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Supply chain management: A strategic issue in engineer to order manufacturing

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Abstract

The characteristics of Engineer to Order (ETO) companies are described in terms of their markets, products and the internal processes of their organisation. These are set in the context of current trends in supply chain management. The business processes associated with the procurement and marketing functions and the interactions with other processes are analysed. These are compared for a number of different types of ETO company. The variety of work in ETO projects, the customised, complex products and the underlying uncertainties of markets all indicate that procurement and marketing need to be integrated with other processes, particularly tendering and design. These characteristics put constraints on the application of established supply chain management methods. It is argued that a strategic view of supply chain management in which procurement makes a greater contribution in the tendering and early product development activities has the potential to improve performance. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Supply chain management; Engineer to order; Business processes; Strategy

1. Introduction

Companies in all sectors are examining ways to reduce costs, shorten product development times and manage risk. The transactions between companies in supply chains are characterised by adding value up through the chain and incurring costs (and consequent payments) down the chain. Supply chain management aims to reduce costs, risk and lead-times associated with these transactions, thus releasing value. There is limited research into supply chain management in the low-volume Engineer to Order (ETO) sector. This is in contrast to the extensive literature on the high-volume sector, particularly automotive and electronics [1,2].

This paper examines how the special nature of the ETO business constrains the application of supply chain methodologies. The characteristics of ETO companies and associated supply chain management issues were derived from studies of ETO companies involved in the design, manufacture and construction of capital equipment for the power, materials handling and offshore industries. The research focused on modelling business processes, planning and control, analysis of specifications and supply chain management.

A business process approach to describing ETO companies was adopted. This helps to identify the

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nature of relationships between customers and suppliers. These are particularly complex in ETO businesses, which are involved in many different types of supplier relationships. A systems modelling approach to representing this complexity is reported elsewhere [3]. The ways that internal organisation and structure constrain the role of supply chain management in ETO companies are considered. The paper does not investigate in any detail the consequent issues of supply chain relationships, but rather identifies the environment in which these relationships are established and maintained. Procurement decisions in ETO companies are analysed from an operational and strategic perspective.

2. Description of ETO companies

The research was conducted in collaboration with seven companies in the power generation, high-integrity materials handling and offshore sectors. The main business activities of the companies are the design, manufacture and construction of capital equipment. A summary of the characteristics of the collaborating companies and their products is shown in Table 1.

Companies A, B, D and G are the largest in terms of turnover and number of employees. For all the companies except company F, each order is a large proportion of annual turnover and is therefore of strategic importance. A–F are ETO companies that supply highly customised products to meet individual customer requirements. Company G has high value orders but these are typically for over 10 units. It has a standardised range of products that are configured to meet a broad range of national and international electrical distribution requirements. They are supplied on a make to order basis. Companies A–E produce products with complex and deep product structures whilst companies F and G produce less complicated items with a shallower product structure.

A summary of the collaborating companies and their business processes is provided in Table 2. All of the companies have design and project management capabilities. These are considered to be core competencies in all cases. Companies A–D also perform manufacturing, factory-based assembly, construction and commissioning at customers' sites. Company E produces similar products to company D but is much smaller in terms of turnover and numbers employed. It only has a design and project management capability as all other activities are outsourced. Company F produces electronic control systems, which are designed to meet individual customer requirements and are assembled from generic electronic components. The company installs and commissions its equipment at customers' sites. Company G has a strong design capability, but in general, products are developed

Table 1
Collaborating ETO companies and their products

Company	Turnover	Employees	Products	Typical order (£m)	Customisation	Depth of product structure
A	200	800	Steam turbine-generators[a]	50–300	High	Deep
B	200	3500	Oil platforms	20–25	High	Deep
C	75	400	Power station boilers	50	High	Deep
D	125	100	Mechanical handling	20	High	Deep
E	25	50	Mechanical handling	10	High	Deep
F	25	100	Electronic control systems	3	High	Medium
G	150	600	Switchgear	50–100	Low	Medium

[a]Company also project manages power station contracts. This business has a high level of outsourcing as the company only manufactures turbine generators.

Customisation: Low – mainly standard products, Medium – customised options, High – engineer to order.

Depth of product structure: Shallow – 1 to 3 levels, Medium – 3 to 6 levels, Deep – >6 levels.

Table 2
Processes in collaborating companies

Company	Processes	Manufacturing processes	Vertical integration
A	DPMACC	JBFA	High
B	DPMACC	JBA	High
C	DPMACC	JBA	High
D	DPMACC	JBA	Medium
E	DP	None	Low
F	DPACC	A	Low
G	DPMACC	JBA	High

Processes: D – design, P – project management, M – manufacturing, A – assembly, CC – construction and commissioning.
Manufacturing processes: J – jobbing, B – batch, F – flow, A – assembly.

to meet the requirements of regional markets rather than individual customers. The company has a wide range of manufacturing and assembly processes and installs and commissions its equipment on site.

Company A has the widest range of manufacturing capability which includes jobbing, batch, flow and assembly processes and a wide range of manufacturing technologies. Fabrication of complex structures is the main manufacturing activity for companies B and C. This involves jobbing, batch and assembly processes. Company D has a significant fabrication capability, but it also produces a wide range of mechanical components. It has a range of jobbing, batch and assembly processes. Company F does not manufacture components and only performs assembly activities. Finally, company G has a wide range of manufacturing technologies ranging from steel pressing through to electrical assembly and testing. These include jobbing, batch and assembly processes.

The level of vertical integration and outsourcing varies considerably within this group of companies. It can be seen that companies A, B, C and G are highly vertically integrated with substantial manufacturing capabilities. These companies manufacture most of their products in-house, but outsource standard components and systems. The level of outsourcing is greater for company B as it produces structural components but outsources all mechanical systems. Company D, although having some manufacturing capability, is less vertically integrated than companies A, B and C. It is, therefore, more dependent upon outsourced items. Companies E and F are not vertically integrated and are therefore more dependent upon their suppliers.

Table 3 shows some of the characteristics of supply chain management in the collaborating companies. It can be seen that all of the companies are highly dependent upon outsourcing. This is particularly so for company E which outsources all of its physical activities and company F that only performs assembly, construction and commissioning activities. Companies A–C and G have reduced their supplier base whereas companies D, E and F still have a large number of suppliers. Companies A and B have established strategic alliances with their customers and suppliers. Company B, in particular, has derived substantial competitive advantage from this approach. Only companies A and B have formal partnership agreements with their suppliers, but these are not single sourcing agreements.

Table 3
Supply chain management in collaborating companies

Company	Outsourcing	Supplier base	Strategic alliances	Partnership agreements	Single sourcing agreements
A	Extensive	Reduced	Yes	Some	No
B	Extensive	Reduced	Yes	Yes	No
C	Extensive	Reduced	No	No	No
D	Extensive	Diverse	No	No	No
E	All physical processes	Diverse	No	No	No
F	All manufacturing	Diverse	No	No	No
G	Extensive	Reduced	No	No	No

The ETO sector encompasses many types of company, designing and manufacturing a diverse range of products. Individual products are generally highly customised to meet individual customer requirements and are produced in low volume on an engineer, or make to order basis. The main products have deep and complex product structures that give rise to many levels of assembly process. They contain a diversity of components, some of which are required in very low volume, whereas others are required in medium or large quantities. Certain components and systems are highly customised whilst others are standardised. Some components such as the control systems are technologically advanced whereas other items such as structural steelwork are not. In general, high levels of customisation lead to increased costs, higher risks and long lead-times. It also makes outsourcing more difficult as component and subsystems requirements are only fully specified after the design process has taken place. Most of the companies have recognised these difficulties and are trying to increase design standardisation based upon modular design principles. In many cases, this approach has proved difficult due to diverse customer requirements. Many designers also have a strong desire to produce creative customised solutions.

3. Business processes in ETO companies

For the purposes of describing the business processes within ETO companies we decompose the complex processes of interaction with customers and suppliers into three stages. The first stage is marketing, which is a two-way process that develops potential customers' awareness of the company and its products. It provides an opportunity for the ETO company to identify market trends, technical and non-technical customer requirements, as well as the customer's criteria for assessing competing offers. It is based upon relationship marketing [4]. Decisions on whether an invitation to tender is worth responding to are made at this stage. These are based upon an assessment of customer requirements, commercial factors, the company's ability to compete and the likelihood of success. Where the markets for major products are in decline, the marketing activity may include identifying new business opportunities that can be exploited using existing expertise and resources. Over the last decade, the nature and significance of the marketing function has changed in the collaborating companies. It is now strategic. The privatisation of the electricity supply industry has transformed the competitive environment for companies A, C, F and G. The decline in the oil price, the shift towards smaller oil fields, and the globalisation of the industry has had a similar effect on company B.

The second stage is the response to an invitation to tender for a particular contract. The tender 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 with suppliers that aim to match overall project cost and lead-time with anticipated customer and market requirements. A technical specification, delivery terms, price and commercial terms are agreed at this stage. This represents a major commitment. Success requires a detailed understanding of customer needs including technical features, price, delivery and quality requirements. This would imply the need for a strategy based upon customer intimacy [5]. Konijnendijk [6] reported that the tendering success rate is often less than 30%. Research with our collaborating companies indicates that the strike rate is often lower.

The third stage takes place after a contract has been awarded. Initial activities are non-physical [7] including the development of an overall project plan and detailed design. This is followed by procurement, then the physical processes associated with component manufacturing, assembly, construction and commissioning. The level of involvement by the company itself in these physical activities varies from company to company and is dependent on the level of vertical integration. As in other sectors, ETO companies are reducing the degree of vertical integration as they increasingly rely on outsourcing [8]. The interaction of processes within these three stages will emerge as an important aspect of our analysis of supply chain management.

ETO companies respond to their markets in unique ways [6]. The product range is mostly based upon previous orders. Product innovation may be general, such as developing an underlying technology, or it may be specific to meeting the requirements of a particular customer or order. Medium- and long-term planning is usually based upon aggregated information expressed in terms of value or labour content. Typically a yearly sales plan co-ordinates marketing and manufacturing requirements. Decisions to outsource manufacture are often taken at this level. Delivery dates in tenders are based on lead-time estimates. These are usually produced without information on available capacity, as it is common for there to be several "floating" quotations awaiting responses from potential customers. Detailed specifications that determine work content and duration are also uncertain at this stage. It is, therefore, necessary to reconsider the lead-times and delivery dates at the order acceptance stage and to confirm arrangements with the customer. It may also be necessary to review outsourcing decisions at this stage.

A key competitive factor in ETO markets is delivery performance. Improving performance has two components: reducing lead-time and increasing the reliability of lead-time estimates. Lead-time reduction has been achieved by shortening the duration of individual processes and by increasing the overlapping of previously sequential activities. Improvements in technology such as the application of large multifunction machine tools can reduce process times and improve dimensional accuracy. This in turn reduces assembly times and their variability. Improvements in software support including computer aided manufacturing (CAM), computer aided production management (CAPM) systems, computer aided design (CAD) enable faster response, better planning and facilitate product innovation. Concurrent engineering methods promote design for manufacturing and assembly as well as the overlapping of these activities. Unexpected redesign and unnecessarily complex manufacture are avoided, thus giving more reliable lead-time estimates. Delivery performance can also be improved by streamlining products and processes through modularity and standardisation. This may be driven by the customer seeking familiar product features and a minimum diversity of spare parts, or by the supplier's desire to minimise costs and complexity.

The ETO sector is characterised by a large design content per order, the types of products produced, the business processes and the nature of the markets. Before proceeding to discuss how these affect supply chain management in ETO companies, different approaches to vertical integration within the sector are considered. Vertical integration is particularly relevant as it is a variable feature in ETO organisations and affects the level and type of outsourcing.

4. Vertical integration

The research undertaken has shown that ETO companies can be classified according to the level of vertical integration. They span a continuum from in-house manufacture of all components and assemblies at one extreme, to a pure design and contract organisation at the other. Furthermore, two types of design and contract business can be identified. In the first type, all items from suppliers are delivered to site and the ETO company carries out the construction and commissioning phase of the work. In the second type, all physical activities are undertaken by either suppliers or subcontractors. Only marketing, design, procurement and project management are performed internally.

In considering the appropriate level of vertical integration, ETO companies seek an optimum response to a number of factors. These include: reconciling customer delivery times with available capacity; reducing costs; the availability of capital for investment in equipment; potential utilisation of plant; internal and external capabilities and flexibility. These factors vary from firm to firm giving rise to differing levels of vertical integration. This variability makes it difficult to prescribe best practice for supply chain management in ETO companies. Our observations on ETO companies suggest that there has been a trend towards vertical disintegration driven by financial pressures and the need for cost reduction. Vertical disintegration can increase flexibility by making alternative product configurations possible, but it can also reduce the scope of

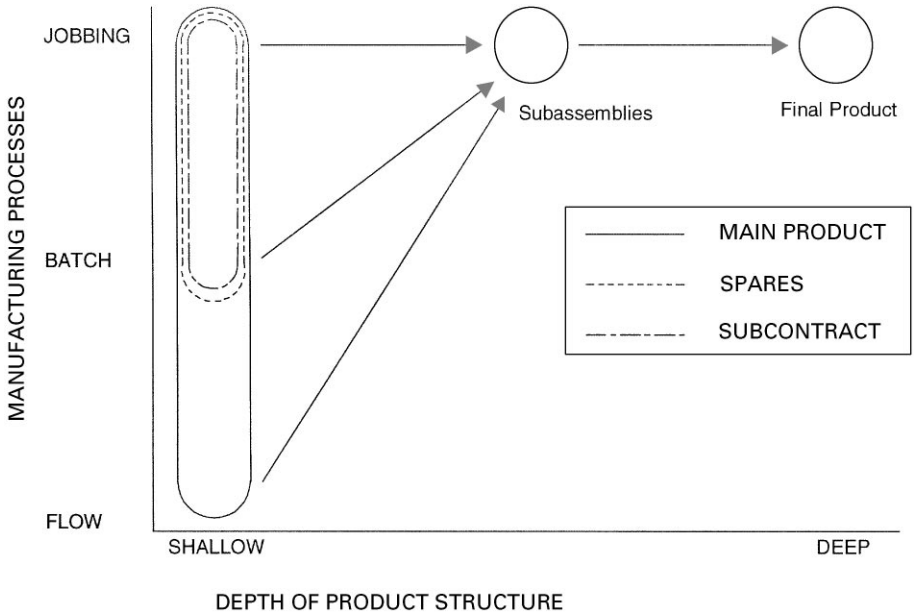

Fig. 1. Vertically integrated ETO company.

concurrent engineering and the flexibility to deal with design changes.

Fig. 1 illustrates the manufacturing processes performed by a vertically integrated ETO company. The company produces, in low volumes, a main product that has a deep product structure. This typically consists of a number of major subassemblies that have medium levels of product structure that are delivered to the customer's site for final assembly. These subassemblies are produced from a range of components that are manufactured using jobbing, batch and flow processes. An example would be a large steam turbine generator. The high-pressure, intermediate and low-pressure turbines and the generator are delivered to site for final construction and commissioning. The turbine units consist of a turbine rotor and four turbine casings that are produced in low volume on a jobbing basis, together with several hundred blades that are manufactured on a batch production basis. The generator has components, such as the rotor and the core frame, that are produced on a jobbing basis, with some components (for example, the conductor bars) that are required in intermediate quantities. These are produced in batches. Each generator also includes several hundred thousand core plate laminations that are manufactured using a dedicated flow line.

The model in Fig. 1 above shows that the business activities of ETO companies are more complex than suggested by Tables 1 and 2. A service and spare parts business supplies items with shallow product structures. In some cases, additional business activities have been developed to exploit expertise or to increase the utilisation of resources. The main product and spares businesses tend to be profit generators with the additional businesses generating cash during times of low demand for the major product. The spares and subcontract engineering activities involve the jobbing and batch production of components with shallow product structure. For the main product, different types of manufacturing processes need to be co-ordinated with common assembly and construction activities. Fig. 1 describes the general structure of manufacturing activities undertaken by the vertically integrated companies A, B, C, D and G.

The approach to the outsourcing of manufacturing activities varies from firm to firm. A common approach has been to concentrate on assembly

processes, as these are considered to result in high levels of added value. Some companies have also retained jobbing processes when manufacturing technologies, or other capabilities, provide competitive advantage. In some cases, such as the production of large heavy components, in-house manufacturing capability is necessary due to a lack of potential suppliers. At the other extreme, some ETO companies have outsourced all manufacturing, assembly, construction and commissioning activities as a mechanism for minimising overhead costs.

In general, there has been an increase in outsourcing by ETO companies. This makes supply chain management strategically important, because of the reliance upon suppliers for technology, design and manufacture. The next two sections compare the ways that supply chain management is addressed by companies in the high- and low-volume sectors.

5. Supply chain management trends in high-volume industries

In the high-volume industries, four key trends in supply chain management have been identified in the literature: outsourcing of non-core activities to suppliers [9,10]; focusing of operations [11,12]; a reduction in the supplier base as companies shift from multiple to single sourcing [13,14]; and the establishment of long-term collaborative relationships with suppliers [1,15,16]. The outcome of these changes is that companies are establishing new forms of relationships with their suppliers.

The traditional buyer–supplier model prevalent in British industry in the 1970s was based upon adversarial, arms-length relations. Buyers tightly defined production and process specifications. Components were obtained from multiple sources. Little information was disclosed to suppliers on technologies, processes and projected production targets [17]. Price competitiveness was the primary criterion on which contracts were awarded.

Adversarial relations proved counterproductive to both parties, and by the beginning of the 1980s a partnership model was being adopted to reduce costs, resolve scheduling problems and other technical difficulties. This strategic change was essential if manufacturers were to implement total quality principles embodying just-in-time manufacturing techniques, minimum inventory, "right first time" and Kaizen. The partnership, or obligational model, is characterised by: close operational and strategic linkages between buyer and supplier; the provision of technical and managed assistance to suppliers; and the establishment of preferred supplier status or single sourcing agreements [18].

Some doubts have been expressed about how far the obligational model has displaced the adversarial model. Indeed, research suggests that the adoption of these new practices tends to be piecemeal, and not widespread in practice, but concentrated in specific sectors such as the automotive or electronics industries [19]. Even within "leading-edge" companies a number of constraints have been identified. For example, mistrust between buyers and suppliers has been found to be prevalent [20]. There have been difficulties in establishing tiered systems of component supply [21] and problems in implementing JIT systems [22,23]. This suggests that the adoption and implementation of new obligational practices are far from widespread. Indeed, in spite of the emphasis placed on quality and delivery, price and cost are still the key determinants of contract awards [19,23].

Outsourcing, in particular, poses a number of challenges and opportunities for companies. There are many strategic benefits of outsourcing to best-in-class suppliers: greater flexibility in the purchase of rapidly developing new technologies; a reduction in design cycle times and higher quality. In addition, risks relating to contractual obligations, or investments in research and development, may be transferred to the supplier [10]. The inherent danger is that a technology critical to competitive success may be outsourced, leading to the loss of "architectural knowledge" [24].

As a company increases the scope of its supply, the proportion of the activities and resources that it directly controls decreases. An alternative strategy available to the company is to develop close collaborative relationships with its suppliers to extend the boundary of the firm and exert indirect control over their resources. The growth in outsourcing and the trend towards single sourcing has led

companies to strengthen their relationships with the remaining suppliers. The strategic imperative for the buyer is how to capture and integrate the technology and knowledge of the supplier with the company's own internal capabilities. There is evidence that involving suppliers at an early stage in design and product development improves quality, increases productivity and reduces lead-time [25,26]. The suppliers may also be an important source of innovation in development of the product [27].

Researchers have also questioned the unequal distribution of power in the new collaborative relations between buyers and suppliers. In many cases, co-operation was underpinned by strong buyer control, enforced through vetting and monitoring [17]. In effect, the more powerful buyers simply imposed terms and conditions on the weaker, dependent suppliers [23]. The main weaknesses of previous research on high-volume manufacturing, especially in the automotive industry, is that it has focused upon mass production of standardised products, in repetitive and routine assembly processes. These are normally controlled using JIT systems that require close operational integration between customers and suppliers. Research has concentrated upon supply chains dominated by a focal producer able to exert a significant degree of control over its much smaller suppliers [18]. This situation does not hold for many of the buyer–supplier relationships in ETO, low-volume manufacture.

6. Supply chain management in ETO companies

In ETO companies, the relationships with suppliers were found to vary considerably due to: differing levels of vertical integration; variations in volume for different types of components; the degree of customisation of components; the level of concurrent engineering activity; the value of the item concerned; the proximity to the critical path; and the power balance within the particular buyer/supplier relationships. This variability within, and across companies, means that caution should be exercised in assessing the transferability of supply chain management practices from the high volume to the capital goods sector.

Multi-sourced adversarial trading is widespread in ETO companies. This is characterised by "win–lose" transactions and mutual mistrust. Multiple sourcing constitutes a strategy for reducing purchasing uncertainty [28]. However, ETO companies recognise the importance of developing a more collaborative approach to suppliers. This is because bought-out items and services usually account for a large proportion of total contract value. Attempts to shift towards collaborative relationships are often frustrated by lack of trust due to prolonged adversarial relationships. This situation supports the view of Boyer [29] who identified that cultural constraints, the absence of trust and the prevalence of opportunism were barriers to change in buyer–supplier relationships.

Core activities can be interpreted in several ways [9]. A core activity might be one that is: (a) traditionally performed internally; (b) critical to business performance; (c) creating current or potential competitive advantage; or (d) driving future growth, innovation or rejuvenation of the enterprise. In the ETO sector, the interpretation ranges across these possibilities. This is one of the reasons why the level of vertical integration is varied. In the highly vertically integrated companies, core activities of type (b) were prevalent. At the other extreme, in the design and contract organisations, core activities were of type (c).

The non-physical processes associated with tendering, design and contract management are considered to be core capabilities in ETO companies. This results in more attention being paid to product capability and features than to design for manufacture or assembly. This results in increased cost and excessive variety of components and subsystems. Changing design through standardisation, as well as understanding the product development process [30], offers the potential for managing design and reducing costs.

Large batch and flow line production systems generally exhibit the characteristics of standardisation of products, repetitive manufacturing and assembly processes that are necessary to allow the full application of JIT techniques. For example, the implementation of Kanban, as a method of production scheduling, requires a steady-state flow of materials. However, techniques such as Cellular

Manufacturing, Total Quality Management and inter-company JIT can be applied more widely. Indeed ETO companies use cellular manufacturing methods for items with sufficient volume and stability of demand. Implementations of Cellular Manufacturing and associated team working initiatives involve considerable change in management and workforce attitudes. There are several examples of the successful adoption of these approaches in ETO companies. Statistical Quality Control is often used in such situations but this is restricted to batch and flow processes. It is possible that many of the features of inter-company JIT such as supplier quality certification and point of use delivery could be of use in ETO manufacturing.

Bresnen [18] recognises that the majority of research in supply chain management has focused on particular industrial sectors, such as the automotive industry. The model of a large-scale (hence economically powerful) manufacturer supported by smaller (economically weaker) suppliers, or subcontractors, that applies in the automotive industry is often inappropriate in the ETO capital goods sector. Power within supply chain relationships may be biased toward the supplier, especially for items required in low volumes, on an infrequent basis. The value of the order may not be significant to the supplier. In some cases, the customer specifies the type and source of supply of important sub-systems. For example, a customer purchasing material handling equipment may specify the manufacturer and standard model for control systems. This is to minimise both the diversity of spare parts and the requirement for operator training. Another example of buyer dependence is in the purchase of large, high-integrity forgings, or complex castings used in power generation equipment. In these cases, it is because there are few potential suppliers.

7. Procurement in ETO companies

Procurement obtains the specifications for components and sub-systems from the design function. The effectiveness of procurement in the ETO environment depends upon whether the specifications are correct and appropriate. 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, introduce innovation and reduce costs [31]. Detailed technical specifications reduce the design choices available to the supplier. This may constrain innovation and result in unnecessary design and procurement activities, which increase cost and lead-time. There is a tendency for companies with current, or previous manufacturing capability, to produce specifications that are too detailed. 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" [24]. A 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.

ETO companies make procurement decisions at different stages of product development. First, customers may specify preferred suppliers, or present detailed specifications that can only be satisfied by a limited number of suppliers. Second, components and subsystems may be specified at the tendering stage and cannot be subsequently changed. These decisions sometimes take place by default. Designers select items from suppliers' catalogues based upon their functional characteristics, often without regard to procurement or commercial implications. Third, engineering design may specify items during the detailed design process. This may cause a delay in the availability of detailed specifications. Parts that have long lead-times should be considered early in the design process. Special supplier relations are required to handle the remaining uncertainty in the exact specification. Finally, when standard parts are specified, procurement may respond to requirements at any stage. On the other hand, there may be insufficient constraints on specifications at the early stages of design. For example, if there is only limited re-use of engineering designs across orders unnecessary variety can be introduced. This variety increases the

complexity of procurement and introduces uncertainty and risk [32]. In general, the use of standard designs allows sourcing decisions to be made later [33].

ETO companies tend to have reactive procurement functions that are departmentalised and predominantly clerical in nature. Many sourcing decisions are predetermined by either customer specifications or early design decisions at the tender stage. In many cases, companies use a lowest price ordering strategy. This fails to recognise the benefits of creating partnerships, and the importance of having fewer, more reliable vendors. Consequently, the companies engage in continual vendor assessment and goods inwards inspection, which is wasteful, time consuming and expensive.

To conclude, ETO companies are committing costs through contractual agreements based upon customer or internally generated specifications. Burt and Doyle [34] identified that 75–80% of total avoidable cost is controllable at the design stage. Hence, early, proactive involvement of procurement in tendering and product design decisions is essential to reduce costs. The variety and range of specifications and the high proportion of contract value that is outsourced by ETO companies strongly suggests that procurement should be regarded as strategic. In design and contract companies, bought-out components account for more than 80% of total costs. A strategic view not only assigns procurement operational significance but makes it part of the corporate planning process [35,36].

Matthyssens and Van den Bulte [37] suggest that the procurement specialist needs to evolve into a "supply strategist", whilst Spekman et al. [38] propose that the procurement manager should become an "information manager and manager of external manufacturing". This manager would have responsibility throughout the supplier value chain to gather knowledge about products, processes and competition that could affect the firm's competitive position. Vaughan [39] develops this argument further, suggesting that procurement should be viewed as a strategic process in which the company as a whole participates. He argues that the procurement process in the capital goods industry should be based on cross-functional, project-based teams. The procurement specialist would act as an "information and knowledge broker", obtaining knowledge about markets, competition and innovation.

8. Conclusions

This paper has examined the characteristics of a group of ETO companies engaged in the supply of capital goods. These companies supply high value, customised products, with deep and complex product structure. Their business processes and company structure are described in terms of vertical integration, internal manufacturing processes and outsourced supply. Company structures ranged from vertically integrated businesses, that had significant manufacturing capability, to design and contract organisations that outsourced all physical activities.

There are three stages of interaction between ETO companies and their customers. The first is marketing, which provides an opportunity for the ETO companies to identify market trends, technical, and non-technical customer requirements, and customer criteria for assessing competing offers. The second stage is tendering that involves the preliminary development of the conceptual design and the definition of major components and systems. A technical specification, delivery schedule, price and commercial terms are agreed. 75–80% of costs is committed at this stage. The third stage takes place after a contract has been awarded and includes non-physical processes, such as design and planning, and physical processes associated with manufacturing, assembly and commissioning [7]. Supply chain management in ETO companies involves the co-ordination of internal processes across these three stages.

ETO companies span a continuum from a fully integrated company that manufactures all components and assemblies at one extreme, to a pure design and contract organisation at the other. The appropriate structure for a particular company is dependent upon many factors including cost, capital available for equipment, potential utilisation of plant, internal and external capabilities and flexibility. These factors vary from firm to firm giving rise to different levels of vertical integration.

Supply chain management in the ETO sector is considered in the context of trends in high-volume manufacturing industry. These have included the outsourcing of non-core activities, the focusing of operations, a reduction in the supplier base and the development of long-term collaborative relationships [40]. Tendering, design and contract management are considered to be core capabilities in ETO companies. This often leads to more attention being paid to product capability and features than to design for manufacture or assembly. This results in increased cost and excessive variety. In general, the focusing of operations has led to a reduction in the level of physical activity as manufacturing has been outsourced. There have been some attempts to reduce the supply base and move towards more collaborative relationships. However, these were often frustrated by a lack of trust due to long-standing adversarial relationships. In many cases, the development of partnerships were not justified due to the low volume and infrequent demand for many items.

Procurement decisions take place at different stages of product development. Product subsystems may be defined either by the customer, through tender specifications, or by engineering design. In general, the use of standardised configurations allows sourcing decisions to be made later in the overall process. The level of detail in specifications was found an important issue that determined the effectiveness of the procurement function. Functional specifications allow suppliers to introduce innovation and reduce costs. Detailed technical specifications constrain suppliers and increase cost and lead-time. There is a tendency for companies with current or previous manufacturing capability to produce specifications that are too detailed.

From the analysis of business processes in ETO, the ways in which procurement and its relationships with other processes can be improved, have been identified. First, effective sharing of knowledge and information requires the use of common databases that support tendering, design, procurement, and project management. This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information. This knowledge is a key source of competitive advantage for ETO companies. Second, limiting customisation using modular configurations and standard items provides more flexibility in the timing of procurement decisions, as well as reducing costs and lead-times. This approach also gives higher quality planning data earlier. Third, proactive procurement implies participation in the development of specifications. This requires technical liaison with tendering and design based upon knowledge of potential vendor capabilities and performance. This infrastructure is necessary to make supply chain management strategic in ETO companies.

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