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The four roles of supply chain management in construction

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Abstract

It is argued that due to construction peculiarities, supply chain management has four specific roles in construction. Practical initiatives in each role to advance the construction supply chain are analysed. The present status of construction supply chains is investigated by means of case studies and a comparison with previous research. Three main conclusions are drawn regarding the present status. Firstly, even in normal situations the construction supply chain has a large quantity of waste and problems. Secondly, most of these are caused in another stage of the construction supply chain than when detected. Thirdly, waste and problems are largely caused by obsolete, myopic control of the construction supply chain. These results concur with the findings made on make-to-order supply chains in general. Finally, the subjective and objective limitations of the four roles are analysed, this being based on empirical findings and the generic theory of supply chain management. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Supply chain management; Construction supply chain; Roles and limitations

1. Introduction

Two issues invite a discussion about construction supply chains: lagging productivity development and increased economic weight of the supply chain. The productivity increase in building construction has been slow. In Finland, for example, the annual increase has only been approximately 1% since 1975 (Vainio, 1999). In the Netherlands, this figure has been approximately 3% (Jansen, 1996). This is still not enough, however, to compensate for the average increase in labour costs. Statistical figures show that, in relative terms, main contractors have been purchasing increasing amounts of labour and material. Nowadays, these represent about 75% of main contractors' turnover (e.g. Scholman, 1997). As a consequence, main contractors have become increasingly reliant on other actors in the construction supply chain (e.g. suppliers and subcontractors). The traditional approach to the control of the construction supply chain is not adequate any more, and a shift of methods for managing the supply chain is needed.

From the end of the 1980s, the construction industry has seen the launch of a number of supply chain management (SCM) initiatives. However, until now these have been scattered and partial. Thus, the goal of this paper is to clarify the roles and possibilities of SCM in the construction industry. Using the lessons learnt from SCM in manufacturing as a starting point, there is a definition of the four roles of SCM in the construction industry, and an analysis of three case studies of present supply chains in the construction industry. There is a comparison between the conclusions from the case studies and both the findings in prior research and the most common problems previously observed in make-to-order supply chains in manufacturing. Finally, there is a discussion of the limitations of the four roles of SCM in the construction industry, and a presentation of recommendations for SCM in construction.

2. Supply chain management in manufacturing

2.1. Origin of supply chain management

SCM is a concept that originated and flourished in the manufacturing industry. The first visible signs of SCM were in the JIT delivery system, as part of the Toyota Production System (Shingo, 1988). This system aimed to

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regulate supplies to the Toyota motor factory just in the right — small — amount, just in the right time. The main goal of this system was to drastically decrease inventories, and to effectively regulate the suppliers' interaction with the production line. Another stimulus for SCM originated in the field of quality control. As early as 1950, in an address to Japanese industrial leaders, Deming suggested that working with the supplier as a partner in a long-term relationship of loyalty and trust would improve the quality and decrease the costs of production (Deming, 1982).

After its emergence in the Japanese automotive industry as part of a production system, the conceptual evolution of SCM has resulted in an autonomous status of the concept in industrial management theory, and a distinct subject of scientific research, as discussed in literature on SCM (e.g. Bechtel and Yayaram, 1997; Cooper et al., 1997). In addition to the Japanese influence, Western scholars like Burbridge and Forrester provided early contributions to the understanding of supply chains (Towill, 1992). Along with original SCM approaches, other management concepts (e.g. value chain, extended enterprise) have influenced its conceptual evolution, which has led to the present understanding of SCM.

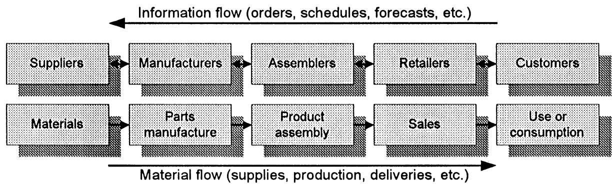

Fig. 1. Generic configuration of a supply chain in manufacturing.

2.2. Concept of supply chain management

The supply chain has been defined as "the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer" (Christopher, 1992).

SCM views the entire supply chain (Fig. 1), rather than just the next part or level, and aims to increase transparency and alignment of the supply chain's co-ordination and configuration, regardless of functional or corporate boundaries (Cooper and Ellram, 1993). The basic idea of SCM is to recognise the interdependency in the supply chain, and thereby improve its configuration and control based on such factors as integration of business processes. According to some authors (e.g. Cooper and Ellram, 1993), the shift from traditional ways of managing the supply chain towards SCM includes particular elements. These are shown in Table 1.

There are also other illuminating typologies of SCM. First, there are development issues of SCM, including order information transparency, reduction in variability, synchronising of material flows, management of critical resources and configuration of the supply chain (Lin and Shaw, 1998). Second, there are strategies for SCM including establishment of stable partnerships, modular outsourcing of components, design for suitability for manufacture, flexible manufacturing technologies, evolution of the supply chain with the product life cycle, and information acquisition and sharing (Lin and Shaw, 1998). Third, there are levels of SCM that can be distinguished, including initial partnership (e.g. building good

Table 1
Characteristic differences between traditional ways of managing the supply chain and SCM (Cooper and Ellram, 1993)[a]

Element	Traditional management	Supply chain management
Inventory management approach	Independent efforts	Joint reduction of channel inventories
Total cost approach	Minimise firm costs	Channel-wide cost efficiencies
Time horizon	Short term	Long term
Amount of information sharing and monitoring	Limited to needs of current transaction	As required for planning and monitoring proesses
Amount of co-ordination of multiple levels in the channel	Single contact for the transaction between channel pairs	Multiple contacts between levels in firms and levels of channel
Joint planning	Transaction-based	Ongoing
Compatibility of corporate philosophies	Not relevent	Compatibility at least for key relationships
Breadth of supplier base	Large to increase competition and spread risks	Small to increase co-ordination
Channel leadership	Not needed	Needed for co-ordination focus
Amount of sharing risks and rewards	Each treated separately	Risks and rewards shared over the long term
Speed of operations, information and inventory levels	"Warehouse" orientation (storage, safety stock) interrupted by barriers to flows; localised to channel pairs	"Distribution centre" orientation (inventory velocity) interconnecting flows; JIT, quick response across the channel

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relations with suppliers and distributors), logistics management (e.g. implementing and controlling the flow involving all actors in the chain), and "genuine SCM" (e.g. continuous improvement of all aspects of the entire chain) (Giunipero and Brand, 1996).

2.3. Underlying theory of supply chain management

Even if rarely acknowledged in literature on SCM, it is easy to see that its emergence is due to the same shift in theoretical concepts as the emergence of JIT and lean production. The traditional way of managing the supply chain (as presented in Table 1) is based, to a large extent, on a *transformation view* of production, whereas SCM is primarily based on a *flow view* of production. The transformation view suggests an independent control of each stage of production, whereas the flow view suggests a focus on the control of the total flow of production (Koskela, 1992, 1999). Related to this is the concept that the supply chain can be seen as a "logical factory". Thus, the same principles and methods that have been used to develop factories can also be used to improve supply chains (Luhtala et al., 1994). On the other hand, practices particular to quality control in SCM have a third basic conceptual basis, which is the *view of production as value generation* (Koskela, 2000).

3. The roles of supply chain management in construction

3.1. Characteristics of construction supply chains

In terms of structure and function, the construction supply chain is characterised by the following elements:

- It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The "construction factory" is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory, and are distributed to many customers.
- It is, apart from rare exceptions, a temporary supply chain producing one-off construction projects through repeated reconfiguration of project organisations. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and the construction of the built object.
- It is a typical make-to-order supply chain, with every project creating a new product or prototype. There is little repetition, again with minor exceptions. The process can be very similar, however, for projects of a particular kind.

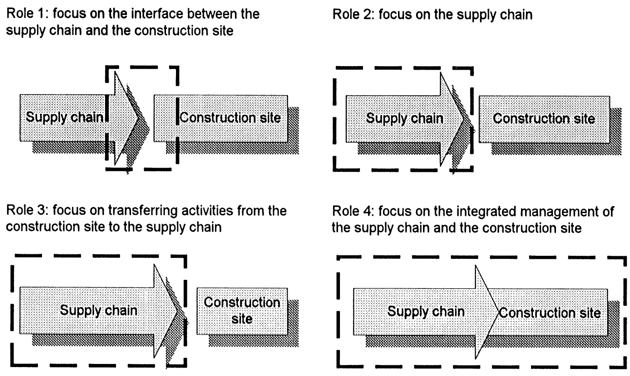

Fig. 2. The four roles of supply chain management in construction.

3.2. Introducing the four roles of supply chain management in construction

The characteristics discussed above also have an impact on the management of supply chains. Four major roles of SCM in construction can be recognised, dependent on whether the focus is on the supply chain, the construction site, or both. Fig. 2 shows these four areas of focus, which are also examined below.

Firstly, the focus may be on the impacts of the supply chain on site activities. The goal is to reduce costs and duration of site activities. In this case, the primary consideration is to ensure dependable material and labour flows to the site to avoid disruption to the workflow. This may be achieved by simply focusing on the relationship between the site and direct suppliers. The contractor, whose main interest is in site activities, is in the best position to adopt this focus.

Secondly, the focus may be on the supply chain itself, with the goal of reducing costs, especially those relating to logistics, lead-time and inventory. Material and component suppliers may also adopt this focus.

Thirdly, the focus may be on transferring activities from the site to earlier stages of the supply chain. This rationale may simply be to avoid the basically inferior conditions on site, or to achieve wider concurrency between activities, which is not possible with site construction with its many technical dependencies. The goal is again to reduce the total costs and duration. Suppliers or contractors may initiate this focus.

Fourthly, the focus may be on the integrated management and improvement of the supply chain and the site production. Thus, site production is subsumed into SCM. Clients, suppliers or contractors may initiate this focus.

It should be noted that the roles as identified above are not mutually exclusive, but are often used jointly.

This paper's focus is the supply chain of a main contractor. However, there is a fifth important role that lies beyond the scope of this paper, namely management of the construction supply chain by facility, or real estate owners. They may well drive the management and development of the construction supply chain on which they are reliant for the continuation of their business, for instance when they exploit a number of facilities that need frequent new development and refurbishment. An example of this is the wide-ranging construction-related programme of BAA Ltd (Duncombe, 1997). Here, practically all the four roles of SCM are simultaneously applied in order to improve both the efficiency and the effectiveness of the supply chain. Indeed, this example shows that in addition to contractors, clients who have sufficient construction volume are able to initiate major improvements in the construction supply chain.

3.3. Practical initiatives to advance construction supply chains

The following section discusses practical initiatives to advance construction supply chains in each of the four roles.

Role 1: Improving the interface between site activities and the supply chain: The clearest initiatives of SCM in construction have been in the field of logistics (e.g. Asplund and Danielson, 1991; Wegelius-Lehtonen and Pahkala, 1998). Here, there has been a focus on the co-operation between suppliers and contractors for improving the total flow of material, whereas traditional treatment of construction logistics and material handling has predominantly concentrated on activities occurring on site (Johnston, 1981).

Role 2: Improving the supply chain: This topic includes initiatives aimed at the development of specific supply chains, such as prefabricated concrete elements (Laitinen, 1993) or elevators (Luhtala et al., 1994). In-depth cost and time analyses are important for identifying potential improvement and for developing supply chains (Wegelius-Lehtonen, 1995). When developing the supply chain, the trade-off between transportation, inventory and production costs should be borne in mind in order to achieve global improvement. Productivity and supply chain performance is decreased by the following factors: uncertainty in the supply chain, varying site conditions and varying capacity conditions (O'Brien, 1995, 1998).

Role 3: Transferring activities from the site to the supply chain: Another group of initiatives aims at the redesign of the supply chain transferring on-site activities off site. Industrialisation, especially prefabrication, can be regarded as a structural means for eliminating on-site activities from the total production chain (Warszaswki, 1990). Thus, the earlier, and still actual initiatives towards industrialisation of construction must also be seen as a form of SCM concentrating on the design of the supply chain (Sarja, 1998).

Role 4: Integration of site and supply chain: New alternatives have been suggested for the integrated management of the supply chain and the construction site. These include open building (Van Randen, 1990) and sequential procedure (Bobroff and Campagnac, 1987). From a production point of view, the basic benefit of open building is in the postponement of the decisions of users regarding the interior of the building. This is realised by separating the infill from the structure. This also provides adaptability for the remaining life cycle of the building so that users can reconfigure the space as their needs change. In the sequential procedure, the idea is to structure the site work as successive realisations of autonomous sequences (this resembles group technology as developed in manufacturing). In both of these approaches, the goal is to replace construction's usual temporary chains with permanent supply chains. Pre-engineering is another related approach, where the customer may choose a pre-engineered building from a certain range of options (Newman, 1992). The supply chains for such buildings are typically stable. Design-build arrangements (Bennett et al., 1996), although more restricted in scope, can also be classified in this group.

In critical terms, prior initiatives on construction SCM have had only limited impact on the industry, and their wider application has been slow. Some of these initiatives are so new that it can be argued that they are in the first stages of their diffusion, typically following an S-curve, which tends to grow slowly in its early phases. Even industrialisation, the oldest initiative that exists, has nevertheless not generally made the breakthrough into building construction (Warszaswki, 1990). A better understanding of construction supply chains is clearly necessary in order to comprehend the reasons for the difficulties of SCM's advance within construction.

4. Analysis of the present status of construction supply chains

The status and characteristics of present construction supply chains have been investigated in three case studies, carried out in the Netherlands and Finland. The supply chains that were observed were randomly chosen and were each representative of a "typical" supply chain and make-to-order construction process. These are shown in Fig. 3.

All of the observed supply chains consisted of flows of prefabricated components. Thus, development from the point of view of role 3 (transferring activities from the site to the supply chain) was present in the supply chains studied. In addition, the contractors involved had carried out sporadic improvement initiatives for realising role 1 (interface between the site and the supply chain).

The case studies addressed the following research questions: What waste and problems were encountered in construction supply chains, and where in the supply chain did their cause lie? What is the root cause of the waste and the problems? Can the waste, problems and root causes encountered in construction supply chains be resolved by applying SCM (e.g. by developing new control principles for construction supply chains)?

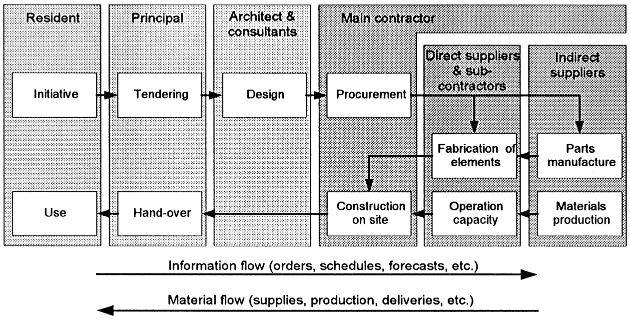

Fig. 3. Typical configuration of a traditional construction supply chain.

By comparing the results of the case studies to the findings in prior research on construction supply chains, a better understanding and justification of the results are achieved. The next step is to compare the consolidated results to findings in make-to-order supply chains in manufacturing.

The case studies merely applied to the part of the supply chain co-ordinated by the main contractor (Fig. 3). The first two case studies focused on flows of prefabricated materials in residential building (Vrijhoef, 1998). The third case study was done in an office building project in which the focus was also on flows of prefabricated materials (Table 2). There were no characteristic

Table 2
Overview of case studies

	Case 1: Time measurement of concrete wall elements	Case 2: Problem analysis composite façade elements	Case 3: Analysis of extra costs for site logistics
Description	This case study refers to time measurement to detect and analyse time buffers in a supply chain process of concrete wall elements, including the excavation and delivery of sand, the fabrication and delivery of elements, and the site installation of elements.	This case study involves problem analysis to identify and locate controllability problems in a chain process of composite façade elements. The observed parts of the process included the job preparation, price negotiation, engineering, assembly, and site installation of the elements.	This case study addressed the issue of traditional trading leading to extra costs for site logistics for a number of building materials (i.e. costs for extra handling and transport of the materials on site due to unforeseen circumstances). The observed activities included site operations, price calculations and bargaining.
Objective	Analysis of the time involved during the process in order to gain insight into how the time was built up, and the magnitude and location of time buffers.	Analysis of the controllability problems along the process in order to gain insight into the occurrence and causes of the problems.	For a number of building materials the average market price was compared with the purchase price and the extra costs made on site for logistics (as an index of the market price: index = 100).
Method	Division of the process into sub-processes and activities	Division of the process into sub-processes	For the materials the approximate baseline logistical costs were calculated beforehand.
	Time measurement of the activities	Determining the controllability problems per sub-process	The extra costs on site were registered when something unforeseen happened, such as unexpected deliveries or deliveries of materials in larger batches than expected.
	Categorising time involved per activity: wasted, non-value-adding, value-adding	Identifying and locating the causes	
	Locating and quantifying time buffers	Finding connections between the problems and causes	
	Determining how the process time had been built up		
Results	It appeared that at the beginning and the end of the sub-processes significant time buffers occurred, particularly due to inventory and delays. The proportion of time buffers to total lead-time was quite large. Underlying problems of the time buffers included uncoordinated planning and point to various root causes such as inter-organisational obstacles.	To controllability problems were many and varied. Root causes included non-collaborative working relations between parties, and adversarial bargaining. Most problems that were encountered on an operational and managerial level were actually caused by strategic and cultural issues, including a lack of common targets, prevailing self-interest, reluctance and opportunism.	The extra costs varied from 40 to about 250% of the purchase price. The extra costs mainly included man-hours spent on remedying unexpected incidents. Extra costs were incurred, for instance, due to procurement of large and inappropriately packaged batches of material that were awkward to handle. These tended to be the materials and goods for which a considerable discount had been negotiated.

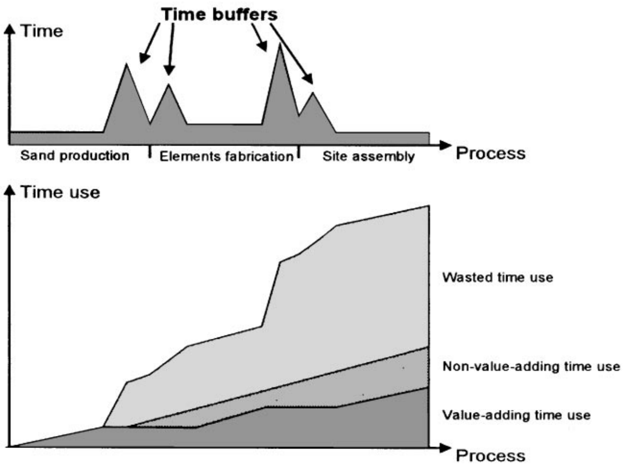

Fig. 4. Case 1: Time measurement of concrete wall elements (represented schematically).

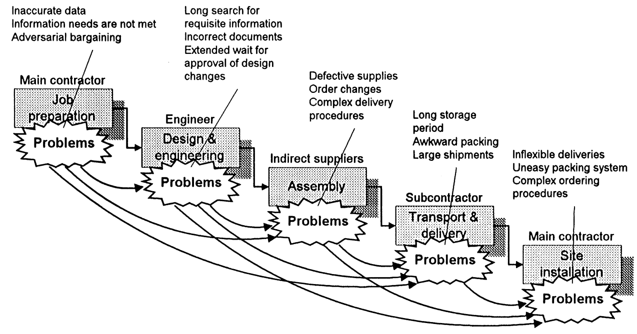

Fig. 5. Case 2: Problem analysis of composite façade elements.

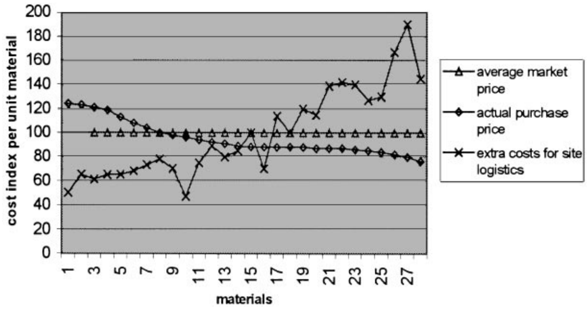

Fig. 6. Case 3: Cost and price analysis of building materials.

differences between the chains in either country in terms of building systems and construction processes.

Initially, the case studies analysed the symptoms of deficient site activities (i.e. waste and problems) and the impact of the supply chain on the performance of site activities (referring to role 1 of SCM). Then further analyses sought out the root causes of the symptoms leading to the domain of role 2 (improving the supply chain) as well as roles 3 and 4 of SCM (transferring activities from the site to the supply chain, and integrated management of the supply chain and the site).

Case study 1: time buffers: The first case study represented a time measurement of the production and delivery process in a supply chain for concrete façade elements in a housing project (Table 2). Time buffers appeared to be mainly located in between the sub-processes; separating the sub-processes in order to cope with variability and non-synchronicity on either side of the buffers. The time buffers had a large impact on the build-up of time in the total process (Fig. 4).

Case study 2: controllability problems: The second case study represented an analysis of controllability problems in the production and delivery process for composite façade elements preceded by planning, engineering and bargaining activities in a housing project (Table 2). The controllability problems appeared to stem often from earlier activities in the chain process performed by prior actors (Fig. 5).

Case study 3: traditional trading: The third case study represented an analysis of extra costs made for site logistics due to bargaining practices in an office building project. The extra costs are compared to the purchase price and average market price of the materials observed (Table 2). The data has been arranged in a descending sequence of the relative purchase price of the materials observed. In general, it appeared that the lower the purchase price was the higher the extra costs for site logistics (Fig. 6). In this case, the extra costs varied from 40% of the purchase price (i.e. 50% of the average market price: material 10) up to about 250% of the purchase price (i.e. 200% of the average market price: material 27).

For instance, the order for material 27 (sand-lime bricks) came on pallets that were far too large and heavy to get them with any ease all the way up using the elevator and through the building. In addition, the heavy weight of the pallets made it impossible to move the bricks around on the floors of the building. Therefore, one man had to spend approximately 50% of his time manually carrying the bricks across the floor to the location where the bricks had to be put in place.

There were various causes for the extra costs, for instance, chaotic material deliveries and unsystematic site organisation. As mentioned above, another reason was the procurement of large and often inappropriately packaged batches of material, which were awkward to handle. It appeared that these were mainly the materials and goods for which considerable discount had been negotiated. Purchasing materials and goods at the very lowest price is common practice among purchasing departments of contractors. In this case, however, it appeared that for many materials this approach substantially increased the extra costs made on site (Fig. 6).

Case study analysis: From the case studies three main conclusions can be drawn. Firstly, even in normal situations a lot of waste and many problems exist in the construction supply chain, though these are often either not seen or are ignored. Secondly, most of the waste and problems are caused in another stage of the construction supply chain than where the waste and problems surfaced. The root causes of the waste and problems were rarely found in the activity where the waste and problems were encountered, but rather in a previous activity by a prior actor. Thirdly, waste and problems are largely caused by myopic control of the construction supply chain.

4.1. Comparison of case study results with findings in previous research

In order to validate the conclusions more generally, the case study results are compared with findings in previous research.

Waste and problems in construction supply chains: Jarnbring (1994) found in his study on construction material flows that the value-added time of those flows is only 0.3–0.6% of the total flow time. Only for the interface between the main contractor and the supplier has an average cost reduction potential of 10% (of material costs) through improved logistical procedures been shown (e.g. Asplund and Danielson, 1991; Jarnbring, 1994). When taking the whole supply chain into consideration, and all improvement possibilities, the amount of avoidable costs must be considerably higher.

Root causes of waste and problems in prior stages of the construction supply chain: Jarnbring (1994) found that deficient planning and information on the amount of requisite material are characteristic for materials purchasing. In a study on the implementation of lean production in construction component manufacturing, Koskela and Leikas (1997) found that there is a tendency to place construction component orders with missing information due to incomplete design data. In a study on the supply of concrete façade component, Laitinen (1993) found that several of the problems observed in the factory were due to external parties. In terms of design information, design documents are often inadequate and difficult issues are not detailed. Changes are caused by unavailable, late, wrong and incomplete information and are often not communicated. On the other hand, the factory caused problems for other parties. In attempting to optimise its activities it supplied elements in a different order to that in which they have to be installed. The factory needed to have all drawings simultaneously because of its own inadequate scheduling of its information needs.

Myopic control of the construction supply chain: In a study into construction logistics, it was found that the purchasing price is the dominating criterion for supplier selection (Wegelius et al., 1996); a finding which Jarnbring (1994) confirms. Särkilahti (1993) found that subcontractors are predominantly selected on the basis of price. According to Jarnbring (1994), decision making on the improvement of logistics is often constrained to those solutions one has experience of. It is customary to use material inventories as buffers against disruption. Similarly, Laitinen (1993) found that nearly all actors in the supply chain add a time buffer to their schedule, and thus unduly inflating the build-up of time.

Comparison of the results of the case studies with prior research justifies that waste and problems in construction supply chains are extensively present and persistent. Due to interdependency, the occurrence of waste and problems in interrelated with causes in other stages of the supply chain. In addition, myopic control of the construction supply chain reinforces waste and problems, and complicates resolution (Vrijhoef and Koskela, 1999).

4.2. Comparison with make-to-order supply chains in manufacturing

Based on various analyses in different companies producing non-standard products in different manufacturing industries, Luhtala et al. (1994) observed typical problems in make-to-order supply chains. The problems spread along the supply chain and typically exist at every interface in the total production process (Fig. 7).

Customers are often seen as the ultimate source of changes in specifications in make-to-order production. However, it was realised in the study that most of the controllability problems and changes in product specifications are of internal origin. They stem from the interaction of the various units of the supply chain. On the other hand, it is often postulated that poor delivery performance of component factories creates most of the problems in the installation phase. Instead, it was realised in the study that the role of the front-line units, responsible for sales and often for installation co-ordination, is crucial for the performance of the whole supply chain, including installation. It was concluded that make-to-order logistics networks contain a vast development potential that can be utilised by managing the

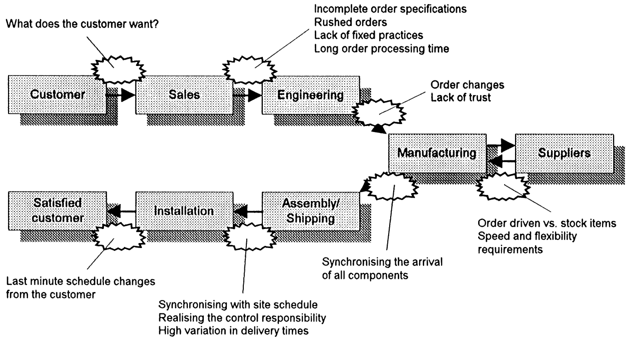

Fig. 7. Summary of the most common problems in make-to-order supply chains (Luhtala et al., 1994). Reproduced by permission of Helsinki University of Technology, Espoo.

delivery processes instead of individual units within them.

These results concur with the findings made in construction regarding the frequency of problems as well as their origin and causes.

The findings from the case studies are in line with the findings in previous research and correlate to typical problems in make-to-order supply chains in manufacturing. This observation largely justifies that many problems existing in construction supply chains have their origin in the deficiencies of obsolete control principles. Therefore, problems encountered in construction supply chains may well be resolved by applying a generic methodology provided by SCM, and developing corresponding control principles and methods.

5. Discussion

Based on the empirical analyses and the generic body of knowledge concerning SCM, subjective and objective limitations in each of the roles of SCM can now be perceived. Subjective limitations are due to a deficiency in conceptualisation; objective limitations are caused by the characteristics of the environment of the problem addressed or peculiarities of construction in general. It can be assumed that these limitations have thwarted progress in developing construction supply chains.

5.1. Role 1. Improving the interface between site activities and the supply chain

It is a *subjective* limitation that the logistics initiatives have stressed (average) costs particularly, and thus failed to address the impact of supply chain variability on site assembly. In this regard, the last planner method (Ballard and Howell, 1998) provides an appropriate augmentation.

In addition, there is an *objective* limitation due to the narrow focus of this role in relation to the whole supply chain. For instance, it is quite possible to improve the dependability of the deliveries of a supply chain through buffering, without addressing the whole supply chain, but the improvement of the dependability of the total supply chain would be a more efficient and effective solution.

5.2. Role 2. Improving the supply chain

Regarding this role, the erratic and undisciplined nature of customer activities (Koskela and Leikas, 1997) causes *objective* limitations. There are problems at both ends of the delivery process. At the beginning, the product definition is incomplete or capricious, and at the end, the delivery date often changes and the installation conditions are chaotic. As far as possible, the supply chain should be shielded from these problems or made robust in relation to them.

5.3. Role 3. Transferring activities from the site to the supply chain

Transferring activities off site yields *objective* limitations. In industrialisation, the structure and behaviour of the total process changes: the process is longer, the amount of design required more substantial, the error correction cycle longer, and requirements for dimensional accuracy usually higher. Thus the total process of industrialised construction tends to become complex and vulnerable to variability, even if the part of the process located on site becomes less complex (Koskela, 2000). The inevitable penalties for variability (Hopp and Spearman, 1996) may grow on account of this. Indeed, if activities are transferred off site, the complexity that results in the supply chain must be managed well and be improved in order to profit from the intended benefits.

However, industrialised construction, with its long and complex supply chain, seems often to have suffered from a lack of basic SCM; a matter of *subjective* limitation. It seems that in badly controlled design, fabrication and site processes the increase in costs due to non-value-adding activities has often nullified the theoretical benefits to be gained from industrialisation. As the study by Luhtala et al. (1994) shows, manufacturing-oriented make-to-order supply chains are also plagued by problems and waste if managed in the traditional way.

5.4. Role 4. Integration of site and supply chain

Here again *objective* limitations can be discerned in many initiatives, related to the nature of constructed objects. The logic of many existing initiatives is based on the idea that SCM is more effective with stable supply chains and with standardised (even if customised) products. However both features, stable chains and standardised products, are restrictive to some extent in respect of market opportunities and the broad spectrum of demand for construction. From this point of view, Naim et al. (1999) suggest developing construction supply chains also in the framework of the "agile paradigm": using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace.

In terms of *subjective* limitations, design-build is a particular example that shows integration to have often been merely partial or superficial. Studies (e.g. Bennett et al., 1996; Konchar and Sanvido, 1998) show that the benefits of design-build, even if statistically observable, are minor. The most plausible reason for this is that the control and improvement of design-build processes have been poor. Presumably, it had been thought that mere improvement of the organisational structure would suffice.

6. Conclusions

This paper contains three contributions to knowledge. *Firstly*, various existing initiatives towards construction supply chain development are explicitly related to a generic SCM methodology. In this context, four roles of SCM have been identified. Previous research has often been partial, focusing solely on one role at a time.

Secondly, the present status of construction is empirically assessed from a supply chain viewpoint. The result of this investigation is revealed to be compatible both with previous observations in construction and in make-to-order supply chains. The result provides a new, empirically founded understanding of construction supply chains and shows that great potential exists for their improvement. The majority of the causes of waste and problems are related to traditional management of the supply chain, and thus new principles and methods of modern SCM should provide a solution.

Thirdly, based on the new empirical understanding and generic theories of SCM, limitations in each role have been recognised and discussed. These limitations had previously only rarely been discussed. Regarding each of these roles, subjective limitations have to be eliminated while objective limitations, related either to the narrow definition of the problem or to the characteristics of construction like site production, have to be recognised and suitable countermeasures taken.

All in all, it can be assumed that the generic body of knowledge accrued in the framework of SCM leads to improved understanding of the nature of construction supply chain problems, and provides direction for action. However, the practical methods for SCM implementation have to be developed so they take into account the characteristics and the specific situation of construction.

References

Asplund, E., Danielson, U., 1991. Räta ut Byggsvängen (Straightening the Building Roundabout). SBUF, Stockholm.

Ballard, G., Howell, G., 1998. Shielding production: essential step in production control. Journal of Construction Engineering and Management 124 (1), 11–17.

Bechtel, C., Yayaram, J., 1997. Supply chain management: a strategic perspective. International Journal of Logistics Management 8 (1), 15–34.

Bennett, J., Pothecary, E., Robinson, G., 1996. Designing and Building a World-Class Industry, University of Reading.

Bobroff, J., Campagnac, E., 1987. La Démarche Séquentielle de la SGE-BTP (The Sequential Procedure of SGE-BTP). Plan Construction, Paris.

Christopher, M., 1992. Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Service. Pitman Publishing, London.

Cooper, M.C., Ellram, L.M., 1993. Characteristics of supply chain management and the implications for purchasing and logistics strategy. International Journal of Logistics Management 4 (2), 13–24.

Cooper, M.C., Lambert, D.M., Pagh, J.D., 1997. Supply chain management: more than just a new name for logistics. International Journal of Logistics Management 8 (1), 1–13.

Deming, W.E., 1982. Out of the Crisis. Massachusetts Institute of Technology, Cambridge.

Duncombe, L., 1997. The BAA project process: a partnership approach. In: Anumba, C., Evbuomwan, N. (Eds.), Concurrent Engineering in Construction CEC'97: Papers presented at the 1st International Conference, London, 3–4 July 1997, pp. 288–295.

Giunipero, L.C., Brand, R.R., 1996. Purchasing's role in supply chain management. International Journal of Logistics Management 7 (1), 29–37.

Hopp, W., Spearman, M., 1996. Factory Physics. Foundations of Manufacturing Management. Irwin/McGraw-Hill, Boston.

Jansen, F.J., 1996. Bouwbedrijf en Bouwtechniek (Construction Company and Construction Technology). Economisch Instituut voor de Bouwnijverheid, Amsterdam.

Jarnbring, J., 1994. Byggarbetsplatsens Materialflödeskostnader (Material Flow Costs on the Building Site). Lunds Tekniska Högskola, Lund.

Johnston, J.E., 1981. Site Control of Materials. Butterworths, London.

Konchar, M., Sanvido, V., 1998. Comparison of US project delivery systems. Journal of Construction Engineering and Management 124 (6), 435–444.

Koskela, L., 1992. Application of the New Production Philosophy to Construction. Technical Report No. 72, CIFE Department of Civil Engineering, Stanford University.

Koskela, L., 1999. Management of production in construction: a theoretical view. Proceedings of the Seventh Annual Conference of the International Group for Lean Construction IGLC-7, Berkeley, July 26–28, 1999, pp. 241–252.

Koskela, L., 2000. An Exploration into a Theory of Production and its Application to Construction. VTT Publication No. 408. VTT Building Technology, Espoo.

Koskela, L., Leikas, J., 1997. Lean manufacturing of construction components. In: Alarcón, L. (Ed.), Lean Construction. Balkema, Rotterdam, pp. 263–271.

Laitinen, M., 1993. Elementtijulkisivun Tietovirrat ja Toimitus (Information Flows and Delivery of Concrete Façade Elements). Rakennusteollisuuden Keskusliitto, Helsinki.

Lin, F.R., Shaw, M.J., 1998. Reengineering the order fulfilment process in supply chain networks. International Journal of Flexible Manufacturing Systems 10, 197–299.

Luhtala, M., Kilpinen, E., Anttila, P., 1994. LOGI: Managing Make-To-Order Supply Chains. Helsinki University of Technology, Espoo.

Naim, M., Naylor, J., Barlow, J., 1999. Developing lean and agile supply chains in the UK housebuilding industry. Proceedings of the Seventh Annual Conference of the International Group for Lean Construction IGLC-7, Berkeley, July 26–28, 1999, pp. 159–170.

Newman, A., 1992. Engineering pre-engineered buildings. Civil Engineering, 62, 58–61.

O'Brien, W.J., 1995. Construction supply-chains: case study, integrated cost and performance analysis. In: Alarcon, L. (Ed.), Lean Construction. Balkema, Rotterdam, pp. 187–222.

O'Brien, W.J., 1998. Capacity Costing Approaches for Construction Supply-chain Management. Stanford University, Stanford, CA.

Sarja, A., 1998. Open and Industrialised Building. E & FN Spon, London.

Scholman, H.S.A., 1997. Uitbesteding door Hoofdaannemers (Subcontracting by main contractors). Economisch Instituut voor de Bouwnijverheid, Amsterdam.

Shingo, S., 1988. Non-Stock Production. Productivity Press, Cambridge.

Särkilahti, T., 1993. Rakennushankkeen Aliurakat 1993 (Subcontracts in construction projects 1993). Rakennusteollisuuden Keskusliitto, Helsinki.

Towill, D.R., 1992. Supply chain dynamics: The change engineering challenge of the mid 1990s. Proceedings of the Institution of Mechanical Engineers (206), 233–245.

Vainio, T., 1999. Well-Being Through Construction 1999. VTT Building Technology, Espoo.

Van Randen, A., 1990. Separation of support and infill: a chance for a quantum leap in productivity. Proceedings of the Open Industrialisation: A solution for Building Modernisation, Stuttgart, February 21–23, 1990.

Vrijhoef, R., 1998. Co-makership in Construction: Towards Construction Supply Chain Management. Thesis of Graduate Studies Delft University of Technology/VTT Building Technology, Espoo.

Vrijhoef, R., Koskela, L., 1999. Roles of supply chain management in construction. Proceedings of the Seventh Annual Conference of the International Group for Lean Construction IGLC-7 Berkeley, July 26–28, 1999, pp. 133–146.

Warszaswki, A., 1990. Industrialisation and Robotics in Building: A managerial Approach. Harper & Row, New York.

Wegelius-Lehtonen, T., 1995. Measuring and re-engineering logistics chains in the construction industry. International Federation for Information Processing Working Conference on Reengineering the Enterprise Galway, April 20–21, 1995.

Wegelius-Lehtonen, T., Pahkala, S., 1998. Developing material delivery processes in cooperation: an application example of the construction industry. International Journal of Production Economics 56–57, 689–698.

Wegelius-Lehtonen, T., Pahkala, S., Nyman, H., Vuolio, H., Tanskanen, K., 1996. Opas Ratertamisen logistiikkaan (Guidelines for Construction logistics). Rakennusteollisuuden Keskusliitto, Helsinki.