An Analysis of Company Structure and Business Processes in the Capital Goods Industry in the U.K.

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***Abstract*—This work is based on a study of capital goods suppliers to the power generation and distribution, materials handling, and offshore industries. Business processes are project-based and interdependent. They include sales, marketing, tendering, engineering, manufacturing, procurement, assembly, and commissioning. A model is presented which groups these processes into three categories: nonphysical, physical, and support processes. Capital goods companies have dynamic and evolving structures, aggregating processes in ways which seek to exploit new and changing markets. The model provides a mechanism for describing and analyzing structures. The combination of structural, process, and operational perspectives offers a framework for the analysis of capital goods companies.**

***Index Terms*—Business processes, capital goods.**

I. Introduction

CAPITAL goods companies form an important industrial sector of the British economy. The main business activities are the design, manufacture, and construction of plant. They supply highly customized products, in low volume, on a make-to-order (MTO) or engineer-to-order (ETO) basis. Their markets are mature and cyclical with supply exceeding demand. Prices have reduced in real terms over the last decade, and customers require faster and more reliable delivery. Demand has also shifted from specific items of plant toward turnkey contracts and through-life solutions. These companies have been neglected by academic research. The limited research that has been undertaken in the low-volume engineer-to-order sector has focused on production control [1], information systems [2], manufacturing systems [3], and the coordination of marketing and manufacturing [4]. Research relating to MTO companies has focused on strategy [5] and on planning in subcontract engineering job-shops [6]–[10]. Previous research has not investigated company structure and its interrelationship with business processes.

This paper is based upon four case studies of typical companies producing capital goods for the power generation, power distribution, materials handling, and offshore industries. The first part of the paper describes the characteristics of these companies, their markets, and their products. The second part reviews company structure and operations through the application of a model of business processes. These are classified into nonphysical, physical, and support processes. The first category relates to information and knowledge-based processes such as tendering and engineering. The second group of processes involves the physical realization of the product through manufacture, assembly, and construction. The third includes staff functions such as finance and human-resource management.

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II. Capital Goods Companies, Products, and Markets

Information on the collaborating companies is provided in Table I. The main products of all of the companies have deep and complex product structures, which give rise to many levels of assembly processes that need to be coordinated with component supply. The products contain diverse components. Some items are required in very low volume, whereas others are required in medium or large quantities. Certain items are highly customized, while others are standardized. Components such as control systems are technologically advanced whereas other items such as structural steel-work are not. The demand is "lumpy," with each unit of demand representing a large proportion of design and manufacturing capacity.

Companies A, B, and C produce main products with high levels of customization. These require substantial product development to meet specific customer requirements. The products are therefore produced on an ETO basis. Companies A and C have a service and spare-parts business, which involves the supply of items with shallow-to-medium product structure. Company A has an additional subcontract engineering business. Switchgear (company D), spares (A and C), and subcontract engineering (A) are normally fully specified at the order acceptance stage. Companies A and D produce these items on a MTO basis, while company C outsources manufacturing.

Companies A, B, and D are involved in strategic alliances. Company A has established a technology-sharing agreement with a competitor. Company B participates in strategic alliances established by the oil companies. Company D has established joint ventures with companies in India and China, to facilitate low-cost manufacture.

The supply of capital goods is characterized by significant financial and commercial risk and by high levels of uncertainty with respect to the specification, demand, and duration of processes and lead-times. The overlapping of manufacturing and design activities as well as engineering revisions often complicates production. This is a major source of uncertainty that complicates the management of capital goods manufacturing.

A. Markets

In all of the companies, innovation and technical features have become less important, making it possible to meet customers' requirements with more standardized modular designs. Price and

TABLE I
CAPITAL GOODS COMPANIES

Company	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	Cranes	Material Handling	25	60	10	ETO
D	Switchgear	Power distribution	150	600	50-100	MTO

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. Improving delivery is dependent upon reducing lead-times and improving 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. Improving the reliability of lead-time estimates requires accurate forecasting of the duration of activities at the contract negotiation and planning stages. In the markets served by companies A and C, there has been an increasing requirement for turnkey solutions rather than specific plant items.

Capital goods companies supplying the U.K. power industry have been affected by the Electricity Act of 1989. This provided a framework for the privatization of the electricity supply industry and its separation into competitive sectors comprising generation and supply with regulated monopolies responsible for transmission and distribution. In both cases, there has been a shift in focus from engineering to the customer. Capital goods supplied to the industry are now obtained on a competitive rather than cost-plus basis.

Gas has become a preferred fuel for electricity generators for a number of reasons. In comparison with coal-fired power stations, new combined cycle gas turbines (CCGTs) have low capital cost. Shorter construction times allow for greater flexibility in deciding when to build new stations. Modular design makes them ideal for turnkey contracts. They consume less fuel and have lower emissions of carbon dioxide and nitrogen oxides [11]. The restructuring of the electricity supply industry has eliminated the demand for large steam turbines in the U.K. Gas turbines are physically smaller than steam turbines and are technologically different in terms of design, materials, and manufacture. Company A has been unable to respond to these market changes; it declined rapidly, and the manufacturing facilities were eventually acquired by a competitor.

Company D is a supplier to the electrical distribution industry. It has developed a new range of switchgear using carbon fiber insulators. The design dramatically reduced the number of components and the complexity of manufacturing and assembly. The products are technically superior, are produced at lower cost, and with shorter lead-times. The company has remained competitive in national and international markets.

Suppliers in the offshore industry have been affected by the changing economics of oil exploration and extraction. Oil prices have fallen, larger fields in the North Sea are becoming exhausted, and there is a shift to more marginal fields. This has reduced the requirement for static oil rigs, while the demand for reusable and mobile production units, developed from refitted oil tankers, has increased. The offshore market has been transformed by the changing structure of supply chains. The oil companies have considerably reduced their in-house design and technical expertise. Their new strategy is to transfer this expertise down the supply chain and to form strategic alliances with suppliers.

Company C is a leader in the application of high-integrity and severe-process crane technology. It supplies custom-built cranes to the nuclear, defense, steel, power generation, and waste-handling industries. Many of these markets 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. Through this strategy, the business achieves very high margins compared to selling plant directly. New competencies in finance and operations are required to support this activity.

In all of the subsectors of the capital goods industry, it is often necessary for key procurement and manufacturing activities associated with long-lead-time items to take place before the design is finalized. This can result in engineering revisions that need to be dealt with by manufacturing, procurement, 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 [5]. 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.

III. COMPANY STRUCTURE

There are two distinct stages of interaction between a capital goods company and its customers and suppliers. The first stage is tendering in response to an invitation to tender (ITT) for a particular contract. The second stage of contact takes place after a contract has been awarded. Contract execution starts with nonphysical activities including the development of an overall project plan, detailed design, and procurement. This is followed by the physical processes of component manufacturing, assembly, construction, and commissioning.

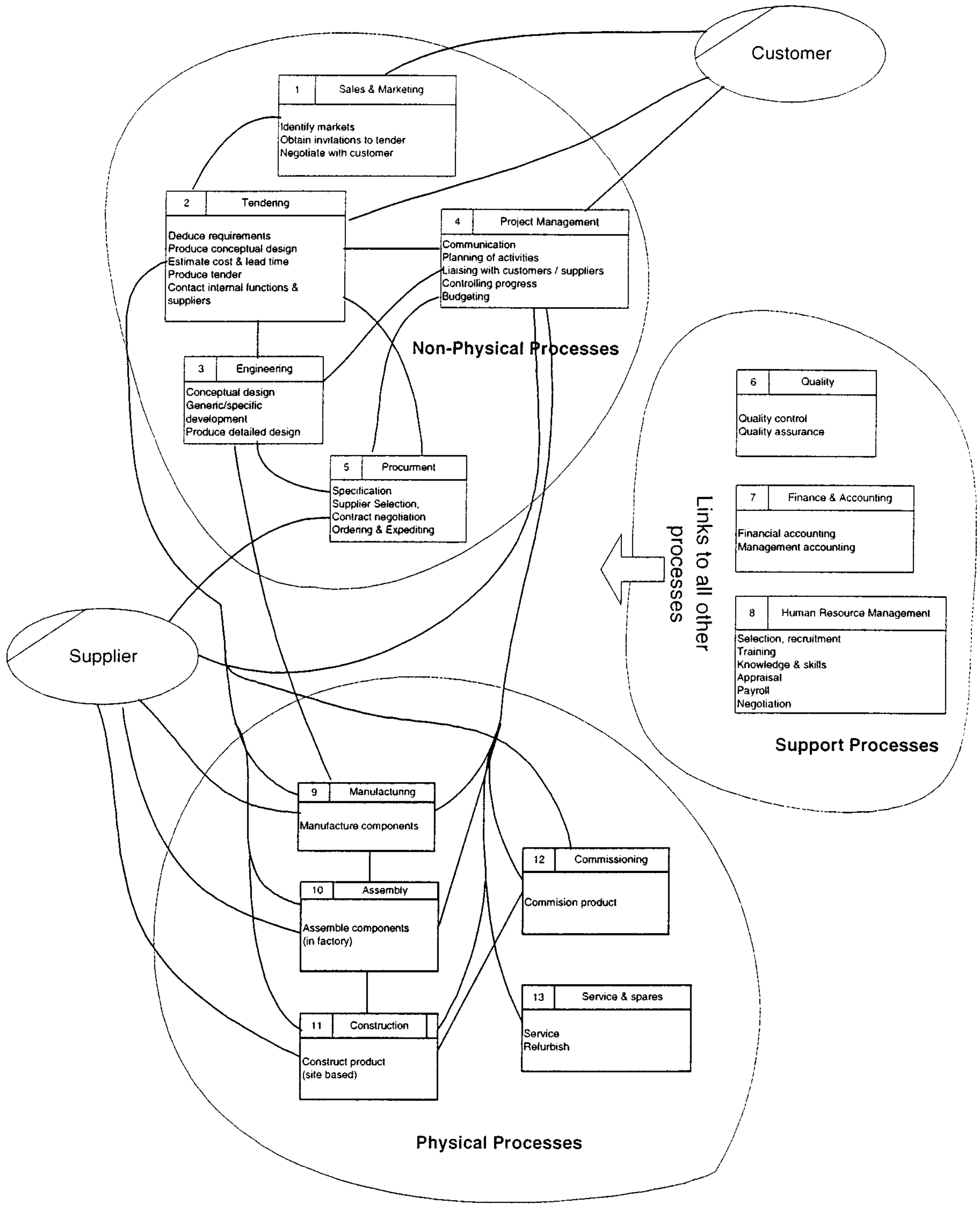

Fig. 1. Model of business processes.

The amount of physical activity is dependent upon the level of vertical integration.

The extent of product definition at the order-acceptance stage is important. It determines the requirement for design activity and also whether products are supplied on an MTO or ETO basis. Product development may be generic, applying to a range of products, or it may be specific to a particular contract. ETO companies, producing customized products have high levels of specific design activity supported by generic engineering. Specific product development is far less important in MTO companies.

ETO supply involves a nonphysical stage that includes tendering, engineering, design- and process-planning activities, and a physical stage that comprises component manufacturing, assembly, and installation [1]. MTO companies operate in a similar way. This classification of nonphysical and physical processes, with the addition of support processes, forms the basis of the model shown in Fig. 1. Companies possess subsets of these processes and relationships, which depend on market, product, and capability. For example, if a company has no manufacturing, the function and all of its relationships are omitted. An important characteristic of capital goods companies is that the processes engaged in by particular companies may change radically and evolve quickly in response to market opportunities. A vertically integrated company would have nonphysical, physical, and support services. A pure design and contract organization would have only the nonphysical and support processes with all physical processes outsourced to suppliers. Other forms of organization are possible. For example, a project management company may coordinate the activities of a design contractor and other suppliers on behalf of a client.

A. Nonphysical Processes

The classification of nonphysical processes covers the activities from marketing to procurement shown in Fig. 1. These will be considered in further detail in the following sections.

1) Marketing and sales: The marketing function identifies market opportunities, develops potential customers' awareness of the company and its products, and establishes initial contacts. Sales receives ITT from customers and is responsible for preliminary negotiations. All of the companies were more sales- than marketing-oriented. They possessed limited quantitative market information and often used an informal approach in making marketing decisions. Demand is difficult to forecast due to the cyclical nature of the markets and the low tendering success rate. The lack of formal and systematic analysis has constrained the identification and development of new markets. Konijnendijk [4] suggests that the coordination of marketing and supply in ETO companies has three aspects.

1) *Specifications*: ETO companies will usually offer a range of products based upon earlier experiences and product developments related to basic technology used in each machine or installation. Innovation is often related to customer orders. Specifications can only be coordinated for specific customer orders. It is common for senior management to become involved in the product specification and contract negotiation processes as order acceptance is often strategically important;
2) *Volume and Mix*: Due to the highly customized nature of many products, medium- and long-term planning is usually based upon highly aggregated information expressed in terms of value or labor content. Decisions regarding in-house capacity and outsourcing often take place at this level.
3) *Lead-Times*: The quotation developed during tendering normally includes a delivery date, based upon an estimate of lead-time. This is usually produced without using information on capacity availability. This may be due to "floating" quotations awaiting responses from potential customers. The detailed specifications that determine work content and type are also uncertain at this stage. It is therefore necessary to reconsider the lead-times and delivery dates at the order acceptance stage.

Our research indicates that in addition to coordinating marketing and supply, it is essential that capital goods companies coordinate marketing, product development, procurement, and manufacturing activities to improve their success in obtaining new business. This could be accomplished by sharing information, knowledge, and decision making.

2) Tendering: Tendering is the key business process responsible for producing solutions that are competitive in terms of functionality, price, delivery, and quality. Typically, 85%–90% of cost is committed by the tender [12]. Customer requirements are deduced and translated into a conceptual design, which defines major components and systems. Contact is made with manufacturing and selected suppliers to obtain technical information, costs, and lead-time estimates. There are a number of phases of negotiation that aim to match design specification, overall project costs, and lead-time with explicit and implicit customer requirements. A technical specification, delivery schedule, price, and commercial terms are included in the tender. The development of the specification requires knowledge of the specific product application and individual customers' preferences. This would imply the need for a strategy based upon customer intimacy [13].

A tendering success rate is often less than 30% [4]. Success in gaining individual contracts is of strategic importance. Tendering costs are substantial; it is, therefore, important for management to assess the likelihood of winning a particular contract in order to justify the financial outlay. Improved marketing information could increase the success rate and potential profitability of contracts gained. The delivery times quoted act as a major constraint after the contract has been awarded. The tendering activity, therefore, has a large impact on the performance of capital goods companies.

The realization of potential competitive advantage gained from research and development, engineering design, and suppliers depends upon the sharing of knowledge and information with the tendering function. Tender documents need to include innovations in the preliminary designs submitted to the customer. It was found that in companies A and C, the integration of these functions was poor, with tendering having separate databases from the other functions. Knowledge was only shared informally. Information developed by tendering was not always used by the engineering departments, which sometimes started the design without reference to the tender document. In these cases, there is likely to be considerable variance between planned and actual costs and lead-times. Company D, which had better integration of tendering and engineering, had a higher tendering success rate.

3) Engineering: Engineering is responsible for product development that involves both conceptual and detailed design activities. All of the companies considered it a core activity. Information and knowledge are stored using formal and informal systems. In most cases, this was found to be a mix of paper-based and computer-based methods. The major benefits of computerized systems are that the retrieval and reuse of engineering information is far easier. Integration of design with analysis software and manufacturing provides a mechanism for the effective sharing of information. Computer-aided engineering (CAE) techniques enabled the companies to improve product performance and reduce costs while reducing the need for prototype testing and physical model building.

The design engineers' knowledge of customer requirements often provides a competitive edge. For example in Company

C, an engineer's field experience may help to develop products that are easier to maintain. Experience of manufacturing and assembly facilitates the development of products that are easier and cheaper to produce. For companies without physical processes, it is difficult to acquire and maintain such experience. Knowledge of potential suppliers and their products and capabilities is also essential. An awareness of costs and the relative benefits of "make" versus "buy" are also important. Much of this knowledge is tacit rather than explicit [14], which can cause problems when personnel changes occur. Developing effective systems for capturing and sharing information and knowledge is a critical issue.

The effective management of the engineering function is very important as the design determines the functionality of the product and has a large influence on manufacturing, procurement, assembly, construction, cost, and lead-time. The planning and control of design is often difficult due to its uncertain and iterative nature.

4) Project management: Project management is responsible for developing overall plans and monitoring progress after a contract has been awarded. This involves coordinating the internal functions and meeting with customers and suppliers. The due date, product configuration, and major costs are committed by the tendering activity. This is a major constraint on the project management function. Whether project managers should be involved in the development of tenders was an issue in companies A and C.

All of the companies used computerized project management systems of varying sophistication based upon techniques such as the Program Evaluation and Review Technique (PERT) or the Critical Path Method (CPM). Both are centered on the "project structure" represented by a network of tasks that depicts the activities involved and how they depend upon each other in terms of sequence and interrelationships. Networks allow for the linking of activities whose start and finish times are not coincident with immediate predecessors and successors [15].

Caron and Fiore [3] describe project management in an ETO context. Once a contract has been agreed upon, a work breakdown structure (WBS) is drawn up. They distinguish between the following.

1) Standard subsystem work packages (manufacturing work packages), which have a defined bill of materials and lead-time information correspond to standard parts or kits of standard parts. These may be amenable to material requirements planning and control.
2) Nonstandard work packages (development work packages) include design activities that result in the definition of the product and the bill of materials. The management of these work packages requires coordination of design, manufacturing, and assembly activities.

Manufacturing work packages apply to MTO supply (company D), whereas ETO activities (companies A, B, and C) may have both manufacturing and development work packages. The significance of the nonstandard work packages is determined by the level of customization. In companies B and C, the products are more customized than those produced by company A and the nonstandard work packages are therefore more significant. The development work packages are characterized by greater cost and uncertainty than standardized work packages. Caron and Fiore [3] suggest that due to organizational learning, some functional subsystems initially characterized by a high rate of innovation (and therefore complex to plan and control) may show a tendency to stabilize over time, finally reaching actual standardization. It would be advantageous for companies A, B, and C to maximize the level of standardization as the reuse of knowledge (designs, plans, etc.) reduces uncertainties and helps minimize costs and lead-times. It also simplifies inventory management.

Process durations associated with bespoke activities are difficult to estimate before the product development process has been completed. Lead-times depend upon internal and external factors. The former comprises

1) number of iterations involved in the design process;
2) existing workload;
3) availability of resources;
4) relative priority of the contract, which includes the delivery performance of suppliers and subcontractors.

All four of the organizations surveyed had a matrix management structure. The perception of project managers was that many of their problems were due to interactions with other functions rather than with project planning [16]. The research revealed that the relative power of the functional departments was greater than project management in companies A, C, and D, which led to problems with the prioritization of work. The move toward turnkey and through-life solutions has increased the scope of supply to include civil engineering activities for companies A and C. This has increased the level of outsourcing and the importance of project management.

5) Procurement: Bresnen [17] recognizes that the majority of work in supply chain management has been narrowly focused on particular industrial sectors such as the automotive industry. The common model of a large-scale (hence, economically powerful) focal manufacturer supported by smaller (economically weaker) suppliers or subcontractors that applies in the automotive industry is often inappropriate in the capital goods sector. It is common to find that power within supply chain relationships is biased toward the supplier. Many items are required in low volumes on an infrequent basis, and the value of the order may not be of much significance to the supplier. There is considerable diversity in procurement practice in the capital goods industry. Company D, that supplies standardized products on a MTO basis, has sufficient volume to have developed strategic procurement initiatives. The ETO companies, A, B, and C, have unstable, low-volume demand, and have therefore had difficulty in applying a strategic approach.

Hicks *et al.* [18] identified that buyer–supplier relationships in the capital goods industry are influenced by the type of specification (functional or technical). Detailed technical specifications reduce design choices available to the supplier, constrain innovation, and may increase costs and lead-times.

The tendering and contract execution phases of capital goods supply both involve communication with procurement. Tendering requires accurate data on items purchased. Engineering needs information on current and potential suppliers at both the conceptual and detailed design stages. Procurement, therefore, needs access to knowledge about the functionality and specification of components and subsystems to enable the proactive development of supplier relationships. To fulfill this role, procurement personnel require both technical and commercial expertise, as they need to understand the other functions at the tendering stage and during contract execution.

B. Physical Processes

The classification of physical supply processes comprises activities from manufacturing to commissioning as shown in Fig. 1. It can be seen that there are two sets of links with the nonphysical processes. The first is at the tendering stage when estimates are required on costs and activity durations. The second is at the contract execution stage. Product descriptions are obtained from engineering. There is communication with project management that coordinates activities, provides plans, and monitors progress. This model shows a configuration in which the physical processes communicate with the nonphysical processes through project management. There is additional informal communication between business processes. For example, if there is a material shortage, manufacturing may contact procurement directly, rather than going through projects. The physical processes will be considered in more detail in the following sections.

1) Manufacturing: Manufacturing activity is capital-intensive with high recurrent costs. In vertically integrated companies, it is responsible for most of the capital employed. Overheads are a large proportion of total costs and they change over time due to fluctuating demand. In consequence, capital goods companies have increasingly outsourced manufacturing to reduce overheads and uncertainty. The extreme example is company C, which has outsourced *all* manufacturing.

On the other hand, manufacturing capability can lead to competitive advantage. Concurrent engineering has become increasingly important as a mechanism for overlapping design and supply activities. This effectively couples design and manufacturing activities, which results in a more complex planning and control problem. In company A, manufacturing activities sometimes started before all the design information was available. This is possible because manufacturing personnel have a good knowledge of design practice and common features. Informal communication provides a mechanism for verification to ensure that manufacturing produces components consistent with the developing design in such situations. Manufacturing's knowledge of the product and design practice and its ability to deal with incomplete designs may provide the vertically integrated company with a strategic advantage. Concurrent engineering relies upon the coordination of internal processes, whereas concurrent procurement needs internal and external processes to be coordinated. The latter requires the establishment of partnership sourcing arrangements based upon "goodwill trust" [19].

Capital goods companies have diverse manufacturing technologies and processes. Companies A, B, and D have jobbing, batch and flow, and assembly processes coordinated to meet delivery requirements. The physical size and weight of components varies considerably, ranging from light components that could be carried manually to heavy items that need to be transported using cranes with a capacity greater than 100 t. The level of investment in manufacturing is high. Technicians and engineers are highly skilled and flexible.

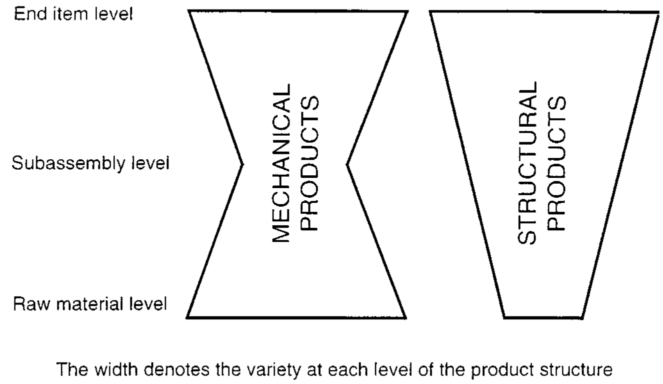

Fig. 2. Product structures for mechanical and structural engineer-to-order products.

It is helpful to classify products as being structural or mechanical. Companies B and C produce products that have a large structural component with fabrication activities. In these cases, the raw material is either steel-plate or standard sections that are cut into appropriate shapes prior to fabrication. The nesting of shapes is particularly important as it determines material waste and the availability of components for the assembly operations. Companies A and D produce products that are mechanical, with machining, assembly, and testing as generic activities. Some items are required in low volume while others are required in medium-to-high volumes. For 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 volumes on a jobbing basis. The blades also have complex geometry and are manufactured in batches. Other 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. Fig. 2 illustrates that the product structures of structural and mechanical products are different. With structural products, variety is lowest at the raw-material stage as many components are produced from standard steel sections. Mechanical products have minimum variety at the subassembly stage as the range of components and end items are large.

The level of technology varies considerably. With structural products, fabrication is the dominant manufacturing activity. The important issues involve the scheduling of work to meet assembly programs and quality assurance associated with the integrity of welded structures and pipe-work. With mechanical products, there is a mix of technologies. Some components have complex machining processes that can be classified in two ways:

1) items with many duplicated features, which require a large number of machining processes, such as a turbine rotor that has many grooves to accommodate turbine blades;
2) components with complex geometry, such as turbine blades with an aerofoil cross section, that sometimes vary along the length of the blade. These items are typically manufactured using multiple axis computer numerically controlled (CNC)/direct numerically controlled (DNC) machine tools or by copy milling from masters.

The layout of manufacturing facilities varies depending upon the type of product and the processes employed. With structural products, the assembly and construction activities are the focus of operations. Fabrication takes place in large sheds using portable welding equipment. The sheds normally contain flame-cutting equipment that is used to generate the sections for fabrication. In the case of suppliers of mechanical equipment, the manufacturing layout varies considerably. Cellular manufacturing has become more prevalent over the last few years in companies A and D. It is particularly appropriate when products are being produced in medium-to-large batches. However, this approach is not appropriate in all situations. When component variety is large and operation routings are complex, it is not possible to identify appropriate clusters of machines for cellular manufacturing unless the cells are large [20]. It has been shown that cells need to be independent and have seven to 15 workers to be effective [21].

The primary performance indicators used by manufacturing management were based upon resource utilization. Consequently, delivery performance and inventory levels were often poor. The increasing importance of delivery performance in the market place would suggest that there should be more emphasis placed on monitoring delivery performance and inventory.

2) Assembly: In general, the costs of assembly are considerably less when they are undertaken at the manufacturer's factory rather than the customer's site. This is due to travel expenses, subsistence payments, and premium payments. Assembly operations are more difficult to plan and coordinate as they are dependent upon access and infrastructure, such as the availability of power and cranage. The balance between in-house and site-based assembly is dependent upon logistics, which constrains the weight and size of units that can be dispatched to site. Structural products may be classified as floating structures, for example, ships and oil rigs or nonfloating structures such as cranes. With floating products, costs can be minimized by dry-dock assembly.

Manufacturing Requirements Planning (MRP) and Manufacturing Resources Planning (MRPII) techniques have been applied by companies A and D for coordinating manufacturing and assembly processes. Harhalakis [22] identifies three shortcomings to this approach.

1) MRP and MRPII perform only a backward pass that results in a schedule that contains only the latest times. It does not perform a forward schedule or provide information on slack.
2) Hierarchical description of the bill of materials is restrictive. Elements in the bill of materials must have a material content and must be arranged so that the structure cascades downwards from the end item. Temporary assembly, which involves disassembly (common in capital goods manufacturing) cannot be represented.
3) Nonmaterial related tasks, such as inspection and testing (which are often key milestone activities) cannot be included in the bill of materials or scheduled by MRP.

The use of project planning methods overcomes the problems associated with the bill of materials' hierarchical constraints, such as temporary assembly. However, it does not have the inventory management and control functions provided by MRP. These conclusions of Harhalakis are valid in companies A and D.

Companies A, B, and D had implemented process-planning systems for component manufacture, but assembly planning was sometimes dealt with by project management (company B), informal systems (company A), and kits of parts (company D).

3) Construction: Capital goods suppliers take responsibility for the supply associated with the whole project, which includes civil, mechanical, and electrical engineering activities that need to be coordinated. It has been necessary for capital goods suppliers to acquire expertise in site construction and large-scale project management. In companies A and B, the strategy adopted has been to hire project managers with experience in large civil engineering projects. These new skills have posed a number of human-resource management issues. First, recruiting staff in an area in which a company does not have in-depth experience involves potential risk. Secondly, retaining staff at the end of projects has proved difficult, as the individual is often committed to the project rather than to the company. There may not be sufficient continuity of work due to fluctuations in demand to offer staff continuous employment. Finally, there is the strategic issue of how the companies retain knowledge associated with the new skills and activities. This is essential due to staff turnover. Measuring an individual's performance and providing appropriate rewards in new areas has also proved difficult for companies A and B.

Company C outsources all of its construction activity. Company D, on the other hand, supplies generic products that are housed in customized facilities. Construction makes engineering and project management activities customer-specific. This is the ETO component of supply for this predominantly MTO company.

4) Commissioning: Commissioning involves the final configuring and testing of the product, for example, cabling, instrumentation, and calibration. The customer, or their representative, witnesses the satisfactory performance of the various subsystems. The completion of these tests can be milestones in the project plan, which are sometimes linked to stage payments. It is common for a large proportion of commissioning work to relate to instrumentation and its calibration. Modular designs that enable completed subassemblies to be tested before dispatch to site provide a means of minimizing expensive on-site activities.

5) Service and spares: For companies A, C, and D, service and spares is a lucrative business associated with the maintenance and periodic overhaul of existing plant, and equipment. Demand for service and spares is easier to forecast than original equipment as the plant-in-use, maintenance schedules, and service intervals are known. Spares are similar to components within the major product. However, the competitive criteria may be significantly different. For example, in the case of company A, when turbine blades are produced as part of a contract for the main product, cost and delivery are the main competitive criteria. In the case of the spares business, the customer may be faced with very high costs due to the lack of production while the plant is unavailable. The opportunity for the customer to use alternative suppliers varies depending upon the item. For example, if the customer does not have detailed design information, or if an item is safety-critical, the risks of using third-party suppliers may be unacceptably high. In such situations, the customer demands a very rapid response but is insensitive to price.

C. Support Processes

Support processes are distinguished by being linked to all the nonphysical and physical processes. They include quality, finance, and human-resource management.

1) Quality: Quality has two aspects: quality assurance and quality control. Compliance with appropriate standards such as BS5750 or ISO9000 is a condition of most contracts. Product liability is a significant issue for all four companies, particularly in relation to safety-critical items. These are tested to meet statutory-, industry-, customer-, and insurance-related requirements. For example, in welded structures, nondestructive testing (NDT) using ultrasound or X-rays is used to ensure the integrity of the welds.

Quality control methods varied considerably depending upon the nature of the product and the manufacturing processes employed. In all companies, there is 100% inspection of safety-critical items. In company A, the geometry of certain items requires sophisticated metrology, such as precision probing systems, or special jigs designed for measuring specific components. In companies A, B, and C, for large bespoke components, the inspection process sometimes requires extensive communication with engineering design. If, for example, a large forging has a machining error, it may not be possible to scrap the item. It may be necessary, therefore, to change the detailed design so that the component can be salvaged. This may result in changes to other items. The only application of statistical process control was in company A where it was limited to items that were produced in medium-to-high volumes.

2) Finance and accounting: Finance and accounting in capital goods supply is different to other sectors. This is due to the long-term nature of contracts, with lead-times frequently spanning two or more accounting periods. Contracts normally include stage payments that take place when important milestones have been accomplished. These are necessary for a stable cash flow to be maintained. Another characteristic of capital goods contracts is that they frequently include substantial penalties if the product is not completed on time. These can make it a commercial imperative to deliver according to plan, although this is often not reflected in the measures of performance used by manufacturing management. Timely delivery is frequently achieved by increasing overtime (and, therefore, resource utilization), but this approach has an adverse effect on costs. The range of projects in companies can be considered to represent different combinations of risk and reward. Risk has two components: systematic and specific. Exchange rate fluctuations are an example of systematic risk, whereas the late delivery of a product, which causes a penalty to be incurred, is a specific risk. In the capital goods industry, there is a third risk associated with not winning a contract. In this case, committed overhead costs have to be supported, effectively reducing the utilization of resources and the profitability of existing contracts. In companies A, B, and C, this issue is significant because of the large discrete nature of orders. A given set of projects may be considered to represent a portfolio, yet none of the companies applied formalized risk analysis methods. The application of financial instruments, which provide a mechanism for offsetting risk, was very limited. The practical approach taken was to outsource activities to minimize downside risk.

All of the companies used absorption costing methods. Company C had a uniform rate, whereas companies A, B, and D applied different rates for each area. This distorts the costings used. Old machines are fully depreciated to their residual value. Newer machines, obtained at high capital cost, are subject to depreciation and interest charges. However, they are often charged out at a uniform rate. This has several effects. Not only are product costs distorted, but in some cases, the customer demand is influenced by a cost-plus pricing strategy. This causes backlogs on resources with under-recovery and spare capacity on resources with over-recovery. It was suggested by management that some make/buy decisions were biased, as supplier prices were often compared to in-house manufacture with full overhead recovery. This tended to increase overheads and the general level of outsourcing.

3) Human resource management (HRM): In capital goods companies, responsibility for strategic planning is delegated to individual strategic business units (SBUs). The management style practiced by all of these companies was based upon financial control [23]. Consequently, there has been little emphasis on long-term strategic planning. Instead, the corporate center has imposed tight financial controls emphasizing short-term performance measures. It could be argued that this has had a detrimental effect on the viability of companies A, B, and C where a long-term strategic approach may be considered more appropriate.

It may also be argued that exacting compliance through financial control may act as a major barrier to the development of more effective human-resource management policies, especially if every SBU is pursuing its own policies [24]. Indeed, there is little evidence that HRM is regarded as strategic by these companies, with respect to being inextricably linked into corporate strategy [25]. However, does this really matter? As each of these companies is part of a large diversified group, product–market requirements would dictate that different policies should emerge in different SBUs [26]. This certainly appears to be the case.

In all of the companies, the management of human resources can be characterized as that of traditional personnel management, with its emphasis on management–union as opposed to management–employee relations. In companies A and B, management is developing a duality approach [27], maintaining collective bargaining with trade unions, while simultaneously implementing a “pick and mix” approach to HRM [28]. In other words, a selective range of HRM practices including team-working, culture-change programs, and briefing groups were bolted on to the traditional pluralist approach to labor relations.

In companies A and B, a large component of the human resources strategy is concerned with identifying the skills and knowledge that are commonly required together with the competencies that would be required in the future to service potential contracts. All four companies were involved in downsizing as markets contracted. Therefore, management found it necessary to continually review the classification of “core” and “noncore” skills.

The strategy of companies A, B, and C was to make use of blue- and white-collar contract labor during periods of high demand to achieve numerical flexibility [29]. This strategy may have resolved their immediate problems, but it did not address the long-term strategic HRM issues that confronted them. In all of the companies, a large proportion of the staff were approaching retirement. Their skills and aptitudes were often not concomitant with the changing requirements of the companies. For example, in company A, the movement toward turnkey contracts for power engineering equipment has created the requirement for engineers and project managers with civil engineering experience, whereas the increase in outsourcing reduces the requirement for manufacturing personnel. In company B, process engineers are similarly in short supply.

The task facing companies A and B is how to recruit and retain these skilled engineers, many of whom may show commitment to the project rather than to the company. Indeed, those staff working on short-term contracts may be unwilling or unable to share their knowledge and skills with the indigenous workforce, especially if the company has no strategy for assimilating knowledge associated with the new skills. Instead, once their contracts have expired, their knowledge and experience is likely to be transferred to competitors. This makes it difficult for companies to maintain a competitive position based upon design leadership.

IV. Conclusions

This paper reports the results of a comparative study of four capital goods companies. Several observations have been made in the course of reporting the study. These cover company, product, process, and market characteristics which display significant differences and similarities across the four companies. The major features that distinguish and identify capital goods businesses are described. These features provide mechanisms for company classification. The study identifies common trends in the sector. Other general conclusions are methodological and relate to the model of business processes used in conducting the comparative study.

A. Company Characteristics

Companies engaged in capital goods supply can be distinguished by various characteristics. First, companies can be positioned along a continuum from ETO to MTO. This is determined by the balance between the generic and specific aspects of product development. High levels of both specific and generic design characterize the ETO company while in MTO companies, generic design predominates. Second, companies are distinguished by the level of vertical integration.

B. Products

The variety of components and subassemblies at different levels in the product structure distinguish broad classes of product. In particular, the study showed a clear distinction between mechanical and structural products. Products of capital goods companies may be categorized according to whether they are subsystems of a complete project or an entire turnkey contract. This is dependent upon customer and market requirements.

C. Processes

An inclusive model of business processes and relationships between processes was developed. Processes were classified as physical, nonphysical, or support. Individual processes within the categories define the structure of a company. This structural model is the main tool used in the comparative study. There were, however, significant differences in the nature and integration of processes. The degree of integration between processes is an important determinant of company structure. Three major areas of integration emerged from the study. First, integration of tendering with other processes leads to competitive advantage. Second, integrating engineering and product development with market and manufacturing through concurrent engineering overlaps processes, reduces lead-times and costs. Third, the integration of procurement with other processes is increasingly important, as the scope of supply has broadened and the level of outsourcing has increased. It has particular significance when concurrent procurement and partnerships are necessary to satisfy the requirement for reduced lead-times.

Companies in the capital goods sector are changing rapidly, not only in the ways that processes are performed and supported, but also in the structure, relationships, and choice-of-process within the boundary of the company. New structures and the reorientation of business across different groups of processes raise new strategic issues. Design and contract companies have eliminated the physical processes altogether through outsourcing. The major driver was cost and overhead reduction. Other structures exist, for example, project management companies that join with design houses and contractors responsible for the physical realization of the product. The relative success of different configurations is dependent upon the market.

D. Markets

Capital goods companies can be classified according to the characteristics of their markets and customers. These are particularly important as they represent the external drivers and constraints on the operation of a company's internal processes. The study revealed three main axes along which markets are distinguished. First, an axis runs from cost-plus to competitive pricing for products. Second, capital goods may be supplied to regulated or competitive industries. The electricity supply industry has both regulated and competitive components. Third, order winning criteria are important features of markets for capital goods. These are necessarily complex and multidimensional (corresponding to the complexity of many capital projects) but key variables will include price, delivery, operational performance, maintenance, and through-life costs. The comparative study indicated that price and delivery are crucial. Finally, the barriers to entry and exit are high in the capital goods industry. Customers tend to be in a strong position due to over-capacity in many of these markets.

E. Structural Model

Individual companies represent subsets of the structural model of business processes and their relationships. This allows the effects of different mechanisms within processes and relationships to be examined. For example, the effects of different market features on the internal functions of tendering and design engineering were explored in the study. The general and inclusive character of the model enables the diverse companies in the capital goods sector to be described, as well as the ways that these companies change in response to market conditions.

This paper provides a comparison of four capital goods companies using the model of business processes. In the course of the study, characteristics emerged which served to identify similarities and differences. These characteristics are summarized above. Two extensions to this research are currently being considered. First, the model is being applied as a classification tool for determining appropriate structures for particular company types. Second, possible alternatives to the business process model are being examined.

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