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A Typology of UK Engineer-to-Order Companies

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ABSTRACT *A typology of four ideal types has been developed to classify the different forms of engineer-to-order (ETO) company. This framework is used to examine the impact of market changes on the configuration of production processes. Markets that were once stable are now dynamic and uncertain. The research found that ETO companies have responded to the environmental changes by adopting new configurations. Internal and external supply chains have been reorganised to gain competitive advantage. There has been a shift from vertical integration to the outsourcing of physical processes, as companies seek to reduce costs and lead-times whilst increasing external flexibility. The typology can be used first to map process configurations to environmental conditions, and second to identify the main drivers of configuration change.*

Introduction

Engineer-to-order capital goods suppliers form an important industrial sector of the British economy. Their main business activities are the design, manufacture and construction of plant. They supply highly customised products, in low volume, to meet specific customer requirements. The markets that they compete in are mature and cyclical with supply exceeding demand. Prices have reduced in real terms over the last decade. In addition, customers require faster and more reliable delivery. Demand has shifted from specific items of plant towards turnkey contracts and through-life solutions. ETO companies produce a wide variety of capital goods that are supplied to diverse industries. Some companies have additional businesses,

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which supply fully specified items, such as spare parts, on a make-to-order (MTO) basis.

The limited research that has been undertaken in the low volume ETO sector has focused on production control (Bertrand & Muntslag, 1993), information systems (Wortman, 1995), manufacturing systems (Caron & Fiore, 1995) and the co-ordination of marketing and manufacturing (Konijnendijk, 1994). Research conducted into MTO companies has focused on strategy (Marucheck & McClelland, 1986) and on planning in subcontract engineering job-shops (Hendry & Kingsman, 1989, 1991, 1993; Tatsiopoulos & Kingsman, 1983; Tobin *et al.*, 1987).

The characteristics of companies are determined by their production systems, products, business processes and markets. McCarthy (1995) reviews a range of classification methods and taxonomies of manufacturing systems. Groups of manufacturing systems can be formed through identifying common attributes. If an ideal (or reference) model can be identified for a group it may help reduce the time and costs associated with developing solutions for individual companies.

Joan Woodward (1958, 1965) was one of the first researchers to investigate the relationship between production processes and company structure. She categorised organisations into three groups based upon the manufacturing processes they employed: jobbing, batch or flow. A similar approach was adopted by Burbidge (1971) and Wild (1989). Voss (1987) proposed a two-dimensional classification based upon product and process complexity. Hicks (1998) classified ETO companies according to the depth of product structure and the type of process employed. He identified that many companies have a mix of different types of production process that need to be co-ordinated to meet assembly requirements. This approach forms the basis of the typology developed in this paper.

Methodology

Structural contingency theory argues that there should be a fit between the organisational processes and the environment (Burns & Stalker, 1961; Lawrence & Lorsch, 1967). Configurations that match the environmental requirements should perform more successfully than those that do not. This suggests that under-performing companies may prefer to adopt a new configuration that better fits the environment. However, research into organisational configurations indicates that companies rarely change configurations because strategic and structural changes are expensive and time-consuming (Caves & Porter, 1977, cited in Ferguson & Ketchen, 1999).

The focus of this research was not to examine the relationship between organisational configurations and performance *per se*. Rather, the aim was to explore the factors that determine the configuration of processes. Four ideal types of company were developed to explain how production processes are organised within ETO firms. These were generated deductively from previous research undertaken in ETO companies (Hicks, 1998; Hicks *et al.*, 2000a, b; McGovern *et al.*, 1999). These ideal types were used as a framework for describing, analysing and comparing ETO companies with different configurations of physical processes. The research investigated how these different types of company compete in both stable and dynamic environments. In particular, the trade-off between potential added value and risk/uncertainty was considered.

Five case studies of typical ETO firms with different configurations of processes are presented. These are compared with the ideal types that span a continuum from a vertically integrated company through to a project management organisation.

A Typology of ETO Companies

Figure 1 shows the manufacturing activities and key characteristics of four ideal company types. The variables used to classify companies are the depth of product structure, which indicates product complexity, and the volume of production, which determines whether jobbing, batch or flow processes are employed. All of the ideal types of company shown in Figure 1 have products with deep product structure. The final products are constructed from major assemblies with medium levels of product structure that are produced in low volumes. Components required in low volume are produced on a jobbing basis. Others, required in medium volume, are produced by batch processes, whilst those required in high volume may be produced using flow systems. The various processes involved in component manufacture and assembly

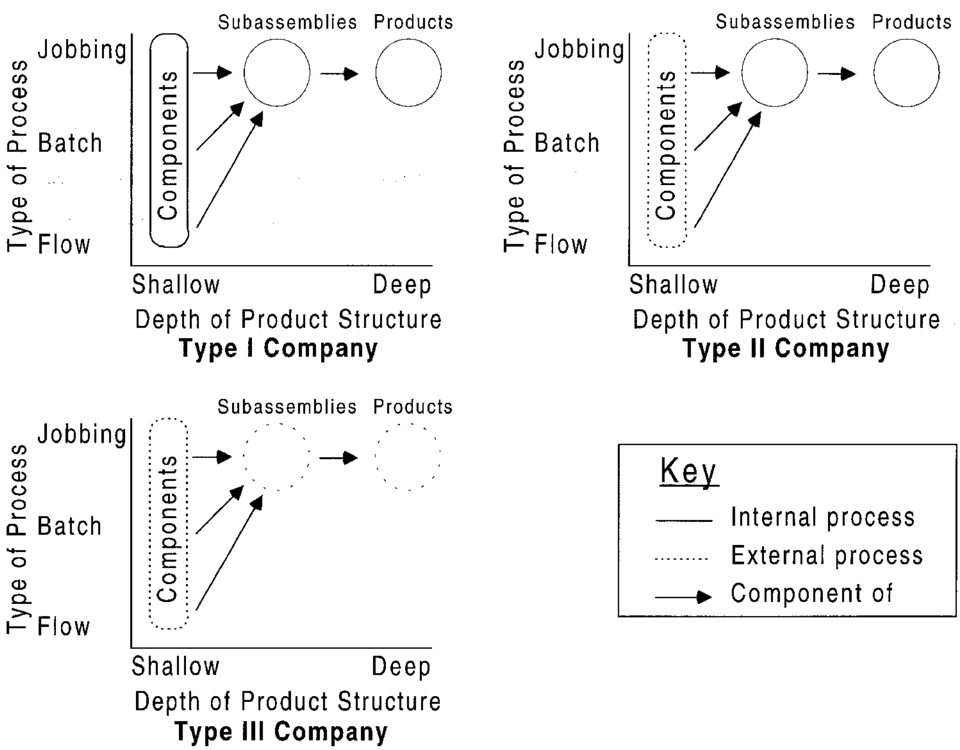

FIGURE 1. A Typology of ETO Companies.

TABLE 1. Four Ideal Types of ETO Companies

	Type I	Type II	Type III(i)	Type III(ii)
Definition	Vertically integrated	Design and assembly	Design and contract	Project management
Core competencies	Design, manufacturing, assembly, project management	Design, assembly, project management	Design, project management, logistics	Project management, engineering expertise, logistics
Competitive advantage	Product and process knowledge; integration of internal processes	Systems integration; co-ordination of internal and external processes	Systems integration; co-ordination of internal and external processes	Reputation; engineering knowledge
Vertical integration	High	Medium	Low	Very low
Supplier relationships	Adversarial	Partnership	Partnership	Contractual
Environment	Stable	Uncertain	Dynamic	Dynamic
Type of risks	Capacity utilisation, return on capital, under-recovery of overheads	Lack of manufacturing may undermine design capability. Sharing core knowledge with suppliers makes them potential competitors	Overall contractual risk, capability and performance of suppliers	Loss of reputation

should be co-ordinated to minimise inventory as well as to enable the final product to be delivered on time. Type I is a vertically integrated company. Type II outsources component manufacture, but maintains assembly and construction activities in-house. Type III outsources all physical processes. There are two forms of this company: the design and contract company, which retains design and project management in-house; and a project management consultancy that outsources design. A description of the main characteristics of the four ideal types is given in Table 1.

Type I: Vertically Integrated Company

Type I companies have core competencies in design, manufacturing, assembly and project management. Their competitive advantage arises from product and process knowledge and the integration of internal processes. For example, product or process leadership may be gained from in-house research and development. Flexibility arises from the organisation and management of the internal supply chain.

There are advantages in being able to match design to in-house manufacturing capability. Design produces full technical specifications, based upon knowledge of available processes, which facilitates design for manufacture and assembly. Technical specifications may be inappropriate for bought-out items, because they limit the design choices available to the supplier. This may constrain innovation and result in unnecessary design and procurement activities, thereby increasing costs and lead-times (McGovern *et al.*, 1999). Integration facilitates concurrent engineering, which permits the overlapping of design and manufacturing activities to reduce lead-times. Relationships with suppliers are subordinate to the management of internal processes. In type I companies multiple sourcing and adversarial trading constitute a strategy for reducing purchasing uncertainty (Hicks *et al.*, 2000a). High value orders with the prospect of repeat business increases the power of the buyer, whereas low value or infrequent purchases increases supplier power. This provides an incentive for ETO companies to employ modular designs with common components and systems.

Having a highly integrated manufacturing capability maximises the potential added value within the internal supply chain. However, this configuration is capital-intensive and gives rise to high overheads. It is necessary to utilise effectively capacity to justify high capital investment and recover large overhead costs. There is a risk that type I companies may not generate sufficient orders to utilise capacity adequately, resulting in a poor return on capital and under-recovery of overheads. This structure was widely adopted by companies supplying nationalised industries with capital goods priced on a cost-plus basis. This type of organisation had an assured market with correspondingly low levels of risk.

Type II: Design and Assembly Company

Type II companies have core competencies in design, assembly and project management. Competitive advantage arises from systems integration and the co-ordination of internal and external processes. Product leadership is based upon in-house design. These companies, through outsourcing component manufacture, have lower overheads and are less capital-intensive than type I companies. However, high value adding assembly processes are retained in-house.

In the ETO sector there are companies that fall clearly between type I and type II. These retain in-house production of critical items manufactured on a unit basis. Although these items vary, their production is characterised by complex and high value added processes. For the purposes of the typology these are regarded as type II companies.

Type II companies have greater volume flexibility than type I companies. However, lead-time reduction depends upon concurrent procurement, which requires the establishment of partnership relationships with suppliers. In practice, in capital goods companies, this approach has been less successful than concurrent engineering applied by type I companies. Design should produce functional specifications, as there is no need to produce the technical specifications that are required for in-house manufacture. Relationships with suppliers are based upon partnerships that facilitate the sharing of product and process knowledge. The balance of buyer/supplier power within relationships depends upon a number of factors. These include the volume of demand for particular items, the value, the number of alternative suppliers, switching costs and customer preferences.

The capacity utilisation and overhead recovery risks are lower than for type I companies due to the absence of component manufacture. Increased outsourcing requires more sharing of knowledge with suppliers. There is a potential loss of competencies such as the ability to design for manufacture. There is a further risk of suppliers becoming potential competitors as barriers to entry are reduced.

Type III(i): Design and Contract Company

Type III(i) companies have core competencies in design, project management and logistics. All physical processes including component manufacture, assembly and construction are outsourced. Competitive advantage is based upon systems integration and the co-ordination of internal and external processes, with product leadership based upon in-house design. There is an increased use of standard components and systems that may reduce costs and lead-times. The use of functional specifications allows suppliers to develop their own designs, introduce innovation and maximise value.

This type of company controls design and supply by retaining the expertise to integrate subsystem performance specifications to meet stated and unstated customer requirements (McGovern *et al.*, 1999). The necessary sharing of design information and knowledge with suppliers and contract staff may make it difficult to retain product leadership, as potential competitors may have access to detailed product knowledge.

Outsourcing all physical activities reduces capital employed and lowers overheads. Components, subsystems and labour may be obtained from low cost economies such as Eastern Europe or China. The use of external resources provides substantial configuration, delivery and volume flexibility. The lack of in-house manufacturing expertise may limit the ability of these firms to design effectively for manufacturing and assembly. As systems integrators, these companies may bear overall contractual risk. However, suppliers normally only accept the risk associated with their component of supply. Relationships with suppliers are based upon partnership sourcing agreements.

Type III(ii): Project Management Company

This type of company is a consultancy that manages contracts on behalf of a client. All physical processes and design are outsourced. It has core competencies in project management, engineering and logistics. Consultants compete on reputation, performance on previous contracts and engineering knowledge and expertise. The overheads and capital employed are very low. Engineering is a prime function upon which the company's reputation depends. It is responsible for the initial specification and the technical evaluation of tenders from design houses, suppliers and subcontractors.

Recommendations are made to the client based upon their evaluation criteria. This may either encourage or inhibit innovation.

The consultant takes responsibility for the management of the overall project on behalf of the client. Consultants derive flexibility from their "open architecture", which permits dynamic relationships with multiple clients, suppliers and subcontractors. These are based upon clearly defined contractual liabilities. Consultants may charge for their services in several ways: a percentage of contract value, an hourly rate (where the total may have an agreed ceiling) or a fixed lump sum. Financial risk is borne by the client, suppliers and subcontractors. The type III(ii) company bears little risk.

ETO Companies and Their Products

Five companies were selected for comparison with the ideal types. They are representative of different types of company within the ETO sector in terms of their configuration, products, markets and size. A summary of the main characteristics of these companies is provided in Table 2.

Companies A and B are the largest in terms of turnover and number of employees. They have considerable in-house manufacture. In the case of company A, a turbine consists of a rotor, casings and blading. The rotor and casings are physically large and heavy. They have complex geometry and machining processes. Manufacture is in low volume on a jobbing basis. The blades have complex geometry and are manufactured in batches. Other

TABLE 2. ETO Companies

Company	Major Product	Sub-sector	Turnover (£M)	Employees	Typical Order (£M)	Type of Order
A	Steam turbines	Power generation	200	800	50–300*	ETO/ MTO
B	Offshore production facilities	Offshore	100	900	20–100	ETO
C	Electronic controls and instrumentation	Power electronics and instrumentation	20	200	0.5–5	ETO
D	Cranes	Material handling	25	60	10	ETO
E	Consultancy	Power generation, distribution and utilisation	22	550	50–500*	ETO

* Value of contracts managed.

items such as core plate laminations for a generator stator may be required in very large volumes and are manufactured on a flow line basis. Companies B and D produce products that have a large structural component with associated fabrication activities. In these cases, the raw material is either steel plate or standard section that is cut into an appropriate shape before fabrication. Company B has its own fabrication facilities, whereas company D does not. In both cases, mechanical, electrical and control systems are bought-out. Company C designs and assembles bespoke electronic control systems using proprietary components. These are supplied predominantly to the power generation and distribution industries. Company D is a leader in the application of high integrity and severe process crane technology. It supplies custom-built cranes to the nuclear, defence, steel, power generation and waste-handling industries. Company E is an engineering consultancy that specialises in the provision of project management and engineering services to the utilities.

The main products of companies A–D have deep and complex product structures, which give rise to many levels of assembly process that need to be co-ordinated with component supply. Certain items are highly customised, whilst others are standardised. Components such as the control systems are technologically advanced whereas other items such as structural steelwork are not. For the vertically integrated companies A and B, co-ordination is predominantly internal, whereas the other companies, which have extensive outsourcing, mostly depend upon the successful management of external relationships. ETO products contain a diversity of components. Some items are required in very low volume, whereas others are required in medium or large quantities. This leads to a variety of supply chain relationships.

Companies A and B correspond closest to type I, C to type II, D to type III(i) and E to type III(ii). Companies A–D supply main products with high levels of customisation. These require substantial product development to meet specific customer requirements. The products are therefore produced on an ETO basis. Company A has mini-businesses involved in service and spares and subcontract engineering. These involve the supply of fully specified items with shallow-to-medium product structure on a MTO basis. Company C has four strategic business units. These all operate on an ETO basis. Company E may act as a consultant for the customers of companies A–D.

Risk

There are many sources of uncertainty with respect to demand, cost, price, specification, duration of processes and lead-times. Missing information and engineering revisions caused by the overlapping of manufacturing and design activities are major sources of uncertainty that complicate the management of ETO manufacturing. Muntslag (1994) identified three categories of order-dependent risk in ETO supply: technical, time and financial. Companies A–D are exposed to technical, time and financial risk. The risk associated with bought-out items is normally transferred to the supplier. However, risk magnification may occur. This is because problems with a sub-system may result in companies A–D incurring penalties on the whole contract, yet the supplier is liable only for the parts it supplies. Company E, on the other hand, is risk-averse. For all company types the level of risk is dependent upon the degree of mismatch between the ideal type and its market environment.

Comparison of Collaborating Companies with Ideal Types

In this section, the market environments of the collaborating companies are described. The link between market environment and company configuration is reviewed. Fundamental changes in customers' markets, for example the deregulation of the electricity supply industry, have transformed the market for capital goods. These changes have profound implications for the competitiveness of capital goods companies with different configurations. In particular, there has been a shift from vertically integrated configurations towards increased outsourcing.

Market Environment

The companies in this study, in the main, supply the offshore and power industries. ETO companies supplying the UK power industry have been affected by the Electricity Act of 1989. This provided a framework for the privatisation of the electricity supply industry, which was separated into a competitive market for generation and supply and regulated monopolies responsible for transmission and distribution. In both cases, there has been a shift in focus from engineering to the customer's functional requirements. Similar deregulation has occurred in the USA and elsewhere. ETO goods supplied to the industry are now obtained on a competitive rather than cost-plus basis. The once cosy relationships between power plant suppliers and local state-owned utilities encouraged capital goods companies to pursue country-centred strategies (Porter, 1986). Deregulation resulted in a break-down of these relationships and capital goods companies now compete in global markets. This has led to severe pressures on margins and in some cases suppliers have cut their factory costs by up to 50% as a means of reducing prices (Wagstyl, 1996). Customers are seeking turnkey solutions as they scale down in-house engineering and project management to reduce costs.

Prior to the market changes, company A corresponded directly to ideal type I, with all activities undertaken on a single site. However, this configuration required an assured market and low levels of risk. There were several attempts to meet the new market conditions, but they proved to be of no avail. Company A was unable to generate sufficient business to cover its overheads. High losses were incurred and the company was eventually acquired by a competitor. The turnaround strategy adopted by the new management was to focus on component manufacture, with some assembly. This capitalised on specific capabilities and resources. The volume of work increased as the facilities became the new group's manufacturing base for specific components and assemblies. This allowed the company to achieve the required economies of scale. The output was supplied to the group's other plants. The combination of activities covered by the merged organisation created a new multi-site type I organisation with global specialisation and increased scale and scope.

Company B is a vertically integrated company of type I. It has competencies in design, manufacture, assembly, construction, commissioning and project management. However, its in-house activities focus upon structural items and associated fabrication activities. Mechanical systems, instrumentation and control systems are bought-out. The offshore industry has evolved due to changes in the economics of oil exploration. Until recently oil prices were relatively low, and the recent rise has not yet produced new orders for oil platforms. Larger fields are becoming exhausted and there is a shift to more marginal fields. The oil companies have focused upon increasing flexibility and reducing the capital cost of oil extraction. This has reduced the demand for static oil-rigs, whilst orders for reusable and mobile production units (developed from refitted oil tankers) have increased.

The offshore market has been transformed by the changing structure of supply chains. This has been driven by an industry-wide initiative "Cost Reduction in a New Era" (CRINE), which has received the support of the oil companies and contractors. The aim is to create a world-class supply chain in the UK offshore industry by generating a new culture of co-operation between operators, contractors and suppliers. This represents a shift from adversarial to obligational contracting (Sako, 1992). The initiative has set a target of increasing the UK's share of the global market (outside the UK Continental Shelf) from less than 1% to over 5% by 2003 (Gugen, 1998). These changes have been far-reaching and have led to an overall reconfiguration of supply chains. Industry-wide standard contracts and the adoption of functional specifications are policies that have helped to release value, reduce lead-time and encourage innovation.

The oil companies have considerably reduced their overheads by outsourcing design and technical expertise. Their new strategy is to form strategic alliances with suppliers. Risk and reward are shared, with two types of performance incentive. The first relates to the overall project and applies to all companies within the alliance. The second is an individual incentive that applies to each particular company's performance. The configuration of processes within company B corresponds to ideal type I, although the value and scale of individual contracts have been reduced.

In the past, company C was a type II firm that was a subsidiary of an integrated group of companies that concentrated on the supply of capital goods to the power generation and distribution industries. The core business was the provision of control and instrumentation to group companies. It also had several mini-businesses that operated as independent profit centres. Owing to the changes in the electricity supply industry described above, and a change in ownership, the core business became power electronics, focusing upon the growth market of control systems for aircraft engines. The supply of ETO equipment to the mature and declining power generation business has become non-core. The ETO business associated with the control of electrical distribution was transferred to a sister company, which was later sold to a competitor. A new business that specialises in traffic management systems, including sensing and variable message displays, has been developed that predominantly supplies standard products on a MTO basis. The company is a world leader in this high growth market due to technical leadership, yet surprisingly this activity is considered a non-core business, due to its lack of fit with the company's other activities. The company has retained its type II configuration, although it has increased the diversity of its product range, with assembly becoming a profit centre.

Company D used to be a vertically integrated type I firm. However, the market for cranes has become increasingly competitive and uncertain in terms of volume. As a consequence, this configuration was no longer viable. All physical processes were outsourced to reduce overheads and increase the return on capital, which changed the configuration to type III(i). The company has two businesses: supplying new customised cranes and refurbishing/ extending the life of old machines. These are supplied to five markets: nuclear, steel, power generation, waste-handling and defence. Many of the markets served by company D are mature. There is, however, a trend to refurbish, upgrade and extend the life of existing machines, particularly in the steel and waste-handling sectors. There is also growing competition, especially in the power generation industry, from companies offering modular, off-the-shelf standard cranage. However, the company has identified a market niche by supplying through-life solutions for customers. This includes the financing, installation and operation of the plant over its anticipated life. These additional services substantially increase the profitability of contracts.

Company E is of type III(ii). It competes on price and reputation. Its major competitors are other consultancies, design and contract firms [type III(i) companies] and utilities offering consultancy services. The utilities in the UK have been subject to increasing regulation, which reduced margins through the imposition of price controls. As a consequence, the utilities have developed services that lie outside the scope of their respective regulators. This has significantly increased competition in the markets served by company E. The configuration of this firm has proved to be robust with respect to changes in the market.

Discussion

In the markets served by companies A–D, innovation and technical features have become less important, making it possible to meet customers' requirements with more standardised modular designs. Price and delivery are critical order-winning criteria. Intense competition in global markets has made cost reduction essential. This has been achieved by reducing overheads and improving product design to reduce material, manufacturing and assembly costs. In particular, the reuse of engineering designs and the standardisation of systems, sub-systems and components are important strategies for reducing costs. This has caused a shift away from the vertically integrated type of company towards increased outsourcing. The new configurations are relatively recent phenomena and have been formed from previously vertically integrated companies.

ETO companies derive competitive advantage through understanding customer requirements, translating them into specifications at product and component level and integrating components and sub-systems into products (McGovern *et al.*, 1999). This requires the sharing of knowledge throughout the internal and external supply chain. The understanding of customer requirements is based upon knowledge of the operation of plant. Much of this has been acquired during the final installation, commissioning and maintenance of products. Capturing this knowledge becomes a challenge when these activities are outsourced. Some engineering expertise, such as the ability to design effectively for manufacture and assembly, is difficult to maintain when physical processes are bought-out.

Improving delivery is dependent upon reducing lead-times and increasing the reliability of estimates. Lead-time reduction has been achieved by shortening the duration of individual processes and by increasing the overlapping of previously sequential activities. Sometimes this is also a driver of outsourcing decisions. Improving the reliability of lead-time estimates requires accurate forecasting of the duration of activities at the contract negotiation and planning stages. Effective control is necessary to ensure that each project progresses in accordance with the plan. Project management is critical for all of the companies irrespective of type. The ability of project management to manage contracts effectively is dependent upon the performance of in-house processes and outsourced supply. In type I companies that had matrix management structures, it was common for the balance of power to be biased in favour of functional departments. In such circumstances project managers sometimes preferred to outsource as they had greater leverage and control (Cullen, 1995). In the markets served by companies A and D, there has been an increasing requirement for turnkey solutions rather than specific items of plant. New competencies in finance and operations are required to support this trend.

In all of the sub-sectors of ETO industry, it is common for key procurement and manufacturing activities associated with long lead-time items to take place before the design is finalised. This can result in engineering revisions, which give rise to modifications that need to be dealt with by the manufacturing and procurement functions and suppliers. In certain cases, when an order is of strategic importance to the company and early delivery is crucial, long lead-time items may be ordered on a speculative basis before the contract has been signed (Marucheck & McClelland, 1986). This could be considered a high-risk strategy due to the low tendering success rates and the bespoke nature of the products, which makes the reuse of speculatively purchased items difficult.

Conclusions

The companies in the ETO sector are changing rapidly. A typology of ideal types has two main uses. First, it classifies ETO companies. Second, it provides a framework for analysing how company structure, expressed in terms of the configuration of physical processes, is affected by market and environmental changes.

The case studies reveal that the configuration of processes should not be conceptualised as static. ETO companies can adopt new configurations in response to environmental change. Vertically integrated firms thrive best in stable markets with low levels of risk. Here the major concern is the effective management of the internal supply chain. Relationships with suppliers are usually adversarial. However, as the environment becomes more uncertain and markets more dynamic, vertical integration becomes a high-risk strategy. Companies must adopt new strategies to reduce costs and lower their exposure to capacity utilisation risks. This can be achieved by the adoption of less capital-intensive configurations. Internal flexibility is replaced by a focus upon external flexibility, as companies outsource physical activities to reduce overheads and capital employed. In these dynamic markets, ETO companies may develop specialist roles as systems integrators and project managers. Concurrent procurement may displace concurrent engineering as ETO companies form partnerships with key suppliers.

This research has demonstrated that ETO firms can be classified by the structure of physical processes. Shifts between these structures are made in response to changes in market and environmental conditions. Indeed, dramatic structural shifts have taken place, moving companies from one type to another. This observation from the case studies supports the utility of the proposed typology. However, many questions still remain. Are ETO configurations stable over time? What are the environmental or strategic issues that precipitate a move to another configuration? What are the inertial forces, such as embedded knowledge, working practices and risk avoidance, which prevent companies changing configuration?

Where companies face a lack of fit with the environment, significant differences in performance should be expected across the configurations (Ketchen *et al*., 1993). An assessment should be made of the critical differences between those firms that shift configuration and those that do not. The authors are currently working on extending this research by focusing on strategy and decision-making in ETO companies. The aim is to look at the major threats to the survival and success of each of the configurations, together with the strategies that succeed in particular environments.

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