The challenges of supply strategy selection in a project environment: evidence from UK naval shipbuilding

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Abstract

Purpose – There is a view that firms should decide between a lean or agile approach to supply management primarily on the basis of whether their product offering is "functional" (predictable demand, low variety and a long life cycle) or "innovative" (unpredictable demand, high variety and a short life cycle). This paper aims to present and test the proposition that this dichotomy is less useful in complex, one-off project environments, such as shipbuilding or construction, because projects typically require the assembly of many different, largely functional, products in a unique or innovative configuration.

Design/methodology/approach – The paper reports a case study focusing on one of the supply chains serving a major UK shipyard. The case study data were gathered by means of semi-structured face-to-face interviews with key personnel (procurement, sales, production, materials management and engineering/design) from each company within the defined supply chain.

Findings – The case study reveals that the design and build process used in the shipyard introduces radical unpredictability into the demand for "functional" components of naval vessels.

Originality/value – The paper raises important questions as to the conceptual robustness and the empirical generalisability of some of the extant literature on supply strategy selection. In particular, the case study suggests that a core assumption – that the demand for functional products is relatively predictable – is not sustainable in the context of project specific supply chains where the ultimate demand is generated by an active organisational buyer.

Keywords Supply, Project management, Corporate strategy, United Kingdom, Manufacturing industries, Shipbuilding industry

Paper type Research paper

Introduction

In recent years there has been increased interest in the question of how individual suppliers and extended supply chains/networks might be more proactively managed to deliver improved performance in product quality, cost, cycle time and flexibility/responsiveness. Two of the most widely recognised supply chain management philosophies to have emerged are lean thinking, associated with the concepts of total quality management (TQM), just-in-time (JIT) manufacturing and vendor managed inventory (Harrison, 1992; Lamming, 1993; Ohno, 1988; Womack *et al.*, 1990; Womack and Jones, 1996), and agile thinking, associated with flexible manufacturing and mass customisation (Christopher, 1998; Feitzinger and Lee, 1997; Harrison *et al.*, 1999; Towill, 1996). While each of these philosophies has its committed advocates, there is nonetheless a mature recognition in the literature that each approach has its place in the armoury of supply management strategies. Given this, a central preoccupation is to decide when it is appropriate to adopt a lean supply strategy, when to adopt an agile strategy, and when these strategies might be combined to create a "leagile" supply chain (cf. Naylor *et al.*, 1999).

The literature contains a number of well-known and often quoted contributions on this question (see for example Aitken *et al.*, 2002; Christopher, 2000; Christopher and Towill, 2000; Fisher, 1997; Lee, 2002; Mason-Jones *et al.*, 2000; Naylor *et al.*, 1999). Perhaps unsurprisingly, given that it pre-dates the bulk of the contributions in this area, the article by Fisher (1997) has provided the conceptual bedrock upon which various largely similar models of supply strategy selection have been built. The essential argument of Fisher's article is that the decision as to which supply management posture (physically efficient/lean or market responsive/agile) is most appropriate should be determined by the nature of the firm's product offering (functional or innovative).

It is proposed that the key differentiator between functional and innovative products is the extent to which end customer demand is predictable, which in turn impacts on the degree of uncertainty within the wider supply network. Fisher's demand contingency model undoubtedly has a pleasing simplicity and elegance, and he provides a number of case examples that provide strong support for his core propositions. That said

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there are two important respects in which the demand contingency models put forward by Fisher and by those who have followed him remain underdeveloped and untested.

Firstly, these models are typically formulated and tested in the context of relatively high volume manufacturing supply chains (e.g. food, fashion goods, winter sports clothing, cars), in which the focus is on the management of a repeated production process. There is no consideration of the models' usefulness in generating management advice for supply chains feeding into a low volume or one-off project environment. Secondly, the demand contingency argument is typically focused upon supply chains servicing private consumer demand. In this context the actors responsible for generating the ultimate demand play at best a limited role in product design and specification. There is no consideration of the applicability of these models to supply chains servicing organisational or business demand, where the end customer typically plays an extensive and active role in design and specification decisions (Sheth, 1973; Webster and Wind, 1972).

The key objective of this article therefore is to consider how far the demand contingency models developed by Fisher and others can be sustained if we explore them in the context of low volume, project-specific supply chains where the ultimate demand is generated by an active organisational buyer. Linked to this objective we ask two specific research questions. First, do functional products used in a complex one-off project environment have a predictable pattern of demand? Second, is it appropriate to use lean techniques in the management of supply chains delivering functional products to complex, one-off projects? We address these questions using empirical data from a case study of the supply chain delivering electrical cables to a major UK naval shipbuilder.

The article is structured as follows. In the next section we expand our discussion of Fisher's (1997) demand contingency model and provide a theoretical critique focusing on its usefulness in project-specific supply chains. This is followed by an account of the methodology used to gather our case study evidence. Next we present the empirical findings and discuss the extent to which they support our critique of Fisher's model. The broader managerial implications of our case evidence are also reviewed. The article concludes with a brief discussion of the limitations of our findings and suggestions for further research.

The demand contingency model and project supply chains

Fisher's (1997) model is based upon three fundamental propositions as follows:

1 That products have particular and consistent demand profiles associated with their categorisation as functional or innovative, the former being assumed to have predictable demand and the latter unpredictable demand.
2 That every supply chain performs two distinct functions, physical production/distribution and market mediation, each with its own distinct costs.
3 That minimising physical supply chain costs should be the strategic priority for companies selling functional products, while controlling market mediation costs should be the focus for companies selling innovative products – the former implies the efficient use of resources while the latter is a strategy of effective market responsiveness.

It is through this chain of argumentation that a simple alignment is drawn between product type (functional or innovative) and the most appropriate supply strategy posture (lean/efficient or agile/market responsive). Our aim in the following discussion is to look at each of these propositions in turn and to consider how far they can be sustained in the context of project-specific supply chains.

Proposition 1: on predictable and unpredictable demand

This proposition provides the cornerstone of the demand contingency model. It suggests that if a firm's products are classified on the basis of their demand patterns a consistent bifurcation emerges between primarily functional products with predictable demand and primarily innovative products with unpredictable demand. As Table I shows, Fisher (1997) uses a number of different aspects of demand and supply to create this categorisation.

Fisher (1997, p. 106) argues that functional products are "the staples" that satisfy the consumer's "basic needs", and that because those needs change very little over time such products have "stable, predictable demand and long life cycles." Moreover, because functional products are satisfying the basic needs shared by most consumers there is little variety and customisation in product offerings, the barriers to market entry are assumed to be low and, as a consequence, the typical profit margins are low. Mason-Jones *et al.* (2000) classify such products as commodities.

Turning to the other category, Fisher (1997, p. 106) argues that while innovation might enable firms to limit direct competition and earn higher profit margins, at least for a short period, "the very newness of innovative products makes demand for them unpredictable." Moreover, the lifecycle of innovative products is assumed to be relatively short, because as competitive imitation occurs the margins earned by the first mover firm are eroded and it is forced to undertake further product innovation to recapture its competitive advantage. Finally, it is assumed that innovative products will typically exhibit a greater a number of variants within each category as firms offer consumers an almost bewildering number of options in an attempt to capture as much of the available market as possible. It is argued that this extensive variety compounds a product's newness to further increase the unpredictability of demand. Mason-Jones *et al.* (2000) suggest fashion goods as being typical of this category.

At a superficial level this categorisation is uncontroversial, given that it draws upon some of the central tenets of the long established industrial economics literature (Bain, 1956; Caves and Porter, 1977; Scherer, 1980). We contend, however, that on closer consideration the overarching association between product type and demand predictability starts to break down. A key limitation of Fisher's categorisation is that it is focused upon the demand generated by consumers for products delivered by a repeated manufacturing process. Consequently, it is implicit in Fisher's discussion that both functional and innovative products have a past, a present and a future state. With functional products each of these three states is assumed to be broadly similar, which means that past and present demand can be used with a reasonable degree of certainty as a guide for future demand. Conversely, with innovative

Table I Functional and innovative products: differences in demand and supply

	Functional products (predictable demand)	Innovative products (unpredictable demand)
Product life cycle	More than 2 years	3 months to 1 year
Contribution margin	5 to 20 per cent	20 to 60 per cent
Product variety	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average margin of error in forecast when production is committed	10 per cent	40 to 100 per cent
Average stock-out rate	1 to 2 per cent	10 to 40 per cent
Average forced end of season price reduction	0 per cent	10 to 25 per cent
Lead time for made-to-order products	6 months to 1 year	1 day to 2 weeks
Product examples	Staple goods – bread, milk, meat, fruit and vegetables, office furniture, basic clothing and footwear	Fashion and seasonal goods – designer clothing and footwear, winter sports clothing

Source: Fisher (1997)

products the past, present and future state are each substantially different, which means that past and present demand cannot be used with any real certainty to predict the future.

The difficulty is that this line of reasoning cannot be neatly applied to a one-off or low volume project environment where the project outcome has no comparable past and future state. Rather the project outcome, be it a ship, a bridge or a building, has only a present state; it is *sui generis*. Often it is highly improbable that precisely the same ship, bridge or building has ever been produced before or that it will ever be produced again. Consequently, in this context the predictability of demand associated with functional products, which serve relatively unchanging needs over a long period of time, can no longer be safely assumed. It is of course possible to say, at a very general level, that there will be a demand for basic functional products such as steel, electrical cable and concrete across a series of projects. The problem though is that there are typically substantial differences in design and specification between individual ships, bridges and buildings, which make it virtually impossible to predict the parameters of that demand (type needed, quantity needed, timing) based on past experience. This reveals an important managerial paradox: long-established functional products with an unpredictable demand profile usually associated with innovative products.

A possible response to this observation is that the lack of a past reference point does not necessarily imply that the demand for functional products in a project environment will be entirely unpredictable. Rather it might be argued that the demand for functional products as a project unfolds can be predicted by reference to the initial design specifications and the associated build schedule. Indeed, those responsible for building the Crystal Palace in London were able to achieve a sufficiently stable and predictable demand profile to implement just-in-time (JIT) delivery of major materials long before the concept had been given a name (Wilkinson, 2000). That said, the achievement of such demand predictability within the framework of a single project suggests a highly detailed and complete design that became more or less fixed and was rigorously adhered to once the build phase had commenced. Alternatively, if design changes were permitted once building had commenced this suggests that these must have been centrally approved and communicated in a clear and timely fashion to all of those affected. These behaviours, while clearly not totally implausible, are not typical of most project environments.

One of the major factors in support of this contention is that the end customer in a project environment is typically a large organisational buyer, either a public sector body or a privately owned company. It is well established in the literature that buying decisions in such an organisational setting involve a highly complex, multi-phase, multi-actor process (Sheth, 1973; Webster and Wind, 1972). Moreover, given the number of different organisational actors involved, each of which is likely to be pursuing its own agenda, it is often the case that buying decisions are highly politicised and the outcomes sub-optimal from the perspective of the organisation as a whole (Pettigrew, 1973; Pfeffer and Salancik, 1974). In addition we must consider the generally accepted notion that decision-makers, in both an individual and organisational context, operate on the basis of "bounded rationality" (Simon, 1957). This means that they lack the mental capacity to collect, store, process, and retrieve all of the available information that might be relevant to a particular decision.

Consequently, it is unlikely that a detailed and complete design could ever be drawn up before the commencement of a project. Even if this was possible, the political nature of organisational life suggests that the rational and coordinated action necessary to realise that design, and to agree and communicate changes, would be difficult to achieve. Based on this line of reasoning we suggest that the demand for functional products in a project environment is likely to exhibit greater unpredictability than is proposed by the demand contingency thesis.

Proposition 2: on physical production and market mediation costs

This proposition is largely uncontroversial in that it applies in broadly similar terms to repeated process manufacturing supply chains and to project specific supply chains. Fisher (1997, p. 107) comments that "a supply chain performs two distinct types of functions: a *physical* function and a *market mediation* function" [emphasis in the original]. The physical function of a supply chain is the one that most readily springs to mind and which is most often used to give tangibility to an abstract construct. It involves the conversion of raw materials into parts, components, sub-components and finished goods, and the movement of those items from one supply chain actor to the next until the end customer receives finished goods.

The market mediation function is somewhat less tangible. Fisher (1997, p. 107) comments that the purpose of market mediation is "ensuring that the variety of products reaching the marketplace matches what consumers want to buy." In other words, Fisher contends that one of the key functions of a supply chain is to achieve equilibrium between supply and demand in the end product marketplace.

The second aspect of this proposition is that each of the functions performed by a supply chain incurs distinct costs. The costs associated with the physical function are "the costs of production, transportation and inventory storage" (Fisher, 1997, p. 107). It is these cost categories that are most often considered by firms engaged in cost reduction initiatives. The less obvious costs associated with market mediation "arise when supply exceeds demand and a product has be marked down and sold at a loss or when supply falls short of demand, resulting in lost sales opportunities and dissatisfied customers" (Fisher, 1997, p. 107). These costs have also been classified as obsolescence and stock-out costs (Harrison and van Hoek, 2002). Significantly, the notion of obsolescence costs suggests an additional problem, namely that stock might remain unsold at any price and have to be written off. The important insight here though is that the total costs generated by any supply chain in the product delivery process include both the more obvious physical costs and the costs of market mediation.

If we consider these cost categories in the context of a project-specific supply chain it is clear that they are broadly relevant with one notable exception. This exception is in the category of stock-out costs. Here it is typically assumed that the costs are associated with lost sales and dissatisfied customers in the short-term and the possibility of damage to repeat business in the longer-term. This implies that customers have a choice as to whether they do business with a particular supplier, because the marketplace is highly competitive with little brand loyalty (Harrison and van Hoek, 2002). In the case of a project-specific supply chain, however, it is more typical that customer and supplier are contractually committed to one another. This means that the costs associated with a stock-out situation are more properly the costs of delayed rather than lost sales. Here the supplier may have penalties imposed upon it for causing a delay in project delivery or completion, but the customer is either unlikely or contractually unable to walk away.

Proposition 3: lean versus market responsiveness

The final proposition in the demand contingency thesis brings together propositions 1 and 2 to suggest how product types (functional or innovative) can be aligned with the appropriate supply strategy posture (lean/physically efficient or agile/market responsive). Leanness has been defined as "developing a value stream to eliminate all waste, including time, and to enable a level schedule." Agility on the other hand has been defined as "using market knowledge and a responsive supply network to exploit profitable opportunities in a volatile marketplace" (Harrison and van Hoek, 2002). These strategic postures are summarised in Table II. Fisher (1997) argues that the choice essentially comes down to an understanding of which category of costs is most significant for a particular product type.

In the case of functional products demand is assumed to be predictable, which means that the risks of obsolescence or stock-out are relatively low. This in turn means that market mediation costs are assumed to be less significant than the physical costs of production, transportation and inventory storage. From here it is a short step to the assertion that firms making functional products should prioritise the minimisation of physical supply chain costs by pursuing a lean supply strategy. Moreover, this priority is reinforced by the price sensitivity of most functional products and therefore the importance of cost as a market winner (Mason-Jones *et al.*, 2000).

Conversely, in the case of innovative products, where demand is assumed to be highly unpredictable, the risks of obsolescence and stock-out are relatively high. This means that market mediation costs are assumed to be much more significant than physical supply chain costs. The costs of stock-out are further magnified by the high profit margins available to successful first movers and the importance of capturing a substantial market share before competitive imitation occurs. The costs of obsolescence on the other hand are magnified by the typically short life cycles of innovative products. The market winner for such products is therefore the availability of the right product, in the right quantities, at the right time (Mason-Jones *et al.*, 2000). On this basis those firms selling innovative products are recommended to pursue an agile supply strategy primarily designed to control market mediation costs.

The key problem with this line of reasoning is that it hinges on the assumptions about product type and demand predictability contained in proposition 1. The assumption that functional products are necessarily characterised by predictable demand is questionable, however, when considered in the context of a project-specific supply chain. If we question this assumption an interesting paradox emerges.

The market-winning criterion for functional products tends to be cost, because they are typically produced in an environment of intense competition that keeps prices and profit margins relatively low. This in turn means that the management focus in supply chains delivering functional products should be on the minimisation of physical costs (a lean supply strategy). It is commonly argued that lean supply works best in an environment where demand is relatively stable and therefore predictable (Cox and Townsend, 1998; Harrison and van Hoek, 2002). As we have suggested, however, there are a number of reasons why the demand for functional products in a project environment might be significantly unpredictable. If this is indeed the case the management focus must shift from minimising physical costs to promoting flexibility and responsiveness in the supply chain (an agile supply strategy). The essence of agile supply is that the management of market mediation costs supersedes the minimisation of physical supply costs. Moreover physical supply costs may in some circumstances increase through the pursuit of agility, for example through the holding of generic or modular inventory. This is the heart of the paradox. In the next section empirical support for this proposed paradox is provided by means of a case discussion.

Case study

Methodology

The findings reported and discussed in this paper focus on the supply chain delivering electrical cables to a major UK naval shipbuilder, referred to here for reasons of commercial

Table II Lean and agile supply strategies

	Lean supply strategy	Agile supply strategy
Manufacturing focus	Maintain high average utilisation rates	Deploy excess buffer capacity
Inventory strategy	Generate high turns and minimise inventory throughout the chain	Deploy significant buffer stocks of generic or modular inventory
Lead-time focus	Reduce lead-time as long as cost is not increased	Invest aggressively in ways to reduce lead time
Key supplier selection criteria	Cost and quality	Speed, flexibility and quality
Product design strategy	Simplify design to use fewer parts and to reduce errors/need for rework	Use modular design to postpone final product assembly for as long as possible
Information exchange and enrichment	Highly desirable	Obligatory
Forecasting mechanism	Algorithmic	Intelligent consultation

Source: Adapted from Fisher (1997) and Mason-Jones *et al.* (2000)

confidentiality by the pseudonym Ship Co. These findings are drawn from a larger qualitative study of product characteristics, operational practices and performance outcomes in four supply chains delivering to the UK naval shipbuilding and ship-repair sector. The others studied were those for valves, heating, ventilation and cooling (HVAC) equipment, and painting and scaffolding services. The research method described here was common to all four supply chains. The broader study involved four main collaborating companies (two shipbuilders, one ship-repairer and one components supplier), which were asked to select the supply chains that were examined. One selection criterion was that the chains presented particular performance problems or challenges for the collaborating companies. More significantly, however, the chains were selected on the basis that they delivered "functional" products as defined by the characteristics summarised in Table I. This allowed an exploration of the demand predictability paradox proposed above and consideration of the appropriateness, in terms of Fisher's (1997) model, of the operational practices being used in each supply chain.

The cables supply chain was treated analytically as a closed system, with discrete boundaries defined by Ship Co., rather than descriptively as an open system. This meant that only a limited sample of the potentially very large number of firms operating in the chain was involved in the research. The sample of firms and the people interviewed within them was identified through a process which has been called "snowball sampling" (Scarbrough *et al.*, 2004, p. 1586). This involved asking contacts in Ship Co. to provide an initial list of potential interviewees from their own company and from companies in the chosen supply chain. The contacts were given detailed guidance as to the nature of the research objectives and questions being addressed to facilitate the identification of appropriate interviewees. Additional interviewees were then progressively identified and approached once the fieldwork had commenced.

The research was carried out by a team of two, one a project manager and the other a research assistant, over a period of four months. The principal research method was in-depth, semi-structured interviews with representatives of key functions (procurement, sales, production, materials management and engineering/design) from companies within the defined supply chain. A total of 47 interviews were conducted, each lasting for about one hour. Eight interviews took place in Ship Co. and the remainder was distributed, as shown in Table III, between 17 other companies across the cables supply chain.

Each interview was tape-recorded and then transcribed to allow subsequent cross-tabulation and identification of common themes and variation in responses. A standard schedule of questions was used to ensure that data gathered from different interviewees was directly and easily comparable. The interview schedule was designed to test whether electrical cable used in a naval shipbuilding context has the characteristics expected of a functional product and to provide data about the operational practices being used by firms in the supply chain. The questions were derived from the categories detailed in Table I (characteristics of functional and innovative products) and in Table II (characteristics of lean and agile supply strategies)[1].

Findings and discussion

The key interview findings are presented in summary form in Tables IV and V. The main conclusion that we draw from the evidence summarised in Table IV is that electrical cable used in a naval shipbuilding context does indeed have many of the characteristics associated by Fisher with functional products. The research showed that even though the design of each class of warship varies significantly, the bulk of the electrical cable used on board each ship is selected from a well-established and relatively narrow range of cable types, supplied by a relatively small number of known suppliers.

Table III Distribution of interviewees across the electrical cables supply chain

Stage of supply chain	Number of sample companies	Number of interviewees
Shipbuilder – Ship Co.	1	8
First tier		
– Cable package integrator	1	4
– Cable distributors	3	6
Second tier		
– Cable manufacturers	6	15
Third tier		
– Copper conductor manufacturers	4	8
– Compound coating suppliers	3	6
Total	18	47

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Table IV Electrical cables in UK Naval shipbuilding: functional or innovative?

	Electrical cables	Functional products (F)	Innovative products (I)
Nature of demand	Unpredictable (I)	Predictable	Unpredictable
Product life cycle	More than 2 years (F)	More than 2 years	3 months to 1 year
Contribution margin	Manufacturers 5 per cent to 10 per cent (F) Distributors > 20 per cent (I)	5 to 20 per cent	20 to 60 per cent
Product variety	Low (F)	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average margin of error in forecast when production is committed	20 to 50 per cent (I)	10 per cent	40 to 100 per cent
Average stock-out rate	N/A Product is typically made to order	1 to 2 per cent	10 to 40 per cent
Average forced end of season price reduction	N/A Price varies contract to contract	0 per cent	10 to 25 per cent
Lead time for made-to-order products	3 to 4 months (F)	6 months to 1 year	1 day to 2 weeks

Table V Supply strategy for electrical cables compared with lean and agile

	Observed cables supply strategy	Ideal lean supply strategy	Ideal agile supply strategy
Manufacturing focus	Large-scale batch production	Maintain high average utilisation rates	Deploy excess buffer capacity
Inventory strategy	Significant finished product inventory held by Ship Co. and distributors	Generate high turns and minimise inventory	Deploy significant buffer stocks of generic or modular inventory
Lead-time focus	Ship Co. – reduce as long as cost is not increased Cable manufacturers – not a priority	Reduce as long as cost is not increased	Invest aggressively to reduce
Key supplier selection criteria	Cost, delivery reliability and quality	Cost and quality	Speed, flexibility and quality
Product design strategy	Limited product range designed to sell in a wide variety of sectors	Simplify	Modularise
Information exchange and enrichment	Limited and sporadic	Highly desirable	Obligatory
Forecasting mechanism	Intelligent guesswork	Algorithmic	Intelligent consultation

Over time the cables supply market has been consolidated through merger and acquisition activity to the point where there are now only four major players worldwide and a similar number of suppliers operating on a regional basis. Price competition between cable manufacturers is vigorous, with gross profit margins typically being in the range 5-10 per cent. Suppliers make money on the basis of high sales volumes and economies of scale. In addition, with the exception of certain specialist cables, the pace of technological innovation in this product category is relatively low. Thus, electrical cable is a product characterised by a long life cycle, low profit margins, low variety and a relatively long lead time for made-to-order products, features associated with a broadly functional product.

Significantly, though, our research also showed that electrical cable used in shipbuilding exhibits some features of an innovative product, in particular an unpredictable pattern of demand and a high margin of error in forecasting requirements. There are a number of reasons for these observations. In line with traditional UK industry practice[2] Ship Co. typically begins the build phase when only 35-40 per cent of the design effort has been expended. Moreover, difficulties highlighted once building commences are fed back into the design process and incremental adjustments are made. This means that both the design and the build schedule of a vessel are incomplete and subject to on-going change. This overlapping of design and construction activity is primarily driven by the substantial time and complexity involved in designing a ship and by the irregular pattern of demand from ship-owners. In these circumstances Ship Co. is keen to begin cutting steel as soon as possible after contract award in order to minimise the opportunity costs incurred while their production staff is working at less than full capacity.

This method of working generates substantial uncertainty in the demand for many components of the vessel, including functional products like electrical cable. The demand profile for cable is closely linked to the overall design of a vessel and to the order in which elements of that vessel are integrated and outfitted. Given that the design is a work in progress with significant information gaps when building commences, it is unsurprising that Ship Co. experiences substantial demand uncertainty in relation to cable types, quantities and the timing of deliveries. As indicated in Table IV, the average margin of error in Ship Co.'s forecasts of its electrical cable requirements is between 20 and 50 per cent, well above that usually associated with functional products. These problems are further compounded by the significant lead times, in the region of three to four months, which are typically required by cable manufacturers. Ship Co.'s procurement function is thus forced to place orders for cable based on forecast usage, without having any real confidence in the accuracy of that forecast.

In addition to the demand uncertainty inherent in working with an incomplete and evolving design, we also found evidence that certain of the operational systems and processes in use within Ship Co. are adding further unpredictability to the demand for cable. Most importantly, the degree of interactivity and the quality of communication between the information systems used by the design, engineering, production planning, materials management and procurement functions are somewhat limited and rather spasmodic. Consequently, it is not uncommon for Ship Co.'s procurement function to place orders on suppliers in line with a production plan and delivery schedule that is several weeks out of date. This can lead either to a shortage of cable, necessitating the emergency use of a distributor, or to the early arrival of cable with the associated costs of storage.

The two cable installers interviewed within Ship Co. also commented that they have to work in an *ad hoc* and reactive manner, because they are not given sufficiently detailed and up-to-date production planning information to enable them to enter a particular compartment with a clear idea of the scale and scope of work. This necessity to undertake shop floor re-engineering can generate substantial emergency demand. It can also lead to substantial and costly rework if such ad hoc cable installation interferes with subsequent outfitting activities.

Table V compares the operational practices being used in the cables supply chain with the practices associated with lean and agile supply. The evidence shows that an essentially arms-length and reactive style of relationship management is the norm in this supply chain. Ship Co. uses competitive tendering to award a firm price contract for the cable requirement on each individual vessel. There is no evidence of Ship Co. or any of the firms operating upstream in the supply chain using collaborative and coordinated action to remove waste, improve product quality or enhance responsiveness. Significant finished product inventory is held by Ship Co. and by the cable distributors to provide a bolster against unpredictable fluctuations in demand. The cable manufacturers operate on the basis of large-scale batch production, because significant costs in time and money are associated with changeovers between production runs. The product design strategy deployed by the manufacturers and their key suppliers is driven by the need to achieve economies of scale by selling high volumes of each cable type to customers in a wide variety of industrial sectors. Information exchange and enrichment are limited and sporadic. Demand forecasting is done on the basis of intelligent guesswork. The observed supply strategy for electrical cables is neither lean nor agile.

The evidence in Table V also shows that there are two main performance criteria that are regarded by Ship Co. as crucial to supplier selection in this product category. The first, unsurprisingly given that electrical cable is broadly a functional product, is cost. Ship Co.'s standard procurement practice is to competitively tender the total cable requirement for each individual ship and then to award a single firm price contract to the supplier offering the lowest price for this complete package. Ship Co.'s expectation is that this single supplier will act as a cable package integrator, directly supplying most of the required cables and acting as a distribution channel for those cables produced by other manufacturers. Ship Co. has been awarding such integrator contracts since 2001, when a strategic commodity review identified the significant overhead cost benefits of having a much smaller number of preferred suppliers managed by a single lead supplier. Ship Co. is thus seeking to make savings both on the purchase price of each cable package and on the transaction costs associated with managing the supply base.

The second key selection criterion identified by Ship Co. is a cable supplier's ability to meet delivery targets. The interviewees within Ship Co. specified a number of substantial cost implications associated with significantly early or late delivery of electrical cables, costs that can often outweigh any savings made on the purchase price and on the management of the supply base. In the case of deliveries that are made several weeks or even months in advance of the installation process substantial storage and inventory management costs are incurred. In addition there are less obvious costs associated with lapsed warranties on delivered cable and damage that occurs as a result of inappropriate storage and handling. In both cases additional costs are incurred in the procurement of replacement material. The costs associated with late deliveries are of two main types. These are the opportunity costs associated with the enforced idleness or the inefficient redeployment of a section of the cable installation team and delays in the outfitting process, which has a significant impact on overall project delivery. Again, the interviewees at Ship Co. commented that delivery delays of several weeks are not uncommon.

In addition to these costs of "acceptable" delay, the research also revealed that Ship Co. occasionally experiences unacceptably long delays and is forced to pay the higher prices charged by a cable distributor in order to resolve the situation. Cable distribution companies hold a range of cable types in stock and are able to meet the majority of shipbuilder requirements at very short notice, typically one to two days. This flexibility and speed of response comes at a price however. As Table IV shows, cables purchased from a distributor attract a much higher price, and therefore a much higher profit margin, than the same product bought direct from the manufacturer. The research suggests then that Ship Co. is achieving some savings on the purchase price of electrical cable and on the transaction costs incurred in the management of suppliers, but that these savings are often eroded by the inability of suppliers to consistently meet delivery targets. In short, taking a total acquisition cost perspective the performance of this supply chain is sub-optimal.

Given these findings it seems reasonable to assume that Ship Co. cannot expect the performance of this supply chain to improve without the implementation of a more proactive and coordinated management approach. The key question for Ship Co. then is which supply strategy posture, lean or agile, would be most appropriate to deliver improvements in both product cost and supplier delivery performance? The straightforward answer, if the demand for electrical cable was broadly predictable in line with its status as a functional product, is that Ship Co. should pursue a lean supply strategy designed to minimise the physical costs (production, inventory storage and distribution) in the supply chain. As the evidence presented in Table IV shows, however, we cannot assume that a functional product like electrical cable will necessarily have a predictable demand profile when it is used in a complex project environment. In the next section we discuss how this paradox might be addressed managerially.

Managerial implications

There is an argument in the literature that demand uncertainty in complex projects can be effectively reduced by the adoption of a concurrent engineering (CE) philosophy (Chin, 2004; Prasad *et al.*, 1998; Vajna and Burchardt, 1998; Wear, 1999). This involves the creation of a genuinely integrated product development team, in which key organisational functions in the prime contractor (design, engineering, production, materials management, procurement) and key suppliers work in parallel to deliver a more complete and fully tested design and therefore a more certain demand profile before the build phase commences. Ideally, the CE approach should also be carried over into the build phase so that changes in design, specification or production scheduling are communicated quickly and accurately to each of the actors in the project supply chain to enable them to adjust their behaviour.

This is akin to the notion of "information enrichment" in a consumer-focused, process supply chain, whereby changes in end customer demand are communicated simultaneously, usually by electronic means, to the firms at each stage of the supply chain (Mason-Jones and Towill, 1997, 1999). The objective of this enrichment is to enable the supply chain to avoid demand uncertainty as far as possible by reducing the information lead-time. This is facilitated by removing the distortions and delays that normally occur when demand information is passed progressively from stage to stage. This is not the same as saying, however, that customer demand uncertainty is eliminated. End customer demand remains unpredictable, but each of the firms in the supply chain should be in a better position to respond quickly and appropriately to any changes because they have direct visibility of real-time demand information.

The same observations can be made about the use of CE in a project context. CE does not eliminate demand uncertainty, because even the most advanced practitioners of CE are unable to produce an entirely complete and detailed design and then to ensure full adherence during its implementation. If one accepts the political exigencies of organisational life and the existence of bounded rationality this suggests that some degree of demand uncertainty, even for functional products, is inevitable in a complex project environment. CE might, however, facilitate a richer and more-timely exchange of design and production information to ensure a more effective response to unpredictable changes.

One might conclude then that an agile supply strategy, designed to create a flexible and responsive supply chain, is most appropriate for the cost effective delivery of functional products in a complex project environment. As noted earlier, however, this conclusion creates an important paradox. The market-winning criterion for functional products is typically lowest cost, but at the same time the pursuit of an agile supply strategy suggests that certain physical costs, particularly those associated with holding inventory, are likely to increase. One possible way out of this paradox is for managers working on complex projects to accept that there will always be at least a degree of uncertainty in their demand for functional products. The adoption of this new mindset should enable managers to go beyond the typical focus on production and distribution costs and to see the potential for wider reductions in total acquisition costs (particularly costs of significantly early or late delivery) through more flexible and responsive suppliers.

Another possible route out of this paradox is suggested by the concept of the "leagile supply chain", in which both lean and agile strategies are used in a single supply chain on the basis of a "decoupling point" (Hoekstra and Romme, 1992; Mason-Jones *et al.*, 2000; Naylor *et al.*, 1999; Olhager and Östlund, 1990; Sharman, 1984; Stratton and Warburton, 2003). Based on a reading of the extant literature it is clear that a leagile strategy is recommended in supply chains where ultimate customer demand is highly volatile and unpredictable, but end users are also price sensitive. This combination suggests that while supply chain flexibility and responsiveness (agility) is the market winner, physical cost efficiency (leanness) is an important market qualifier (Mason-Jones *et al.*, 2000). These mixed characteristics of end customer demand are clearly revealed in the electrical cables case study.

The critical question in the implementation of a leagile strategy is where in the supply chain the decoupling point should be positioned, because this is the operational boundary between leanness and agility. The decoupling point is defined as the stage in the supply chain at which undifferentiated inventory is held to act as a buffer between specific, unpredictable end customer demand (volume/variety/timing) on the downstream side and generic forecast demand on the upstream side. The logic is that firms operating on the upstream side should pursue a strategy of physical cost efficiency through lean manufacturing/supply, while those on the downstream side pursue an agile approach to manufacturing and distribution. According to Naylor et al. (1999, p. 112), the positioning of the decoupling point "… depends upon the longest lead time an end-user is prepared to tolerate and the point at which variability in product demand dominates."

If we apply this reasoning to the electrical cables case, we can begin to sketch theoretically where the decoupling point might best be positioned within this supply chain. The case evidence summarised in Table IV shows that the lead-time between the placing of an order by Ship Co. and receipt of the required cable from the manufacturer is typically three to four months. Given the difficulties involved in forecasting cable usage, this lead-time was generally regarded as unacceptable by the interviewees within Ship Co. It is reasonable to assume therefore that Ship Co. would prefer a lead-time of significantly less than three months, which suggests that the decoupling point should be as close as possible to the manufacturing stage of the supply chain.

In terms of the second decision variable – the point at which variability in product demand dominates – the same decoupling point is suggested. The cable manufacturers studied in this research are typically large multinational firms that sell their products to a wide range of sectors, including shipbuilding, electricity, railways, aerospace, construction, and oil and gas. Product differentiation should therefore ideally occur at the manufacturing/assembly stage where the specific requirements of users in particular sectors would be met through the customised assembly of basic cable components. This brief analysis suggests that functional products such as electrical cable might best be delivered in a complex project environment through the leagile supply strategy characterised as "assemble-to-order" (Naylor *et al.*, 1999, pp. 113-14).

Limitations and suggestions for further research

The main limitation of the research reported here is that it focuses on a single case study involving one shipbuilder and one supply chain. We should therefore be very cautious about generalising either our findings or our conclusions to other shipbuilders, to other supply chains servicing the shipbuilding sector, and to other industrial sectors (e.g. construction) where production is commonly organised on a project basis. A replication of this research in cases across these various dimensions is clearly called for before we can be empirically more secure in our challenge to the logic of Fisher's model. As Yin (2003, pp. 10-11) has argued, however, even the single case study presented here has epistemological value, because it is generalisable to and enables the empirical testing of a deductively derived theoretical proposition.

A second important limitation is that our critique of Fisher's model has been used to generate a normative recommendation for Ship Co. to improve the management of its electrical cable supply chain. We have suggested that Ship Co. should adopt a leagile supply strategy, but we have not addressed the question of whether the shipbuilder would be able to work with the other firms in this supply chain to implement such a strategy. To answer this implementation question would require further research to look at the commercial incentives for the firms in this supply chain to integrate and coordinate their manufacturing and distribution activities. It seems safe to assume that the inter-organisational coordination required to make a leagile supply strategy effective does not occur spontaneously. One might reasonably hypothesise therefore that such coordinated action will not occur unless the benefits that it delivers to each of the participating firms are at least equal to the costs that it imposes on them (Cox *et al.*, 2003; Mason-Jones and Towill, 1999).

Notes

1 Before the fieldwork commenced the interview schedule was piloted with two research contacts from each of the four main collaborating companies. No major rewording was necessary. A lack of space precludes reproduction of the interview schedule here, but a copy is available from the authors on request.
2 See Wear (1999) for a good discussion of UK naval shipbuilding industry practice.

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