ABSTRACT

Because of the structure and current practice of the construction industry, construction supply chains tend to be relatively fragmented, resulting in a relatively unstable production environment, including negative symptoms such as low efficiency levels, high unpredictability, low profits, and much rework and waste. In this paper, the application of systems theory and systems engineering is proposed as a solution for the systematic improvement of the construction supply chain. The application of systems thinking is presented as an approach to view and engineer construction supply chains as organisational systems, aimed at higher levels of integration and improvement. Through a configuration process of organisational engineering, the research reported aims to build integrated and improved supply chains in construction using theoretical and empirical building blocks. The theoretical building blocks are found in four types of theory: social, economic, organisational and production theories. Later on in the research empirical building blocks will be identified in applications of supply chain integration in construction compared to other sectors outside construction, to demonstrate the improvement potential and implications of construction supply chain integration. In this paper the application of supply chain systems engineering and the use of the theoretical building blocks are discussed, and the implications for the configuration and control of construction supply chains, and the consequences for traditional construction practice.

Keywords: Construction, Improvement, Integration, Supply Chain, Systems Engineering.
1. INTRODUCTION

In construction, the production system and the supply chain in particular have been deemed to be relatively disintegrated. A more integrated approach to construction has been coined very often as a solution for the many problems and deficiencies existing in construction. On the other hand also the restrictions of integration in construction have often been discussed, because of the temporary and complex nature of construction.

In this paper the idea is studied to view a construction supply chain as a system, and to apply systems engineering to increase coherence of the supply system. Here the underlying principle is that a production system like the supply chain that is delivering a single product should not be fragmented, nor consist of distributed functions. Instead supply chain integration must lead to improvement by developing a more stable, repetitive production environment, similar to what is common in other industries. This idea is developed in this paper by applying systems engineering to (re)build integrated construction supply chains. However to do this in construction some basic issues must be overcome caused by the peculiarities of construction. Taking these into account some basic building blocks of new production models for construction supply chains are formulated. The premise here is that supply chains would function better when approached as a single entity, an extended enterprise. In a way, the broader issue here is whether construction could or should develop itself towards the standards and rules of a “normal”, more systemic and production-driven industry.

2. SYSTEMS THEORY AND SYSTEMS ENGINEERING

Systems theory views the world in terms of collections of resources and processes that exist to meet subordinate goals. Two aspects of systems theory are of particular importance for supply chains: synergy and entropy. Synergy means the parts of a system working together can achieve more than the sum of achievements that each one would achieve separately.

Entropy refers to the necessity of feedback across the chain to prevent debilitation of the system (New & Westbrook 2004). Hassan (2006) suggested the application of system engineering to the design and formation of supply chains. The structuralist character of systems thinking can be helpful building or rebuilding the structure and operations of the supply chain in a systematic top-down manner, assuring its effective functioning.

A supply chain relates to the system taxonomy of a production line: functional (dynamic), purposive and mechanical. And in terms of systems typology, supply chains are designed systems, in contrast to natural systems. Besides supply chains are human activity systems and social systems, consisting of actions performed by individuals and groups of individuals, i.e. firms (Checkland 1981). Supply chains can be characterised by instrumental rationality and particularistic social relations.
between firms, which makes them associative systems, or alliances between economic actors (e.g. firms), engaged in a voluntary relationship to produce and deliver a product or service. Stevens et al (1998) stress the importance of systems engineering to manage the complexity of product development and production including the processes, infrastructure and other support systems.

3. VIEWING THE SUPPLY CHAIN AS A SYSTEM

Supply chains can be viewed as systems (Hassan 2006). A systems approach assures the systematic and logical configuration of the supply chain, and as a consequence improved performance. Particularly in the construction supply chain, which is less structured and systematic by nature, the application of systems terminology to the supply chains should be beneficial. This means applying a systems approach to try and cope with the complexity, unpredictability and instability often associated with the construction process. Besides, the supply chain seen as a production system inherently is an interdependent system, in which components affect each other. Only components that perform primary functions and value adding activities should be included. Besides the components are interdependent and interactive, and thus affect each other. Thus the behaviour of components affects the behaviour of the supply chain as a whole. Integration of components is essential for its success.

Applying systems engineering must lead increased coherence, and integrate the components of the supply chain resulting in coherent behaviour of SC as a whole. In essence, the supply chain must be seen as a single entity of different sub systems and components which needs to be designed. Design and operation of a supply chain and its components must thus support integration. Integration depends on the strength of the relationship between members of the supply chain, and whether the relationship is short term or long term.

As supply chains consist of networks of firms, Rouse (2005) considers the nature of enterprises as systems, and supply chains as 'systems of systems'. This is essential to fully understand and thus be able to find integrated solutions to improve enterprises and systems of enterprises (i.e. supply chains) fundamentally, i.e. enterprise transformation. Rigby et al. (2000) underline the importance of systems thinking for organisational change and improvement, but warn for the risk of underestimation of the complexity of reality when translating this reality into a mental model. Systems approaches are not fully capable of capturing ‘soft factors’ such as power and trust, interdependency and human factors.
4. UNDERSTANDING THE CONSTRUCTION SUPPLY CHAIN

4.1 INDUSTRY STRUCTURE

Often the construction industry has been characterised by complexity, referring to the demography of the industry (many SMEs and specialist firms) and the organisation of construction, including the configuration and coordination of construction supply chains. Indeed, construction as such is a less structured industry compared to other industries, with a vast network of actors of different kinds around a project, i.e. the development and construction of a built object (Figure 1).

![Demand and supply systems in construction](image)

Figure 1 Demand and supply systems in construction (Vrijhoef & De Ridder 2005).

4.2 MAKE-TO-ORDER DELIVERY AND CRAFTSMANSHIP

Construction supply chains are make-to-order supply chains, where project management and engineering are important issues. The fact that construction is often a demand-driven make-to-order process, and design is often disconnected from production lead to various problems of production. The producer is not the designer, and production is very much influenced by craftsmanship. Moreover, production involves many crafts and many relatively small firms. This causes problems originating upstream the supply chain to persist and often become worse downstream, because of the mechanisms of causality and interdependence within the supply chain.

4.3 ONE-OF-KIND AND ON-SITE PRODUCTION

Most production in construction is one-off, and done on site. The ‘factory’ is organised on site, and mostly very few materials and components of the end products are prefabricated or preinstalled off site. The logistics in construction are converging, meaning relatively many suppliers are directly
involved for the production of an end product for one or very few customers.

4.4 ROLE OF THE CLIENT AND END USER

In most construction projects the end-customer is of the start as well as the end of the entire process, and therefore the customer and end-users play a dominant role in construction. This also causes the make-to-order mechanism and the need for reactivity in construction supply chains. This is the reason why in construction products are rarely ‘launched’ and ‘marketed’ as in other industries, and why construction is different than most other industries, e.g. consumer goods. Most contractors are no manufacturers of integrated end-products. Most products are not standard, and processes are not repetitive, and often causing high levels of waste (Vrijhoef & Koskela 2000).

5. APPLYING SYSTEMS ENGINEERING TO INTEGRATE AND IMPROVE SUPPLY CHAINS

5.1 SUPPLY CHAIN INTEGRATION AS A GOAL OF SUPPLY CHAIN SYSTEMS ENGINEERING

One can understand that low levels of integration and repetitiveness in construction lead to problems and underperformance of the construction supply chain as a production system (e.g. Vrijhoef & Koskela 2000). One way of resolving this is to apply concepts that increase integration and repetition within and between project supply chains, such as in partnering arrangements (e.g. Bresnen & Marshall 2000a&b). In general, many research and publications point out the need for more alignment and more structured ways of working in the construction supply chain. Systems engineering can help in a sense that systems engineering’s goal here is supply chain integration, and to ‘engineer problems out’ of the supply chain i.e. the production system (Hassan 2006).

5.2 IMPROVING THE SUPPLY CHAIN BY SUPPLY CHAIN INTEGRATION

Stevens (1989) points out the importance and possibilities of supply chain integration for companies to react to market conditions and reduce cost levels. In order to do so, ‘virtually all firms and functions’ in the supply chain should be connected, operating as it were a ‘factory without walls’. Fawcett and Magnan (2002) argue that often supply chain integration is not fully implemented by companies in a way that the whole channel from ‘suppliers’ suppliers till customers’ customers’ would be integrated. In many cases, they found it is simply impossible to fully integrate an entire supply
chain. This is particularly true for temporary and fairly disintegrated construction supply chains.

In construction, the demand and supply systems are often not well integrated. In essence this seems logical because integration of the systems would practically be rather complex and costly, in an industry that is mainly organised in projects because of the one-off approach to production. Paradoxically, on the other hand, there would actually be a need to integrate both the demand and the supply side. This calls for two new central roles in the demand and supply system: the demand system integrator and the supply system integrator (Figure 2). For instance the client organisation responsible for the procurement could take up the demand integrator role; the main or prime contractor could take up the supply integrator role (Vrijhoef & De Ridder 2005).

6. ENGINEERING THE SUPPLY CHAIN: THEORETICAL ELEMENTS

In essence, applying systems engineering to build integrated supply chains implies a process of organisational engineering. This includes designing and building supply chains as integrated systems. The research reported in this paper tries to find theoretical and empirical building blocks for this process. Theoretical building blocks are found in the explanation of supply chain from four theoretical perspectives: social, economic, organisational and production theories. These four perspectives deliver the elements needed to build a theoretical model for supply chain integration. Empirical building blocks are searched for later on in this research, through cases of supply chain integration in construction as well as in other industries. Below the theoretical building blocks are described very briefly.

6.1 SUPPLY CHAIN VIEWED AS A SOCIAL SYSTEM
In construction the relations between firms are typically maintained for the duration of the project. 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. Increased co-operation and integration between supply chain parties enables delivery of a total product with quality guarantees to the market. Bounded rationality and differences in know-how between firms would be resolved by joint product development. Opportunistic behavior is then replaced by mutual trust, which obviously is necessarily for an open dialogue (language) and an optimal knowledge sharing.

On an industry scale, Dubois and Gadde (2002) distinguish tight couplings in individual couplings in projects and loose couplings in the permanent network within the industry as a “loosely coupled system”. The pattern of couplings influence productivity and innovation, and the behavior of firms. In terms of organizational behavior, cultural and human issues such as trust and learning have been indicated as major implications on construction supply chains (Love et al. 2002). The social systems approach may therefore improve not only the performance of supply chains, but also the socio-organizational basis of the inter-firm relationships within the supply chain.

6.2 SUPPLY CHAIN VIEWED AS AN ECONOMIC SYSTEM

In economic terms a supply chain is a series of economic actors, i.e. firms buying from and selling to each other. From an economic perspective the choice of a co-ordination mechanism or governance structure is made by economizing on the total sum of production and transaction costs (Williamson 1979). Transaction cost economics (TCE) provides an explanation for the existence and structure of firms and for the nature of co-ordination within a supply chain (Hobbs 1996). When transaction costs are low, contracting is used (i.e. market structure), while internalization will prevail for high transaction costs (i.e. hierarchy). Intermediate modes are often referred to as hybrid modes (Williamson 1991).

TCE recognizes that transactions do not occur without friction. Costs arise from the interaction between and within firms as transaction costs: information costs, negotiating costs and monitoring costs (enforcement costs) (Hobbs 1996). Transaction costs would be zero if humans were honest and possessed unbounded rationality. Transactions costs for a particular transaction depend on the three critical dimensions of transactions: asset specificity, uncertainty and frequency (Williamson 1985). Besides these key concepts underpinning TCE (bounded rationality, opportunism, asset specificity, uncertainty, and frequency), Milgrom and Roberts (1992) add two other items: difficulty of performance measurement, and connectedness to other transactions. Both are relevant from a supply chain viewpoint, and influence the possibilities to reduce
transaction costs. Obviously improved collaboration and communication in the supply chain will reduce transaction costs.

6.3 SUPPLY CHAIN VIEWED AS A PRODUCTION SYSTEM

The supply chain is aimed at the delivery of a product or service to an end market of a single customer. This implies a production process which is purposive. Koskela (2000) argues that management of production needs to address the transformation (conversion), flow and value aspects of production in an integrated manner resulting in a transformation-flow-value generation model for production management (Koskela 2000).

![Figure 3: Three view management in construction (Koskela & Huovila 1997)](image)

In construction three fields of production management have been defined: contract management, process management and value management (Figure 3). Contract management creates and maintains the relations between the delivery of value and the performance delivered by the contract parties. Process management plays the role of coordinating the production flow, as well as the flow of information, materials and equipment. Value management ensures that the construction process generates the value wanted by the client. On an aggregate level, production management must address all three management aspects in order to be successful.

6.4 SUPPLY CHAIN VIEWED AS AN ORGANISATIONAL SYSTEM

Firms as well as supply chains are organisational systems built from various vital elements that make them function as they do. By viewing organisations as systems of flows, Mintzberg (1979) identifies various
system representations of organisations, together making up the structure and infrastructure of organisations:

− Organisation as a system of formal authority,
− Organisation as a system of regulated flows (material, information),
− Organisation as a system of informal communication,
− Organisation as a system of work constellations,
− Organisation as a system of ad hoc decision processes.

Typically, the supply chain is a ‘system of systems’, or a ‘superstructure’ of organisations. Firms along the supply chain perform distributed production activities and business functions. This raises the issue of core competences of firms (Prahalad & Hamel 1990), together making up an ‘extended enterprise’. In construction this relates to the idea of the ‘quasi-firm’ coined by Eccles (1981).

6.5 INTEGRATING THE FOUR SYSTEMS APPROACHES

The four systems approaches presented above represent a basic theoretical framework for supply chain systems engineering. In addition, multiple theoretical concepts could be added to the framework to make it a more extended theoretical framework (Figure 4). This implies further development of the framework, and introduction of complementary parameters to engineer and build construction supply chains.

Later on in the research this framework will be refined into a prescriptive theoretical model and a ‘change model’ for supply chain systems (re)engineering and integration (theoretical building blocks), to be validated and verified by researching applications of supply chain integration in construction compared to other sectors outside construction (empirical building blocks).

![Extended theoretical framework for construction supply chain systems engineering](adapted from Vrijhoef et al 2003)
7. Discussion and conclusion: research implications

7.1 GENERAL IMPLICATIONS OF SUPPLY CHAIN SYSTEMS ENGINEERING

The aim of this research to supply chain systems (re)engineering and integration is to improve the functioning of construction supply chains. This will include a process (change model) of ‘organisational rebuilding’ of existing supply chains. In order to do so first all functions along supply chains need to be decomposed. This is followed by rearranging and reconfiguring the functions and the interfaces between these functions. By doing this, the endemic problems and irrationalities should be resolved, eliminating existing waste. The side effect will be that the control of different functions will probably get more centralised into a single entity, an extended enterprise.

7.2 IMPLICATIONS OF SUPPLY CHAIN INTEGRATION FROM DEMAND PERSPECTIVE

Traditionally, clients have played an important and dominant role in construction (Cherns & Bryant 1984). The client’s role can be critical, while he makes the initial decision whether and how to procure construction works (Briscoe et al. 2004). Clients who have the power to shift their procurement strategies vis-à-vis the market are in the position to align the supply chain effectively (Cox & Ireland 2001, Cox & Townsend 1998). Few advanced and professional clients with “buying power” have created multi-project environments and manage their procurement through a portfolio and multi-project approach, aimed at the increase of the degree of repetition, project certainty and “supply chain stability” (Blismas et al. 2004) (Figure 7).

Figure 7 The role of the demand system integrator (Vrijhoef & De Ridder 2005).

7.3 IMPLICATIONS OF SUPPLY CHAIN INTEGRATION FROM SUPPLY PERSPECTIVE
At the supply side, parties have evolved towards more integrated arrangements through project-independent collaboration with other parties in the supply chain as well as internalisation of neighbouring activities or businesses. In both cases, operational and competitive advantages, through higher levels of productivity and efficiency as well as delivering better client value are the drivers for this kind of supply chain integration. Normally this development is lead by a focal firm, the system integrator; this could be a main contractor, but also an architect or engineering firm (Figure 5).

![Figure 8 The role of the supply system integrator (Vrijhoef & De Ridder 2005).](image)

### 7.4 IMPROVED CONTRIBUTION OF CONSTRUCTION TO DEVELOPMENT

The ongoing research reported in this paper aims to improve the construction industry’s performance, through increased efficiency and effectiveness of integrated processes throughout the supply chain. As a consequence, this must result in improved economical performance of the sector, improved satisfaction of clients and users, reduced usage of capital, human and natural resources, and thus the welfare and wellbeing of society as a whole.

### 8. REFERENCES


