IMPROVING SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION: WHAT CAN BE LEARNED FROM THE AEROSPACE INDUSTRY?

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In order to provide for controllable delivery, reliable lead times and efficient customer response, lean manufacturing and platform assembly practices play an important role in supply chains in the aerospace industry. The adoption of lean manufacturing practices ensures an efficient delivery of products to the market. Benefits from the development of platform strategies are a more reliable materials supply and an improved logistics control. The aerospace industry is characterized by a small number of major global players and many small ones. A major part of the design and production has been contracted out to suppliers. In this paper the basic similarities and differences between the construction and aerospace industry and supply chains are analysed. A comparative study of aerospace and construction supply chains is presented to indicate and discuss the applicability of supply chain management concepts to construction, and the improvement potential of these concepts regarding supply chain management in construction. It is concluded that in particular the practice of platform assembly is a fruitful concept to be applied in the construction industry.

Keywords: aerospace industry, construction industry, virtual organization, supply chain management.

INTRODUCTION

In the building industry, designing, constructing, and supplying parties in the supply chain work together in constantly changing coalitions on different building projects (O'Brien *et al.* 1995). In a traditional building setting, multiple bilateral contracts are negotiated between individual parties who will next be involved in a temporary coalition until the completion of the project. Alternatively, the parties can be interpreted as organizational units joining and operating together as a single production organization when it is advantageous (Harland *et al.* 1999), a "temporary multiple organization" (Cherns & Bryant 1983). Thus, the construction supply chain could be interpreted as an "extended enterprise" in which all firms (project developer, architect, engineering firm, contractor, subcontractors, suppliers) virtually operate as "business units" representing the "business functions" (marketing, design, engineering, components manufacture, supply, assembly, delivery) of a "factory without walls" that acts as a collaborative network of organizational units, regardless of location and regardless who owns them (Cooper & Rousseau 1999). In this respect, the construction supply chain must be viewed as a make-to-order supply chain

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Table 1: Governance configurations of extended enterprises

Level of vertical integration	Higher		Hierarchy
	Lower	Market	Network
		Weaker	Stronger
		Supply chain links	

(based on Stock et al. 2000)

(Luhtala *et al.* 1994) consisting of three major operating subsystems: the specification, design and engineering of the end product including determining the materials and commodities that will flow through the supply chain based on information and drawings; the manufacturing of materials and components; and the assembly of the end product bringing together many different kinds of work involving different technologies at the construction site. Typically, this make-to-order process, and thus the construction supply chain, starts and ends with the final customer. In this paper the basic similarities and differences between the construction and aerospace industry and supply chains are analysed. A comparative study of aerospace and construction supply chains is presented to indicate and discuss the applicability of supply chain management concepts to construction, and the improvement potential of these concepts regarding supply chain management in construction. The outline of this paper is as follows. The theoretical framework on supply chain management in general is discussed first. In section two, the focus is on supply chain management in construction. Supply chain concepts used in aerospace are presented in section three. The applicability of these concepts in construction is analysed in the final part.

SUPPLY CHAIN MANAGEMENT: THEORETICAL FRAMEWORK

Christopher (1992) observes that ‘supply chain management covers the flow of goods from supplier through manufacturing and distribution chains to the end user’. The concept of supply chain management (SCM) means that independent firms agree upon the way in which production and information flows are organized. The consequence of this agreement is an integrated organization of logistical activities within a chain or group of firms. Generally, the research on supply chain management has focused on a debate regarding the need for closer relationships between customers, suppliers and other relevant parties, in the search for competitive advantage. Fundamental to the theory of supply chain management is the notion of interlinking and exercising control of an identified sequence of interdependent operations and firms.

The concept of the extended enterprise in the supply chain

Karlsson (2003) observes that contemporary production strategies increasingly put emphasis on the operations that are external to traditional organizational environments, and managing operations in an external network. Karlsson calls this the shift from an enterprise to an “extraprise”. Sturgeon (2002) introduces a similar model: the modular production network. The emergence of the concept of the extended enterprises has raised the question of what co-ordination mechanisms keep these enterprises together (Stock *et al.* 2000). In extended enterprises, individual firms have to be linked to each other. Stock *et al.* (2000) consider three basic governance configurations of extended enterprises: networks, hierarchies and markets, dependent on the level of vertical integration and the strength of supply chain links (Table 1).

With the two dimensions of this framework, the degree of vertical integration and degree of autonomy of participants, the different models governing parties in extended enterprises in construction could be categorized. The first dimension, the vertical integration is defined as the extent to which a focal firm owns the different stages of a production process. The second dimension, the nature of relationships or links between parties, is characterized by a number of different attributes linking the parties together. Information technology plays an important role in connecting separate organizations in the supply chain. In market relations, the strength of the links between parties and the level of vertical integration is low. In a network relation, there are strong links between parties but the level of vertical integration is low. In a hierarchy, both vertical integration and the strength of the linkages are high. A related concept to the extended enterprise is the "virtual organization" or "virtual corporation". Wang (1997 in: Malhotra, 2000) state that 'virtual organizations denote an organizational form which is based on a temporary network of independent companies'. 'The virtual corporation is a temporary partnership, which is neither set up for an agreed upon period of time nor it is an open ended co-operation like a joint venture' (Byrne 1993 in: Malhotra, 2000). The virtual corporation lasts as long as it is beneficial for the partners involved. The main emphasis in virtual corporations is to complement and share resources in order to improve competitiveness as a whole. Another important feature of the virtual corporation is the possibility for smaller firms to join forces and to compete with larger firms. In that manner, for example, SME's could benefit from economies of scale. Thus, in virtual corporations, firms, maintain their independence as well as improve their competitiveness as a whole while being part of a network, which does cause interdependencies between the firms. The management of interdependencies is cited the key challenge (Davidow & Malone 1992, Jarillo 1988). From a resource-based view, the virtual corporation can be viewed as a bundle of resources. Competitive advantage can be achieved to make such resources available to the partners in the virtual corporation. From a knowledge-based view, the virtual corporation can be viewed as a bundle of data, information, knowledge and expertise. Members make their knowledge base available to their partners to make full use of their knowledge potential and fill their knowledge gap, necessary to fulfil certain tasks and compete successfully in existing or future markets (Malhotra 2000).

SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION

Supply chain management (SCM) has been observed as an emerging field of research and potential source of improved performance for the construction industry (e.g. London & Kenley 2001, O'Brien & Fischer 1993, O'Brien *et al.* 2002). However the specific nature of construction supply chains and their industrial and economic context need to be included, particularly the temporal and fragmented character of project-based multi-organizational construction supply chains, compared to the permanent production organizations of manufacturing industries.

Extended enterprise as governance mechanism for construction supply chains

The notion of the construction supply chain as it were 'one firm' has first been discussed by Eccles (1981) by introducing the concept of the "quasi-firm" with strong linkages between firms involved in a construction project. Dubois and Gadde (2002) distinguish tight couplings between firms in individual projects and loose couplings in the permanent network of firms within the industry as a "loosely coupled system".

The extended enterprise in construction supply chains implies a higher level of integration between firms. In order to achieve higher levels of supply chain integration, Dainty *et al.* (2001) observe the need to facilitate inter-firm relationships, achieve mutual benefits and build trust at key interfaces in the supply chain (client/contractor, consultant/contractor, contractor/subcontractors, (sub)contractor/suppliers etc.). It is crucial to take away the ingrained barriers of traditional relationships and the adversarial culture in construction practice, and instead, introduce a change management framework to facilitate the implementation of supply chain management at an operational level (Dainty *et al.* 2001). In centrally co-ordinated supply chains of construction projects, relations between firms are maintained for the duration of the project. Centrally co-ordinated supply chains are not merely directed towards minimizing transaction costs, but also towards enhancing the transfer of expertise and systematic feedback on planning, design, construction and maintenance between parties, and ultimately towards striving for joint value maximization. A more centralized governance in the building industry may therefore decrease costs as well as increase value (Voordijk *et al.* 2000). One important issue of extended enterprises and virtual corporations in the construction supply chain is the division of operations and the allocation of specialized tasks among specialist firms, and the co-ordination of these operations, tasks and firms. This is particularly an issue in the construction industry because of the high share of SME's. This calls for intensive co-operation, co-ordination and communication in the network of firms, i.e. the virtual corporation (Kornelius & Wamelink 1998).

SUPPLY CHAIN MANAGEMENT IN AEROSPACE

Lean and agile manufacturing

Lean and agile manufacturing is common practice in aerospace (Philips, 1999). In these supply chains, as part of this lean manufacturing, components flow from the supply base through supplier tiers towards the assembler. The components are delivered to fit exactly to the structure of the product system and production process of the assembler. Typically, the suppliers of components to the aircraft manufacturer are organized in a pyramid of tiers. The first tier supplier integrates all lower tier supplies and develops complete subsystems that fit together with the other subsystems that the assembler eventually assembles into the end product. This is based on co-operative and intensive relationships between the assembler and suppliers (Womack *et al.* 1990, Lamming 1993). The origins of Lean Production can be traced to the Toyota Production System (TPS), with its focus on the reduction and elimination of waste (Ohno 1988). According to Phillips (1999) and Michaels (1999), the first steps of agile manufacturing are also set in the aerospace industry. More than lean, agile is focussed on flexibility and responsiveness (Christopher and Towill, 2000). Both agility and lean demand high levels of product quality. They also require minimum total lead-times defined as the time taken from a customer raising a request for a product or service until it is delivered. Total lead-time has to be minimized to enable agility, as demand is highly volatile and thus difficult to forecast. If a supply chain has long end-to-end lead-time then it will not be able to respond quickly enough to exploit marketplace demand. Furthermore effective engineering of cycle time reduction always leads to significant bottom line improvements in manufacturing costs and productivity (Towill, 1996).

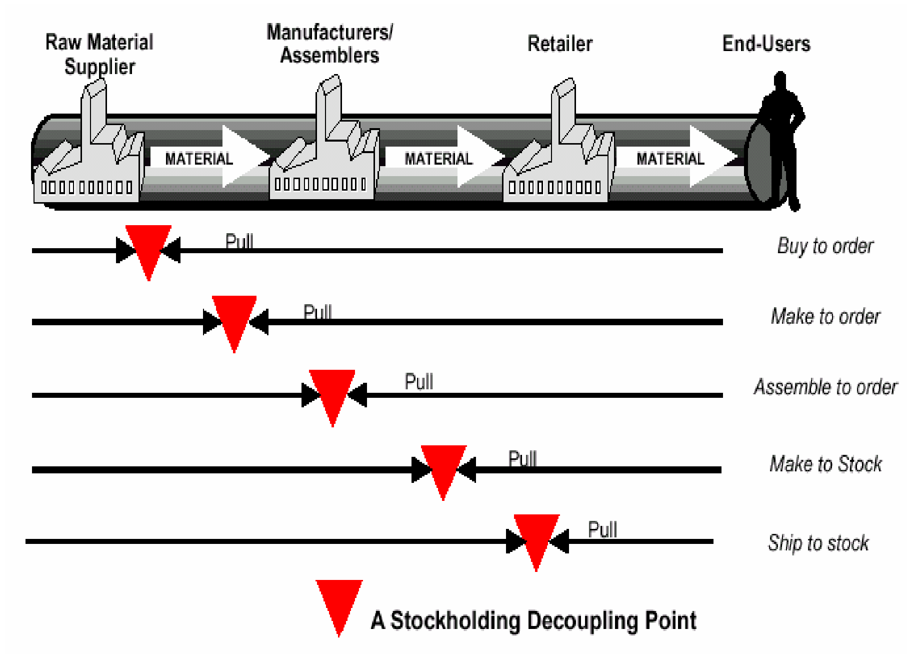

Figure 1: Family of supply chain structures (Hoekstra and Romme 1992)

Platform assembly

Aircraft manufacture is highly dependent on tiers of platform assembly (Williams *et al.*, 2002). Platform assembly has received increasing attention in product development and operations management (Wheelwright and Clark, 1992; Meyer and Lehnerd, 1997). A platform can broadly be defined as a relatively large set of product components that are physically connected as a stable sub-assembly and are common to different final models (Meyer and Lehnerd, 1997). By using a platform approach, a company can develop a set of differentiated products or derivatives (Wheelwright and Clark, 1992). In particular, from the production and assembly perspective, a platform makes it possible to share production tools, machines and assembly lines. According to Williams *et al.* (2002) complex products, such as aircraft, have integral architectures where major subsystems (airframe, avionics, hydraulics and engines) cannot be made up of off-the-shelf components. Aerospace industry supply chains contain a relatively high number of suppliers. Where product complexity can be reduced this may contribute to reducing the complexity in supply chains and lowering transaction costs. This is achieved through replacing integral architectures with modular ones using a platform approach. A platform approach is, simultaneously, a technical and an organizational issue. It is a technical issue because it requires specific problem solving and is related to product architecture and modularization. It is an organizational issue because platform development affects product development organization, i.e. building platform teams and co-ordinating their job with advanced engineering activities.

APPLICABILITY OF SUPPLY CHAIN CONCEPTS AND STRATEGIES FROM AREOSPACE TO CONSTRUCTION

Lean construction supply chains

The decoupling point plays an important role in defining the supply chain that is both lean and agile. The decoupling point has been defined as the point in the supply chain that separates the part of the supply chain oriented towards customer orders from the part of the supply chain based on planning (Hoekstra and Romme 1992). In manufacturing, it is commonly associated with the strategic stock that buffers the supply chain from changes in customer demand, in terms of both volume and variety. Associated with the decoupling point is the issue of postponement and late configuration. As seen in Figure 1, there are two extreme positions. The first is the ‘buy to order’ supply chain in which the product is configured from the outset, that is, from raw materials. In this supply chain all businesses are agile and all respond to changing customer requirements. This supply chain works well as long as the customer is willing to accept long lead-times. The other extreme is the ‘ship to order’ structure in which a standard product is provided from a defined range. Although lead-times are very short (or ‘off the shelf’), the danger of obsolescence has to be considered. Naim *et al.* (1999) highlight the potential for applying standard components and the importance of the location of the decoupling point in house building supply chains in order to develop “leagile” house building supply chains, and postponement strategy that enables to respond to changing customer requirements in an efficient way. This approach needs holistic supply chain reorganization and increase of the level of customization. Barriers to these developments include institutional factors, implications for internal business processes, fragmentation of the supply chain, low innovative capacity, and low technological competence (Naim *et al.* 1999).

Lin and Shaw (1998) define three types of supply chain networks (SCN) including three types of strategies towards the order fulfilment process (OFP), including order management, manufacturing and distribution. The first type is convergent supply chain implying a make-to-stock strategy and early differentiation, e.g. in the agriculture industry. The second type is the divergent supply chain implying a make-to-order strategy and delayed differentiation, e.g. in the computer industry. The third type is also a divergent supply chain, but it implies a build-to-forecast strategy and responsiveness, e.g. in the textile industry. Construction supply chains have been associated to make-to-order supply chains (e.g. Vrijhoef and Koskela 2000). Typically, a make-to-order construction delivery process begins at the customer, through the entire supply chain from initiative to hand-over, back to the customer. In contrast to most manufacturing supply chains, a construction make-to-order supply chain is converging to the construction site where the one-off final product is assembled. Converging chains have been typified by these characteristics (Luhtala *et al.* 1994):

- Type of business: project deliveries
- Production: make-to-order
- Control: pull
- Volumes: low
- Products: investment goods
- Customer focus: single customer
- Cost savings potential: project management
- Production objectives: quality, punctuality, delivery time

Luhtala *et al.* (1994) argue that pure converging chains occur in one-of-kind production and in project delivery business, such as construction. In addition, the competence in make-to-order supply chains is merely based on technical know-how, and managerial issues like information exchange and co-operation between units in the supply chain.

Modular product architectures in construction

Buildings are very complex products consisting of numerous elements, which in themselves also consist of numerous elements. One of the smallest distinct elements of a building is often the brick. Distinct elements may be the roof, the façade, the kitchen, the toilet or the walls. In general, one can distinguish between three generic levels of a building:

- Exterior: the most rigid level of the building design, i.e. the floor plan, volume elements, which determine the shape or exterior of the house
- Interior: the finishing design parts of a building, i.e. roofs, facades, bow windows, use of materials, which determine the infill or interior of the building
- Accessories: colours, type of kitchen, which determine the extras of the building etc.

When we take modular homes as the extreme case of product modularity in the building industry, a number of issues are apparent (Wolters, 2002, 151). First, we see that distinctiveness of components is present at the level of the exterior: the components are modular units or 'boxes', which are manufactured at the factory, including their internal and external features. The connection to adjoining units is completed on the site. A module often contains the completed bathroom and kitchen, including all interior fittings and finishing. Second, the coupling between the modules is loose; they have been developed independent of each other. Third, the mapping between functions and components is also quite clear: entire bathroom, kitchen or plumbing components are designed. Fourth, the interfaces between modules are standardized. This simplifies planning and scheduling of construction and reduces overall construction time. According to Lin and Shaw (1998), applying modularity to the product design, the outsourcing of components, and the organization of production and supplies, is viewed as an improvement strategy of the order fulfilment process and supply chain structure.

DISCUSSION AND CONCLUSION

In terms of the supply chain, modular design and production can be the basis for a lean manufacturing strategy in construction. The subsystems of the building are made of prefabricated parts that are preinstalled in a manufacturing environment. The decoupling point for the different supply chains differs from project to project, and thus needs to be defined clearly for every project. The location of the decoupling point, however, is a strategic decision at the beginning of the building process. From there the process is divided in separate paths through the process, involving separate channels through the supply chain, involving separate contractors (or contracts), respectively for the base building and for the fit-out. Baldwin & Clark (2000) identify three types of modularity which all can be applied into construction: modular-in-production, modular-in-design and modular-in-use. Modularity-in-production rationalizes a product into components and allows parts to be standardized and produced independently before assembly into the final system. Modularity-in-design goes a step further with an overall architecture and standard interfaces, the modules can be designed independently, and mixed and matched to create a complete system. Finally, a product is modular-in-itself if consumers themselves can mix and match components to arrive at a functioning whole. The concept of platform assembly is closely tied to that of modules and product modularization since it allows the product to be differentiated to a high degree and thus meet varied customer requirements. Our future research will focus on the applicability of different platform concepts into the building industry because the improvement potential of these concepts regarding supply chain management in construction is expected to be high.

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