An Approach to Modelling Supply Chain Management Processes in Engineer to order Companies

DR TOM MCGOVERN

Department of Management Studies, University of Newcastle upon Tyne, UK

DR CHRIS HICKS & DR CHRIS F EARL

Department of Mechanical, Materials and Manufacturing Engineering, University of Newcastle upon Tyne, UK

ABSTRACT *This paper describes the characteristics, competitive factors and supply chain management issues of an engineer to order (ETO) company engaged in the supply of capital goods. The Structured Systems Analysis and Design Methodology (SSADM) is used for modelling the internal processes of organisation, as well as interactions with customers and suppliers. Supply chain management decisions are clearly differentiated between tendering and contract execution. The case study demonstrates a requirement to integrate these supply chain management processes. The management of knowledge throughout the supply chain was identified as critical to achieving competitive advantage.*

Introduction

The capital goods sector in the United Kingdom was estimated by Tobin et al (1988) to comprise over 1,000 companies employing 148,000 people with a combined turnover of £3.5bn including exports of over £600m. Despite the importance of this sector to the British economy, it has been neglected by academic research. Supply chain management is a critical issue for these companies. However, the literature in supply chain management has focused on buyer-supplier relationships in the automotive sector (Turnbull et al., 1992; Lamming, 1993). Previous research has also ignored the influence of internal processes of organisation on supply chain management issues (Bresnen, 1996). This paper is based upon ongoing research conducted in collaboration with a group of engineer to order (ETO) companies in the capital goods industry.

The first part of this paper describes the general characteristics of companies engaged in the supply of capital goods in terms of their markets, products, internal processes, competitive issues and supply chain relationships. It has been argued that firms derive competitive advantage from their core competencies and the unique knowledge that they possess (Prahalad and Hamel, 1990). In the case of ETO companies, competitive edge has traditionally been based upon internal design capability. However, the companies are becoming increasingly more dependent upon the capabilities of their suppliers. As companies have only a short time to prepare a bid, the ability to assess and incorporate the knowledge of their suppliers is crucial. The work reported focuses on how internal organisation and company strategies impact upon supply chain management.

The second part of this paper provides a detailed analysis of supply chain management processes in an ETO design and contract company. The Structured Systems Analysis and Design Methodology (Cutts, 1991) was used for modelling the company's internal processes of organisation and its interactions with customers and suppliers. A case study was selected to demonstrate the practical application of this methodology.

Description of Engineer to Order (ETO) Companies

ETO companies range from highly integrated companies with in-house manufacture at one extreme to pure design and contract organisations at the other. There has been an increase in vertical disintegration in the capital goods sector which is similar to trends identified in other sectors (Harland, 1996; Hicks et al., 1997).

ETO companies are involved in the design, manufacture and construction of capital equipment. Individual products are highly customised to meet customer requirements and are produced in low volume. Capital goods contain a diversity of components ranging from low volume items to those required in medium or large quantities. Some components are highly customised whilst others are standardised. Capital goods also contain technologically advanced components such as control systems as well as commodity items such as steelwork. The core products have deep and complex product structures that give rise to many levels of assembly process. The industry is characterised as high risk. Demand tends to be lumpy with each unit of demand representing a large proportion of capacity. Markets are difficult to forecast due to unknown sales volumes and unknown product specifications for future orders. Forecasting the demand, even at the product type level, is extremely difficult due to the customised nature of the products (Muntslag, 1994). Supply in the ETO capital goods sector is characterised by high levels of uncertainty in terms of specification, demand, process durations and lead times (Konijnendihk, 1994). Thus, high complexity arises as a result of: deep and complex product structures; the mix of volumes of demand for different items giving rise to various methods of production; and missing information and engineering revisions caused by the overlapping of manufacturing and design activities.

In an ETO business, the customer is exposed to the total product lead-time, which includes the conceptual and detailed design, procurement, manufacturing, assembly, testing and commissioning. Improving the reliability of lead-time estimates requires accurate forecasting of activity durations at the contract negotiation and planning stages. To achieve a competitive advantage, an ETO company may attempt to reduce product lead time by sourcing long lead items before the design is finalised, or in some cases before the final contract has been signed (Marucheck and McClelland, 1986). This is, however, a high risk strategy given that tendering success is often less than 30% (Konijnendijk, 1994).

In ETO companies, it is possible to distinguish two types of processes: non-physical which includes engineering design and planning activities and physical which comprises component manufacturing, assembly and installation (Bertrand and Muntslag, 1993). There are two stages of interaction between an ETO company and its customers and suppliers. The first is a tendering activity in response to an invitation to tender for a particular contract. This involves the preliminary development of the conceptual design and the definition of major components and systems. Contact with selected suppliers is made at this stage to obtain information on costs and lead times. There are often a number of phases of negotiation that aim to match overall project costs and lead-time with anticipated customer and market requirements. Tendering includes only non-physical activities associated with design, estimating and planning. Success at this stage requires a detailed technical understanding of customer requirements as well as meeting price, delivery and quality requirements. The second stage of contact with the customer takes place after a contract has been awarded. The initial activities are non-physical including the development of an overall project plan and detailed design. This is followed by procurement, component manufacturing, assembly, construction and commissioning. The amount of physical activity associated with manufacturing, assembly and construction performed by the company itself is dependent upon the level of vertical integration.

Supply Chain Management

Bresnen (1996) recognises that the majority of research in supply chain management has been narrowly focused on particular industrial sectors, such as the automotive industry. The results of this work may not necessarily translate to other sectors. The common model of a large-scale (economically powerful) focal manufacturer supported by smaller (economically weaker) suppliers or subcontractors is quite inappropriate in an ETO context. It is common to find that power within ETO supply chain relationships is biased toward the supplier (Hicks et al., 1997). Many items are only required in low volumes on an infrequent basis and the value of the order may not be of high significance to the supplier. In some cases, the source of supply is specified by the customer.

Turnbull et al (1992) found different patterns of inter-organisational linkages occurring amongst the automotive companies and their component suppliers. Indeed, in the automotive industry it is common to have “first tier” suppliers responsible for key components or systems with “second tier” suppliers providing generic components. The range of supply chain relationships in ETO manufacturing is potentially far broader as it is dependent upon more factors. The general supply environment for ETO companies is characterised by far more dynamic change than in other sectors. Demand uncertainty limits the scope for developing co-operative long-term supply chain relationships. Many ETO companies are engaged in multi-sourced adversarial trading, characterised by “win-lose” transactions and mutual mistrust. There is little evidence of operational or strategic linkages with suppliers. There is, however, evidence that companies have recognised the importance of developing more collaborative relations. This is mainly because purchased items and services may account for more than 80% of contract value (Hicks et al., 1997).

ETO companies derive competitive advantage through understanding customer requirements, translating them into specifications at product and component level, and integrating components and subsystems into products. The level of detail involved in the specification of items is an important issue. Functional specifications (what it will do, rather than how it will do it), allow the suppliers to develop their own designs and introduce innovation (Kumpe and Bolwijn, 1988). Detailed technical specifications reduce design choices available to the supplier. This may constrain innovation, and result in unnecessary design and procurement activities with increased costs and lead times. Some important product features that affect customer satisfaction may not be explicitly specified. For example, ease of maintenance requires the designers to have knowledge of the through-life costs and operating conditions of the product. Outsourcing, if not carefully managed, can lead to a “hollowing” out of the company through loss of this “architectural knowledge” (Venkatesan, 1992). The challenge for ETO companies is to control design and supply by retaining the expertise to integrate subsystem performance specifications to meet stated and unstated customer requirements. Our case study supports this view.

Procurement decisions predominately take place in three ways: a) customers specify preferred suppliers; b) the sourcing of components and subsystems is specified at the tendering stage; c) Design may specify items during the product development process. Parts of the product that have long lead times are considered early in the design process. Special supplier relations are often developed particularly when there is still uncertainty in the exact specification. We comment that the accurate estimation of the duration of design activities may make it possible to avoid unnecessary early ordering of parts. The manufacturing and procurement decisions made during the early stages of product design impose considerable constraints. Indeed, many of these constraints arise as a result of decisions made at the tendering stage. These decisions sometimes take place by default as designers select items from suppliers' catalogues based upon their functional characteristics without co-ordinating with procurement. It is not uncommon for there to be limited reuse of engineering designs. Furthermore, many designers enjoy the creative challenge of developing new configurations. These gives rise to unnecessary variety that increases cost, lead-time, uncertainty and risk, which makes procurement and supply activities more complex.

According to Burt and Doyle (1993) 75-80% of avoidable total costs are controllable at the design stage. This would suggest that the early involvement of procurement in tendering and product design decisions is essential to reduce costs, especially in ETO companies with their broad range of component specifications and high level of outsourcing. Our case study below explores the internal constraints that ETO companies need to address if they are to implement strategic supply chain management.

A Case Study in Supply Chain Management Processes

This case study is based upon a detailed analysis of supply chain management processes at a company that operates on a pure design and contract basis. The company produces material handling equipment for specialised applications. It has a strong reputation for its design capability and is a preferred supplier for major utilities. It is normal for contracts to include penalty payments for late delivery, which can have a major impact on profitability. The company used to have its own machine and assembly shop. However, in the mid-1980s, with a diminishing order book and high overheads, the decision was taken to close them. The design and contract strategy was introduced and the organisational structure was changed to matrix management. This approach resulted in an increase in profitability and return on capital. Another feature of this strategy is that it results in a magnification of risk. Any supplier can cause delays that can affect the whole contract. However, individual suppliers are normally only subject to penalties associated with their component of supply. This, coupled with the fact that a large proportion of contract value is due to outsourced items and services, gives rise to a high variability in the profitability of contracts. Uncertainty in supplier delivery performance has led to the use of conservative lead-time estimates, which can result in long quoted lead-times. This is a major problem when delivery performance is a critical competitive factor.

Bresnen (1996) argues that existing research in supply chain management ignores the internal processes of organisation and management action occurring within organisations. It, therefore, ..."provides a superficial, simplified and essentially deterministic view of the structure and dynamics of the buyer-supplier relationship" (p.122). Our research is based on the development of a model of the full spectrum of both internal and external processes. The internal processes of management and organisation within the company and external communication with customers and suppliers were modelled. The systems approach is based upon the hierarchical decomposition of complex systems, which concern people, processes and technology. There are many different systems methodologies. The Structured Systems Analysis and Design Methodology (SSADM) was chosen due to its rich modelling capability, its widespread use, and its graphical representation.

The first stage in modelling the supply chain management processes was to interview personnel in each functional area. Data Flow Sheets (shown in figure 1) were used to record document and information flows between the functions. Each sheet contains information on the roles, processes, data flows and data storage associated with functions. The information from the data flow sheets was used to develop data flow diagrams (see for example figure 2) which represent the system.

At the highest level, there is a data flow diagram called the *context diagram.* It records the relationship between the company, its customers and suppliers (see figure 3). Two interactions with customers and suppliers are shown. The first takes place at the tender stage and includes responses to an invitation to tender (ITT). The second takes place after the contract has been awarded by the customer. This includes the award of contracts to suppliers and the subsequent monitoring and control of their progress.

The next level down (figure 4) shows the relationships and interactions among the various business functions (Tendering, Engineering, Project Management, Quality, Purchasing and General Management) including those with suppliers. Each of these functions is then shown in further detail by a series of lower level models. The supplier selection, ordering and expediting functions are depicted.

The overall analysis of the business processes resulted in the development of thirty SSADM models, which enabled the researchers to examine the effect that internal systems had on supply chain management. Some general conclusions are apparent. Key information was not shared between departments despite similarities between departmental tasks. For example, key suppliers may be selected at the tendering, design or procurement stages of a project. However, each department had localised procedures and their own information storage systems with varying levels of detail ranging from catalogues to databases. The lack of information sharing, together with individual departmental "mindsets", restricted the potential for selecting suppliers on a strategic basis. Tendering, for example, viewed the product as a collection of parts to be acquired at the most competitive price, whilst Design

Engineering and Purchasing took a systems perspective. Consequently, suppliers selected by Tendering were often changed by Design post-tender, which contributed to uncertainty in project costs. Our other more detailed conclusions from the case study are classified by function.

Case Study: Analysis of Processes

The company in our case study was organised around five functional departments: Tendering, Design Engineering, Purchasing, Projects and Quality. The research findings from the modelling of the supply chain management processes, incorporating tendering and contract execution, are reported below under each respective department.

Tendering

1. The Tendering function's communications with the customer was mainly confined to the receipt of an invitation to tender (ITT), specifications, issuing the tender, receiving an order, accepting an order, receiving instructions to start and clarification of the specification. Tendering made no attempt to identify which subsystems the customer considered important in order to identify strategic subsystems (Venkatesan, 1992).

2. Up to 90% of project and product costs are determined during tendering, and designs are dependent upon particular suppliers at this stage. However, the extreme time constraints sometimes resulted in new and untested suppliers (whose financial status, capability, reliability and previous experience had not been rigorously investigated) being included in the tender. Purchasing, however, was not involved in the bidding process, although the department held the largest source of supplier information, including up-to-date supplier approval data.

3. A PC database was used as a source of supplier/product information in the tender development process. It was assembled from information collected from previous bids, buyers' guides, fax and telephone enquiries. It included unapproved suppliers that had not been vetted, as there was no common database with Purchasing or Quality. Much of the data was out-of-date causing uncertainty in contract pricing.

4. The company received functional, performance and technical customer specifications. Some customers provided highly detailed specifications that weakened the company's negotiating position, because of the limitations that it imposed on supplier selection. In some cases, suppliers were specified, further weakening the company's position (Vaughan, 1996).

Purchasing

1. Purchasing's involvement in a project commenced with the arrival of detailed drawings (which included a list of parts) from Design Engineering via Projects. Purchasing was not able to facilitate concurrent procurement or influence the choice of supplier at this stage. Purchasing was, therefore, a clerical, reactive activity. Little information was actively sought from the supply chain and channelled to Design Engineering or Tendering, where it could have provided a competitive advantage.

2. Data stores in Purchasing were a mixture of manual and computer based systems. These systems had no search capability. Both data stores lacked information on supplier performance and their competencies. Post-tender supplier selection, therefore, focused on price and not strategic criteria. As Purchasing was only involved in the post-tender design process, little opportunity was available to adopt strategic supplier selection strategies, or to develop collaborative relations with suppliers. The benefits of concurrent procurement were also negated.

3. No formal system existed within Purchasing to re-evaluate supplier relationships. It could be argued that suppliers of strategic subsystems should be assessed regularly. However, no such mechanism existed to categorise suppliers. The only process that had been established was the early identification of long lead items, but these were not classified as strategic or non-strategic.

Engineering

1. Design Engineering had only limited contact with the customer, and this was restricted to clarifying the specification. Consequently, the department did not use formal methods such as Quality Function Deployment (QFD) to fully comprehend customer requirements.

2. Design Engineering recommended those suppliers that may be used. This could directly influence the choice of suppliers by designing-in proprietary components.

3. Informal communication channels existed between Purchasing and Design Engineering in the post-tender stage. Design sometimes issued drawings directly to Purchasing to circumvent delays in Projects. On many occasions Purchasing requested changes to suppliers specified on the drawing. However, these requests were seldom complied with because of Design's reluctance to change drawings and incur additional design and reissue costs. The formal system for any changes was through Projects.

4. Although design was a core competence, the CAD systems did not contain past designs produced manually. Parametric programming was not widely used. Therefore, the reuse of CAD data was limited.

5. The age profile of personnel in Design Engineering was particularly high. The older designers were employed by the company when it manufactured cranes and they had a wealth of heuristic knowledge needed to produce practical, easy to build and maintain cranes. The younger members of the design team lacked this 'architectural' knowledge. As ease of maintenance was considered a key competitive criterion for customers, there is a real danger that competitive advantage based on this manufacturing knowledge will be lost as the older designers retire. The company will need to adopt a strategy designed to capture this knowledge from suppliers.

Projects

1. Projects only became involved after a contract had been awarded and it had received the files from Tendering. The project manager, therefore, had little prior knowledge of the project requirements and the decisions that were made during the tendering stage. Thus, Projects were effectively excluded from the key decisions which contributed to the cost and lead time of a project. The analysis of the data flow revealed that Projects acted as a "post-office" for the business, with data entering the department being diverted to other departments, causing complicated lines of communication. Weekly meetings only allowed Projects a brief overview of progress and did not facilitate effective control of any project.

2. Projects believed that its influence over Design was limited because most of the internal activities related to a project were in the domain of the latter department. In effect, Projects was viewed as a department that monitored progress, rather than controlled the project.

Quality

1. Supplier vetting and approval were the responsibilities of Quality. However, it was possible, as shown earlier, for an order to be sent to an unapproved supplier before Quality was informed. In addition, supplier-vetting information was not made available to other departments, which reduced any potential influence it may have had on supplier selection decisions.

2. Suppliers were not periodically re-evaluated. The reactive approach encouraged by the internal processes did not foster a culture of continuous improvement amongst the company and its suppliers.

Conclusions

A number of conclusions can be drawn about the general characteristics of ETO supply chain management. These are reinforced by the more specific findings of the case study. First, with changing structures in ETO companies and their markets, internal capabilities and knowledge need to be managed strategically. A key finding is that knowledge of supplier capabilities is becoming more important. Thus, integration of ETO companies and their suppliers with respect to knowledge and capabilities is essential. Second, the systems modelling methodology provides an effective tool to analyse the structure of information flow between functions. It was found particularly useful to distinguish between the tendering and contract execution processes and the respective interaction with suppliers during these stages. Third, the interface between the internal processes and capabilities of ETO companies and those of their suppliers is critical to the success of a design and contract business. Future research needs to consider the changing nature of these relations in ETO businesses. In particular, strategic alliances are being established in the capital goods sector to enable companies to release value and to more effectively co-ordinate activities across supply chains. Additional work is required to evaluate the effect of these alliances on supply chain relationships and their impact on the internal operations of ETO companies. The use of formal modelling as applied in the case study reviewed in this paper should prove a useful tool for investigating these issues.

References

BERTRAND, J.W.M. and MUNTSLAG D.R., (1993) Production Control in Engineer to Order Firms, *International Journal of Production Economics,* 30, pp. 3-22.

BRESNEN, M. (1996) An Organisational Perspective on Changing Buyer-Supplier Relations: A Critical Review of the Evidence, *Organisation*, 3,(1), pp. 121-146.

BURT, D.N. and DOYLE, M.F. (1993) *The American Keiretsu* (Homewood, ILL, Business One - Irwin).

CUTTS, G. (1991) *Structured Systems Analysis and Design Methodology* (London, Blackwell).

HARLAND, C.M. (1996) Supply Chain Management: Relationships, Chains and Networks, *British Journal of Management*, 7, Special Issue, pp. 63-80.

HICKS, C., MCGOVERN, T. and EARL, C.F. (1998) Supply Chain Management in Engineer to Order Manufacturing, *International Journal of Production Economics* (forthcoming).

KONIJNENDIJK, P.A. (1994) Co-ordinating Marketing and Manufacturing in ETO Companies, *International Journal of Production Economics,* 37, pp. 19-26.

KUMPE, T. and BOLJWIN, P. (1988) Manufacturing: The New Case for Vertical Integration, *Harvard Business Review,* March-April, pp. 75-81.

LAMMING, R. (1993) *Beyond Partnership: Strategies for Innovation and Lean Supply* (Hemel Hempstead, Prentice Hall).

MARUCHECK, A.S. and MCCLELLAND M.K. (1986) Strategic Issues in Make to Order Manufacturing, *Production and Inventory Management*, 27, (2), pp. 82-95.

MUNTSLAG, D.R. (1994) Profit and Risk Evaluation in Customer Driven Engineering and Manufacturing, *International Journal of Production Economics*, 36, pp. 97-107.

PRAHALAD, C.K. and HAMEL, G. (1990) The Core Competence of the Corporation, *Harvard Business Review*, May - June, pp. 79-91.

TOBIN, N.R., MERCER, A.L. and KINGSMAN, B.G. (1987) A Study of Small Subcontract and Make to Order Firms in Relation to the Quotation for Orders, *International Journal of Operations and Production Management*, 8, (6), pp. 46-59.

TURNBULL, P., OLIVER, N. and WILKINSON, B. (1992) Buyer Supplier Relations in the UK Automotive Industry: Strategic Implications of the Japanese Manufacturing Model, *Strategic Management Journal,* 13, pp. 159-168.

VAUGHAN, R. (1996) Innovating to Compete, *Supply Management,* September, pp. 46-47.

VENKATESAN, R. (1992) Strategic Sourcing: To Make or Not to Make, *Harvard* Business Review, November-December, pp.98 - 107.

Department : Tendering	Source: A.N.Other	DataFlow ID : H001

PRIMARY ROLES / PROCESSES:

Assess Project Specification
Quote for Main Components
Costing for Tender
Prepare Tender
Review and Maintain Supplier Database

DATAFLOWS TO DEPT :

DEPARTMENT / ENTITY	SOURCE / RECIPIENT	DATAFLOW / DOCUMENT	PURPOSE / PROCESS
Customer	R	ITT (Invitation To Tender)	Assess Project Specification
Engineering	S	ITT (copy)	Design for Tender
Quality	S	ITT (copy)	Prepare CQAR
Supplier	R	Quote	Prepare Tender
Engineering	R	Recommended Suppliers	Prepare Tender
Engineering	R	TPS (*Green Sheet*)	Costing for Tender
Quality	R	CQAR	Prepare Tender
General Manager	S/R	Meeting for Tender approval (financial etc)	Approve Tender
Engineering	R	Conceptual Designs & Skeleton Project Plan	Prepare Tender
Customer	S	Tender	Prepare Tender
Customer	R	Contract awarded (formal documentation)	Project Live (prepare Contract File)
Projects	S	Contract File	Hand Over

DATA STORES :

DATA SUBJECT	RELATED PROCESS (S)	STORE TYPE
Historic ITT details	(Historic information)	D - Customer Database
Supplier details & Pricing	Supplier Selection / Costing	D – PC database

Figure 1 Data Flow Sheet

Data Flow Diagram - High Level

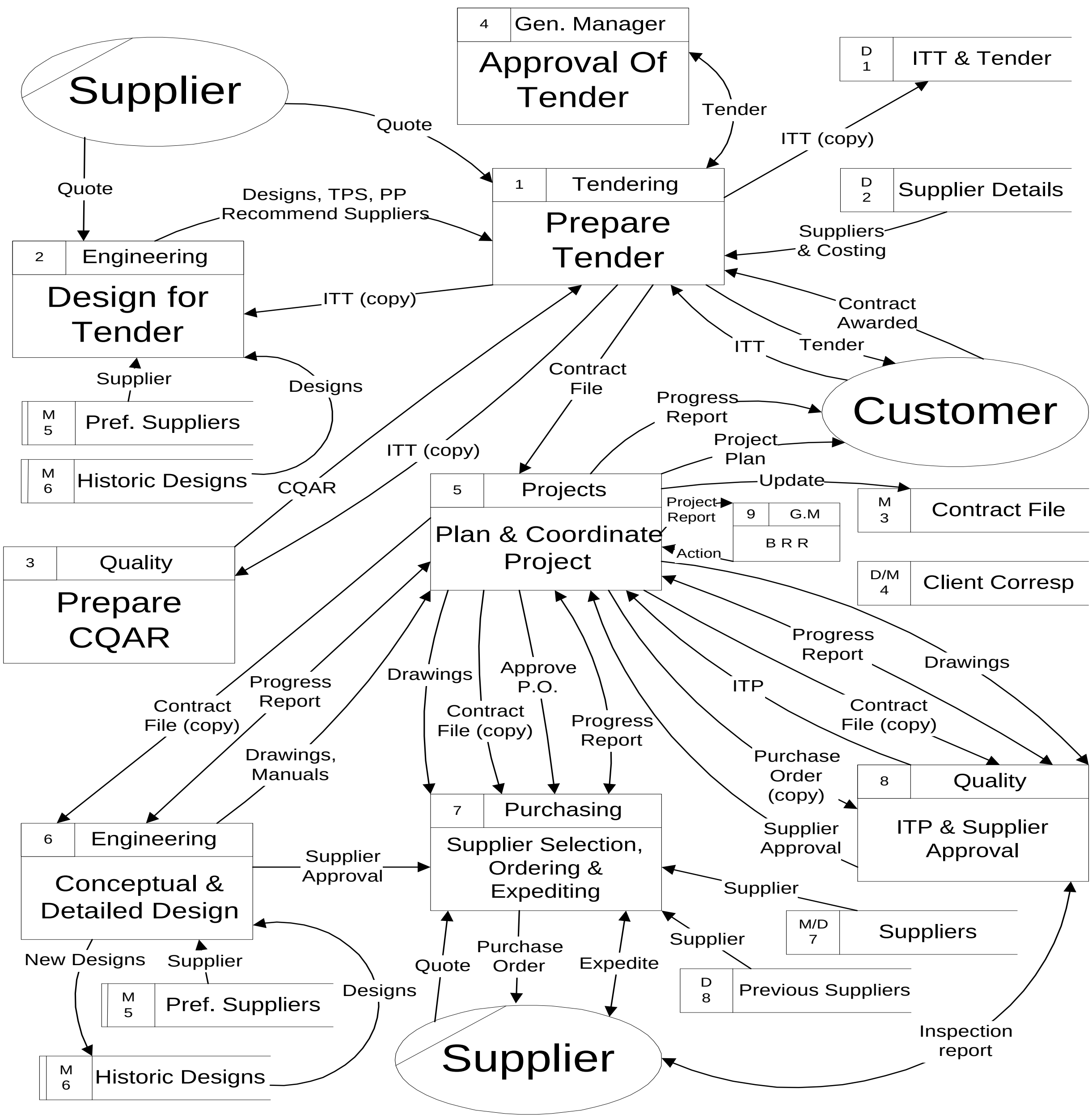

Figure 2 High Level Data Flow Diagram

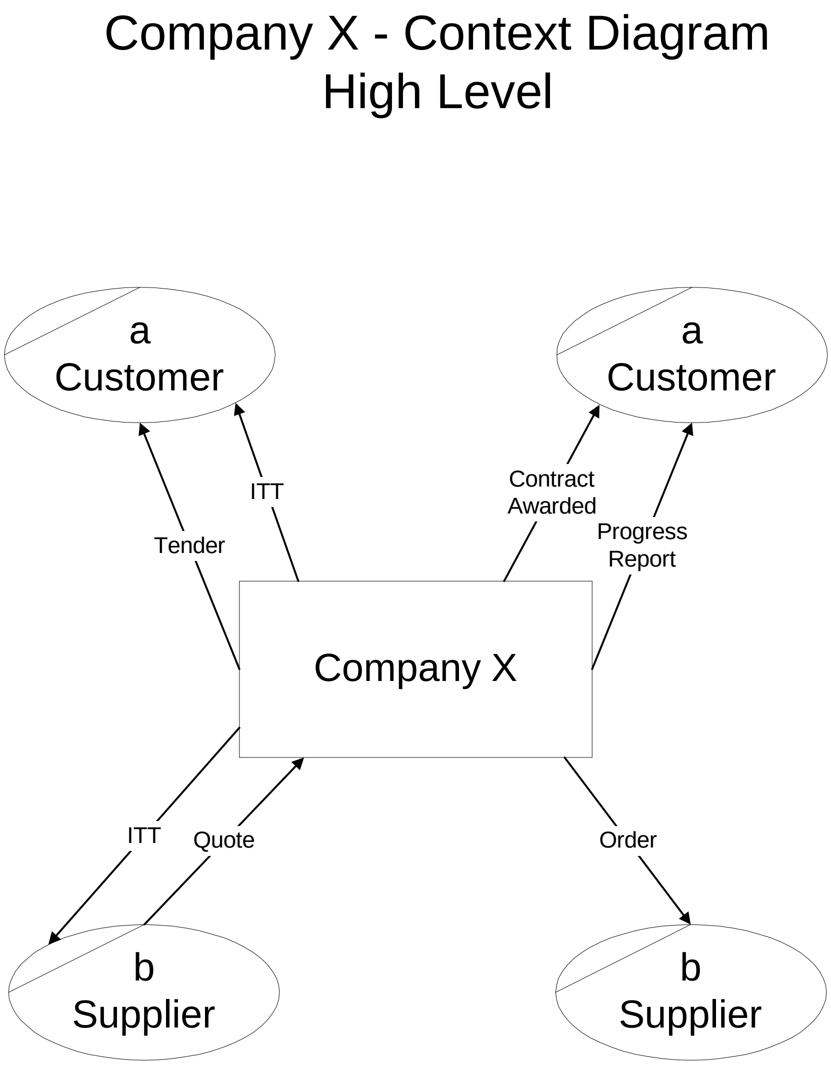

Figure 3 Context Diagram

Data Flow Diagram - Low Level : Supplier Selection, Ordering & Expediting

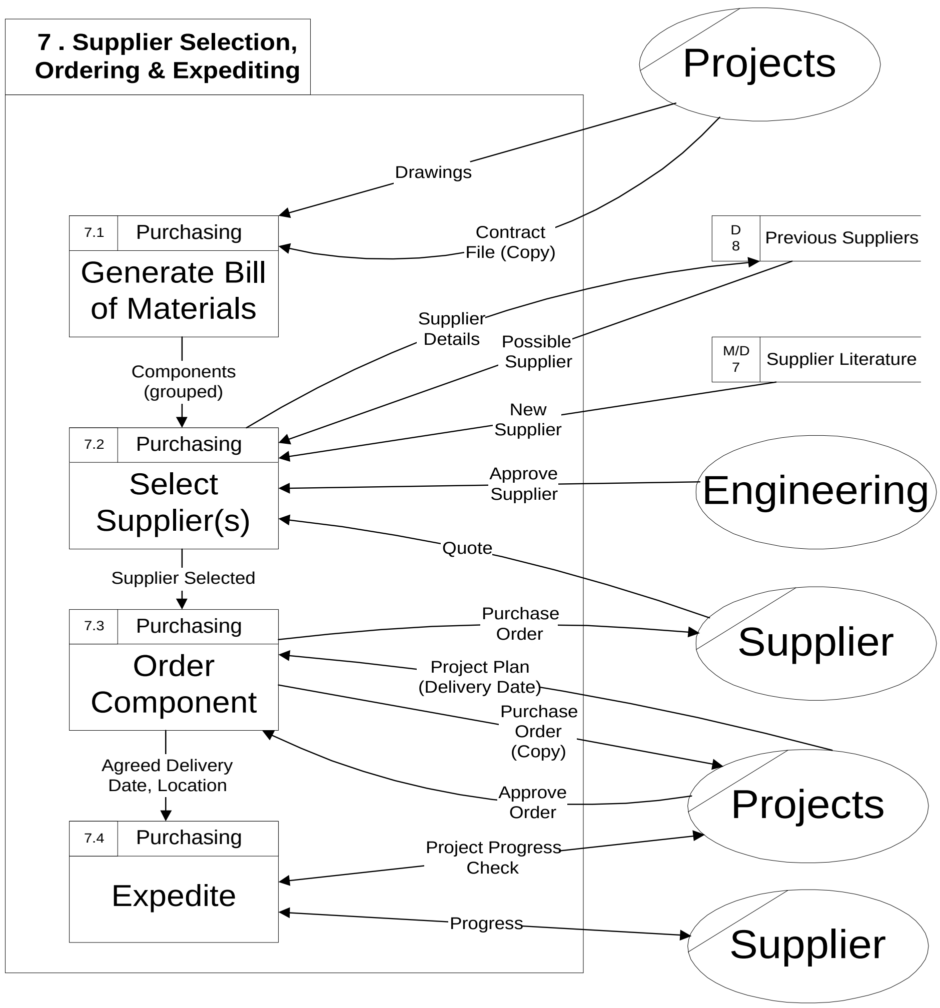

Figure 4 Data Flow Diagram - Supplier Selection, Ordering and Expediting