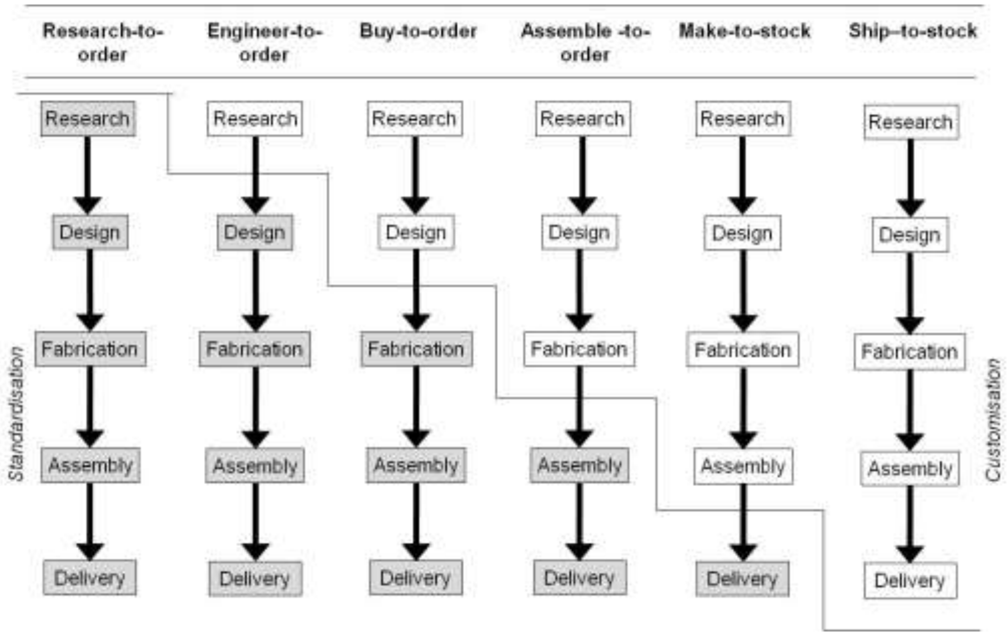


Table 1: Technology Readiness Levels (Source: Mankins, 1995)

TRLs	Definition
TRL 1	Basic Principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment
TRL 7	System/subsystem model or prototype demonstration in an operational environment
TRL 8	Actual system completed and qualified through test and demonstration
TRL 9	Actual system proven through successful operations

When considering research as one activity in the spectrum of supply chain structures, there is now an analogue with Technology Readiness Level (TRL) scales. The importance of technology readiness and capabilities has been recognized as an important driver for the successful deployment of a technological system (Mankins, 1995). TRLs, originally developed in the, 1980s by NASA, offer a well recognised approach for assessing the maturity of generic technology. TRLs have become a tool that has added clarity to technical assessments and the discussion of technological maturity and risk, and have been adopted by some US government agencies and many of the world's major companies to assess the maturity of evolving technologies (Islam, 2010). Since some technologies are not suitable for immediate application when they are first conceptualised, they are usually subjected to experimentation, refinement and testing. Once the technology is sufficiently proven it can be incorporated into a system or subsystem. Table 1 shows the TRL scales.

Government funding is commonly associated with the higher TRL levels, whereas companies are often involved for the lower levels. Disciplines at the mid-TRL stage, somewhere between TRLs 4 – 7, are widely perceived as challenging for many kinds of technologies because of the disappointingly low frequency of success, and is often referred to as the “valley of death” (Maughan, 2010).

Choosing an Appropriate Procurement Contract Form

Procurement is a generic term embracing all those activities undertaken by a client or contractor seeking to bring about the construction of a project (The Joint Contracts Tribunal Limited, 2009). Procurement selection requires selection of a procurement ‘system’, such as design and build, traditional and construction management. It also requires selection of an appropriate contract (Tookey *et al.*, 2001). Contracts are the method by which the client creates the project organisation, and it is through such contracts that companies can be motivated to achieve the appropriate objectives (Winch, 2002). There are various and diverse procurement contract types, which differ in terms of claims procedures, dispute management, roles, liabilities, risk allocation, and payment terms (Construction Industry Development Board, 2005).

Each contract has its own independent risk allocation strategy (Barnes, 1983). This may come in three forms: the client carries all the risk, the risk is shared, or the contractor carries all the risk. Winch (2002) argues that three basic contracting types exist. Fee based contracts are those where goods and services are provided at an agreed rate as a function of an agreed parameter. Fixed price contracts are those where the price is fixed for an agreed amount of work. Incentive contracts mix features of the fee based and fixed price to motivate gain sharing. These different forms of contract offer different risk profiles in terms of allocation of responsibility for the costs of changes in the specification. Turner (2010) also considers a range of contract forms. Cost plus, where an agreement is reached on a cost with a certain fee included on top, remeasurement, where the contractor is rewarded based on the amount of work they do, according to an agreed formula, and fixed price contracts, which can be based on a scope design or detailed design. The final two include target cost and guaranteed maximum price.

It is commonly argued that contracting forms should be 'appropriate', based on power relationships (Cox and Thompson, 1997), levels of risk and uncertainty involved in a particular project (Barnes, 1983), or the level of complexity in a project (Turner, 2010). Appropriate contracts may also depend on complexity of works, capacity and capabilities, and 'contract strategy' (design by employer, design and build, management contract, construction management) (Construction Industry Development Board, 2005). It is argued herein that certain forms of contract are appropriate for different ETO subclasses.

RESEARCH METHODOLOGY

Ottoson and Bjork (2004) argue that when dealing with complex adaptive systems, such as engineering and product development projects, researchers should consider ‘insider’ and ‘participatory’ approaches to research. A co-operative form of inquiry as the means for producing knowledge is adopted herein. In such forms of inquiry the roles of researcher and 'subject' are reconsidered, and research is done with people and not on or about them. The researcher(s) and ‘subject’ jointly conceive, design, manage and undertake the research (Heron, 1996). Thereby, those who might otherwise be subjects of research are to a greater extent engaged as inquiring co-researchers (Reason and Bradbury, 2008).

This approach helps to bring together practical and experiential knowing of processes and patterns from industry, along with consideration of propositions and theory. The interplay and cycle of learning between reflection and experience are considered key to this type of knowledge generation (Heron, 1996). This has much in common with the use of narratives in research, whereby events and past experiences are connected in a meaningful way for a defined audience, and thus offer insights about the world (Elliot, 2005). There is an emphasis on peoples' lived experiences, the context of those experiences, and practical knowledge. The aim here is to link practice and ideas, working together to address key problems in organisations. Co-operative inquiry is used herein as a means of conceptual development, rationalising the different classes of engineering required in construction projects using theory and the experience of a practitioner co-author.

This research was initiated through a presentation given to the ‘Blue Innovation Trust’, an advisory group for the Costain Group and its supply chain. The presentation was primarily concerned with appropriate strategy and characterisation for the ETO supply chain (Gosling and Naim, 2009). This led to an iterative process of conceptual development, cycling between the experience of construction industry professionals and the researchers, with reflection on theory and practice. In order to expand the classification initially proposed by Gosling and Naim (2009), literature relating to TRLs and the decoupling point was reviewed and, via the Blue Innovation Trust network, members were asked to reflect on the range and types of novel engineering required. Using the examples and feedback gathered from this as a basis, knowledge creation was facilitated through further face to face meetings, teleconferences, email exchange and inspection of company documents. This involved cycling between the emerging framework and further feedback.

A CLASSIFICATION OF ENGINEER-TO-ORDER PROJECTS

Figure 2 defines the various ETO subclasses identified, indicating their relationship to the TRLs and the risks and opportunities associated with each subclass. The subclasses were identified and developed through rationalising feedback from presentations to, and interviews with, practitioners.

Research Subclasses

Within this set of ETO subclasses, at the outset it is not at all certain that there is even a solution to the problem. Some form of research is required to develop and prove the concepts, design method, materials or other core feature of the solution. The principal challenge in this subclass is attempting to prove a potential solution is possible. A client or contractor engaging in such projects would be making a speculative investment, but the result could yield high value rewards.

The first subclass within this category is Mathematics Research. In this subclass, we are unsure of the theoretical principles, and even that a solution exists at all. An example of such may include prediction of emergent systems, such as traffic flow breakdown modelling. The risk consequence for an ETO project is that the project is a ‘non-starter’. The second type of subclass within this category is Sciences Research. In this subclass, the theoretical foundations are likely to exist in principle, but the application is uncertain. Nanotechnology or genetic modification may offer good examples of this subclass. The risk consequences are that an ETO project encounters ‘showstoppers’, leading to interruptions or abandonment of the project.

A further subclass within this category is Engineering Research. In this subclass, testing of materials, principles or applications in special circumstances is required. A good example here is the wind tunnel testing undertaken to construct the Burj Khalifa in Dubai to examine the effects the wind would have on the tower and its occupants. These ranged from initial tests to verify the wind climate of Dubai, to large structural analysis models and facade pressure tests, to micro-climate analysis of the effects at terraces and around the tower base (Emaar Pjsc, 2009). The risk here is that the project encounters 'showstoppers', but it may be possible to backtrack or start again from scratch.

Figure 2: A framework for ETO subclasses with risks and opportunities

'Blank Sheet' Subclasses

In this set of subclasses, the purpose of the project can be defined, but there is an open brief as to the solution. There is at least one solution which it is recognised can be designed and delivered without the need for research activity. The principal challenge is to develop the concept. In the First Principles Design subclass, scientific or engineering principles are known and accepted, but they are beyond the scope of accepted design codes. Many major civil engineering schemes, such as the 450m cut-and-cover tunnel on the M25 at Bell Common undertaken for the Highways Agency (Costain Group Plc, 2011), would fall under this category. The risk here is that an inappropriate concept will lead to a highly inefficient solution, which may be dysfunctional. If successful though, the marketplace will need to be revised to incorporate the new solution to accepted codes.

The second subclass within this category is Design to Accepted Codes. Here, all design is to accepted design principles. Such principles are formalised by bodies such as the Institution of Civil Engineers, a good example being the principles set out in the

Eurocode guidelines (Eurocodes Expert Manager, 2009). The solution type, form, layout and architectural design are considered on an order by order basis.

Standard Design Sub Classes

The final set of subclasses utilise existing and standard designs. The principal challenge is to bring these standard designs together for the particular project. In the Adapted Design subclass, there is enough known about the design principles that the design can be prepared in outline by an 'experienced eye'. A professional design engineer can then work up the design as outlined within the parameters predicted. It is the adaptation of existing designs within a new context. An example of such may be a 'standard' bridge designs.

The next subclass within this category is Configured Design. This assembles existing components for a particular solution. The design solution is built up from an established set of parts, each with known characteristics and with the rules for overall configuration being set down. A good example of this subclass is the customised office solution developed by Laing O'Rourke, which uses established building elements to reduce costs and cycle times whilst offering flexibility to accommodate different client demands (Franklin & Andrews, 2011). The final subclass is Products. Here, designs are completed, standard products that are perfectly adapted to requirements. The risk here is that an inappropriate choice of components or delivery partners will cause problems. Examples here may take the form of complete structures of various types, for example barns or standard housing.

APPROPRIATE PROCUREMENT CONTRACTS FOR ENGINEER-TO-ORDER SUBCLASSES

The previous section proposed eight ETO subclasses, each with different risk and opportunity implications. This section considers the procurement implications. Table 2 presents a range of procurement contract routes to consider. Seven are identified in total.

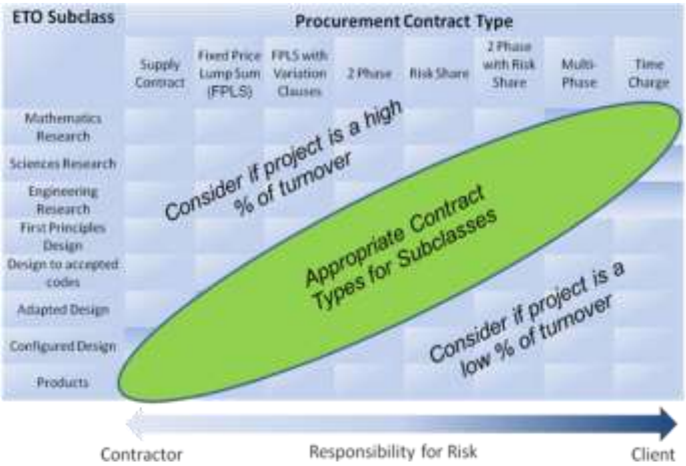
Figure 3 then brings together different elements of the paper, mapping the procurement contract types against the eight ETO subclasses. It shows a 'zone of best fit', which recommends that certain contract forms are more appropriate to achieve 'best value' in the different subclasses.

In the research subclasses, it is likely that a client or contractor may have to engage with research institutions to deliver projects. Within the Mathematics Research subclass, it may be necessary to set up a research institute or development council with broad objectives. Those solving the problems, or engaged in the project, will wish to be confident that funding will continue independent of relationship, thus helping to give them freedom to pursue ideas. If clients wish to engage with such projects, a time charge contract type would be appropriate. For Sciences Research, it may be necessary to fund investigation to develop new science in a particular area identified. A challenge here is to identify relevant expertise, and align them with the issues at hand. Funding must be long term and assured. Clients and contractors engaging with such projects should consider multi-phase or time share as a procurement form. Long term funding may also be required to investigate specific issues and problems that arise in the Engineering Research subclass. Clients and contractors engaging with such projects should consider two-phase with risk share or multi-phase procurement contracts.

Table 2: Range of procurement contract types

Contract Type	Definition
Supply Contract	Single order on a supply only basis. No design work is included.
Fixed Price Lump Sum (FPLS)	The supplier agrees to provide specified services for a specific price. The receiver agrees to pay the price upon completion of the work or according to a negotiated payment schedule.
Fixed Price Lump Sum with Variation Clauses	The supplier agrees to provide specified services for a specific price. The receiver agrees to pay the price upon completion of the work or according to a negotiated payment schedule.
Two-Phase Contract	In the first phase the contractor develops the design and key supply contracts and agrees the price and risk management principles with the client; in the second phase the works are executed either to a fixed price lump sum or with risk share'.
Risk Share	A risk share contract provides specifically for the use of a risk register, risk allocation schedules and performance indicators.
Multi-Phase	In a multi- phase contract, the work to be performed is broken into various phases, and a fixed price is established for each unit of work.
Time Charge	Goods and services are provided at an agreed rate as a function of an agreed parameter.

Figure 3: Matching procurement forms with subclasses



A First Principles Design may require specialist or world class consultants, employed on risk share basis or against a sequence of bite-sized pieces. Control of time and cost will need intuition as well as skilled management and a wide ranging team engagement. A two-phase contract type or limited risk share on success or failure is suitable for delivering value here. All parties should be mindful of the long term success of the other. For the Design to Accepted Codes subclass, it also may be required to employ consultants against a sequence of bite-sized pieces. Control of time and cost will need skilled management, and defining the project purpose and ensuring appropriate teams are empowered becomes key. Interaction and trust are pre-requisites for success. A FPLS with variation clauses contract or two-phase contract would be appropriate for best value here.

In the adapted design subclass, some routine applications remain. Typically, these would take the form of design and build FPLS projects with an emphasis on defining project constraints and pre-agreements. Variation clauses maybe introduced. Design work can be set against target fee, and time and cost can be controlled by rule. In terms of the collaborative focus, each party should be fully aware of what makes a successful project for the other and strive to make this happen as a constant process.

Configured design subclasses may include design and build projects with two or more phases. The design work can be against fixed fee, so a FPLS procurement route or supply contract would typically provide best value here. Cost and time control should not be an issue. Each party should be fully aware of what makes a successful project for the other and strive to make this happen as a constant process. No design work should be required in the products subclass. A fixed price procurement strategy or supply contract would be suitable here. Collaboration between companies may focus on business to business relationship development and process improvement.

CONCLUSIONS

The purpose of this paper was to add more clarity to the ETO supply chain type by identifying any engineering sub-categories and determining their implications on procurement forms and hence risk mitigation. The ETO supply chain type, as described in previous literature, is found to be too generic. Consequently, the family of supply chain structures was extended to include research-to-order activities, and a conceptual framework, consisting of eight ETO subclasses, was then proposed to consider the range of activities in the ETO construction sector. In doing so it refines previous frameworks. Rooted in the ‘no-one size fits all’ approach, this paper has argued that the eight ETO subclasses must be matched with a range of contract types. Seven procurement types were identified, and a 'zone of best fit' to achieve best value in procurement forms was proposed. The paper supports the proposition that contracting forms in construction should be 'appropriate'. By introducing a richer understanding of the ETO marketplace, and matching these with procurement contract types, the paper provides practical decision making guidelines for organisations. The industrial context of this research is, in its current form, limited to the civil engineering sector in the UK. It also focuses on ‘habitual’, as opposed to one off clients. Further research is required to investigate the generalisability and accuracy of the frameworks proposed.

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