CONCEPTUAL FUNCTIONS OF A SIMULATION MODEL FOR CONSTRUCTION LOGISTICS

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ABSTRACT

Currently the focus of SCM in construction is on the strategic interactions of businesses (Egan, 1998). Primarily these interactions are viewed through the lens of the procurement process and contractual obligation. This is largely symptomatic of the adversarial history of the construction industry in the UK and worldwide. However, the operational aspects of SCM are largely overlooked by mainstream authors in construction. That operational aspect of SCM is logistics management. This paper seeks to address the conceptual functions of SCM in construction through an examination of the logistics systems used in the industry, and to improve these logistical functions within construction supply chains. The research focuses on the function of the BM in the supply chain in order to balance the contractor centric research efforts that dominate existing literature. The paper develops a model simulating the flow of materials from BMs to construction sites. Simulation is then used to assess the correlations among the main parameters of the model, namely inventory levels, inventory and transportation costs. The model utilizes data from previous research undertaken in South Africa associated with the transportation and the delivery of building materials (Shakantu et al, 2005). The study of the model's performance under different scenarios allows the identification of the qualitative information needed to improve the model and improve simulation of construction supply chains. The potential changes that will be caused by this additional conceptual information are discussed and the future steps of the research are presented. The interpolation of critical functional information into the simulation model will lead to an improved understanding of the construction supply chain. The paper concludes by discussing potential for various resource savings in construction logistics systems by using simulation and optimized logistical planning.

KEY WORDS

builders merchants, conceptual functions, logistics planning, simulation.

INTRODUCTION

Over the last decade, supply chain management (SCM) has become of critical import to researchers and practitioners in construction, encouraged by the seminal Egan (1998) and Latham (1994) reports. Efforts have been focused on introducing SCM into construction and the consequential reform of generic concepts to match unique construction characteristics.

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Currently, mainstream research focuses on the strategic interactions of businesses with an eye on the adversarial history of construction. However, operational aspects of SCM are largely overlooked and other industries' evolutions in the area of logistics, and development of tools such as EDI, MRP, ERP etc. are not incorporated into construction. SCM is currently considered essentially as partnering the supply chain while construction logistics is restricted to materials handling on site. London and Kenley (2001) point out there is no shortage of construction SCM research, what is missing is theoretical and empirical research that considers the fundamental structural, economic and organizational nature of the industry's supply chains. A position supported and developed by Wegelius - Lehtonen and Pahkala (1998) and Shakantu (2005), who address fundamental operational SCM concepts. Successful implementation of logistics in construction is hindered by the one off, fragmented, temporary nature of project organizations (SFC, 2005). Since effective logistics systems are a prerequisite to effective SCM (Bowersox and Closs, 1996), it is contended that if SCM is going to be implemented in construction the operational aspects of SCM (i.e. logistical processes) have to be fully understood in the context of the built environment.

SUPPLY CHAINS IN CONSTRUCTION

The most powerful organizations are reliant on the capability of their supply chains, thus significantly affected by suppliers' decisions. To demonstrate the complexity construction supply chains and their unique behavior, we should consider their structure compared to a 'typical' supply chain, e.g. manufacturing. In this case, product moves through successive stages characterized by the flow or transformation of product until reaching the client. Figure 1 shows that construction and manufacturing supply chains are identical.

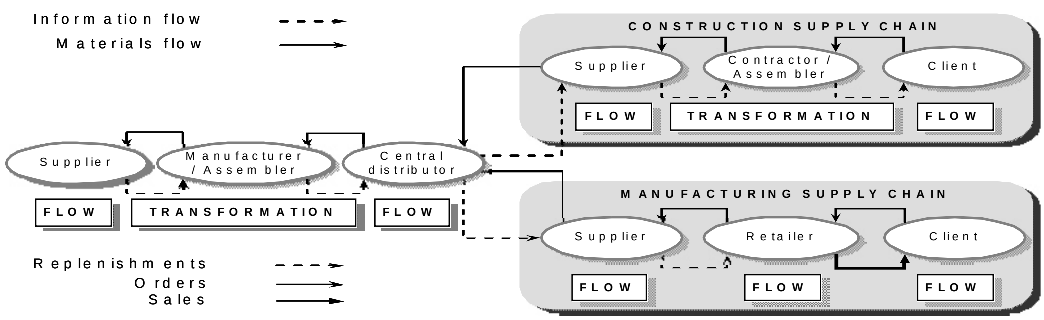


Figure 1: Construction vs Manufacturing Supply Chain

Differences are functional, located at the end of the chain, where contractor's function in the materials' flow to physically transform the product, i.e. construction / assembly of the project. Thus, a contractor could be characterised as both manufacturer and retailer, since he is responsible for putting the product on market.

This dyadic contractor role is important for material and information flow inside the supply chain and significantly impacts its analysis and design. This has motivated various authors such as Vrijhoef and Koskela (2001) to develop the 'manufacturer' role, focusing on productivity, seeking to apply lean principles to construction by forcing contractors to operate like manufacturers. However construction's unique characteristics are thought to be the reason which prevents it from addressing logistics (SFC, 2005) and affect the applicability of SCM in the industry. Ballard and Howell (1998) recognise the fact that turning construction into manufacturing is not always efficient, since:

- manufacturing processes are not efficient for fast, uncertain, complex projects and;
- product uniqueness is becoming ever more characteristic of manufacturing

In order to model construction supply chains it is not necessary to turn construction into manufacturing. However logistics prior application to other industries has to be taken into account, but the dissimilar functions of BMs and contractors from suppliers and manufacturers dictate a new approach for construction logistics. The requirement is to understand the function of BMs in relation to the unique logistical functions of contractors particularly in terms of materials and information flow inside the construction supply chain.

THE FUNCTION OF MATERIALS SUPPLIERS AND CONTRACTORS

Construction supply chains are the same in structure to those of other industrial sectors. In order to demonstrate the dyadic role of contractors and BMs, we must consider the most common applications for logistics planning and design. These applications include location, inventory, and transportation analysis (Bowersox and Closs, 1996). Table 1 summarises the objectives and the data requirements of each analysis. Table 1 (column 3) equates to the role of the BMs, indicating that BMs should incorporate all information associated with contractors' operations in order to create the most appropriate logistics system.

Table 1: Objectives and requirements for logistics planning

Application	Objective	Requirements
Location Analysis	Select the number and location of distribution centres	• delivery location; • movements to each destination (i.e. demand)
Inventory Analysis	Meet desired service levels with minimum investment	• service objectives (lead time); • demand characteristics; • number of echelons; • replenishment times
Transportation Analysis	Minimise the combination of vehicles, hours, or miles required to deliver the product	• network definition • delivery (or pick up) demand • operating characteristics

LOCATION ANALYSIS

Optimum location of BMs' distribution centres is virtually impossible since production facilities of contractors (i.e. construction sites) are mobile, and activity levels are hard to estimate since this depends on the nature of projects undertaken. Uncertainty of market demand is primarily responsible for the temporary structure of construction supply chains. Short-term project organisations are thus the source of many of the industry's inefficiencies. Furthermore, high logistics costs mean suppliers do not service remote delivery locations and contractors switch to the local market. In this case, temporary business with local BMs is perceived as less costly and thus preferred. Consequently, impermanent business can be considered as an efficient industrial self-defence mechanism to overcome its mobile nature. However, in this way benefits from long term relationships with partners are lost. The dilemma for both contractor and supplier, is to select between profitable short-term business solutions for individual projects, and benefits from a long-term relationship for a series of projects. Given the uncertainties and obvious need for cost benefit analysis for competing supply strategies, a decision support system is required to compare costs of alternative networks. This, the authors contend, is an ideal situation in which a simulation may assist in making appropriate distributor location decisions for both contractors and BMs.

INVENTORY ANALYSIS

During inventory considerations for the construction supply chain three major points have to be taken into account which differentiate construction supply chain since they are associated both with the materials and information flow and affect all the actors in the chain:

- Contractors' ability of carrying inventory is limited (and sometimes absent);
- Contractors demand in not communicated upstream until the project is ordered;
- Contractors do not estimate materials demand prior to contracts' nomination.

Contractor inability to carry inventory partially explains the practice of ordering and delivering. Production halts due to lack of materials, but the additional costs of express (JIT) deliveries cannot be borne. Bertelsen and Nielsen (1997) draw attention to the fact that the main reason for this is the lack of a logistics strategy by contractors. In reality BMs operate as buffers for contracting firms, controlling material flow, and bear the holding cost of inventories. Thus, when examining construction materials flow through multi-echelon inventories we should remember we are basically dealing with BMs rather than contractors.

Inventory planning is based on upstream information flowing from lower stages in the supply chain. Contractors' role as retailers positioned next to the client generates additional problems, since demand characteristics do not propagate upstream until the contract is signed. The delays created cause the phenomenon of the Forrester (or bullwhip) effect (Forrester, 1964) in inventory levels, characterised by amplified demand variation moving up the supply chain when supply chains have conflicting objectives (Lee et al, 1997; Chopra and Meindl, 2001). Lee et al. (1997) identify further contributory factors similarly apparent in construction such as order batching; price fluctuation; rationing and shortage gaming. However, their analysis is outside the scope of this paper. Resultant inefficiencies include excessive inventory, poor product forecasts, capacity mismatch, backlogs, uncertain planning, and high costs for express shipment (Lee et al, 1997). The Forrester Effect demonstrates the need for a new approach to construction logistics which includes BMs as upstream information providers in the supply chain. Innovative companies in other industries have found that they can control the effect and improve supply chain performance by coordinating information and planning in the supply chain (Lee et al, 1997).

TRANSPORTATION ANALYSIS

Diamond and Spence (1989) indicate transport costs account for 2.6% of vehicle part production, 7.7% of pharmaceuticals and 12% of wholesale distribution. In construction the figures are significantly higher (SACTRA, 1999), accounting for 10-20% of construction costs (BRE, 2003). Shakantu et al. (2003) further characterise transport as the hidden cost of construction materials. The proportion of embodied cost of construction accounted for by transportation implies an area of research ripe for exploitation. This is particularly the case given that the UK Road Haulage Association demonstrates that the haulage and distribution sector has seen a 12.5% increase in running costs in the 6 months from the start of 2005 until June of the same year. Construction is mainly an assembly operation utilizing materials of generally low value and high volume, moving to geographically mobile points of distribution (Shakantu et al., 2003). From the analysis of general applications for logistics planning and design the fact that construction logistics should be considered a challenge for materials suppliers in the first place, becomes apparent. Location, inventory, transportation and performance considerations should be adjusted to construction and incorporated in a logistics model for the industry, which will be addressed later in this paper.

SIMULATION

MODEL DESCRIPTION

The usefulness of the model is based on its ability to explain supply chain behaviour under different scenarios. Simulation is best used since construction supply chains have constantly changing requirements. Kleijnen (2005) noted that simulation gives significant insight into cause and effect of supply chain performance. Indeed, construction supply chain instability can be dealt with by simulation modelling since it:

- Presents understanding of the process to model events in areas of interest.
- Diminishes the risk inherent to changes in planning
- Investigates impact of strategic decisions and operational change in the supply chain
- Quantifies performance and requirements in service cost and quality

Figure 2 represents the delivery mechanism of a single material from order receipt to materials issue. The flow is designed deliberately consisting of Work Centres and Storage Bins to introduce the SIMUL8 software package in the model design. Simul8 is a discrete-event simulation product developed by Simul8 Corporation and selected for two reasons. Firstly, because of its simplicity, since it utilizes few modelling objects and secondly, its flexibility, since user defined components can be created using Visual Logic, a simplified programming language. In the model, Work Centres (WRC) are considered to act as dynamic decision objects, determining the required time for task completion. Additionally, they change certain aspects of a work item to direct it through different channels inside the model. Storage Bins (SB), are passive objects whose purpose is to hold work items waiting to be processed by WRCs. They can be used simply as queues or as inventories of different product types (Hauge and Paige, 2001). Figure 2 represents inbound and outbound BM logistics utilising one vehicle to service three different sites which are gradually introduced into the system. The model depicts three stages of the supply chain and can be extended with appropriate additional information. On the left side the manufacturer (inventory SB1) replenish BM warehouse (inventory SB2) which is located at the end of the Manufacturer – BM flow area. One the right side, materials are distributed through a flexible network to construction sites (inventories SB S1, SB S2 and SB S3).

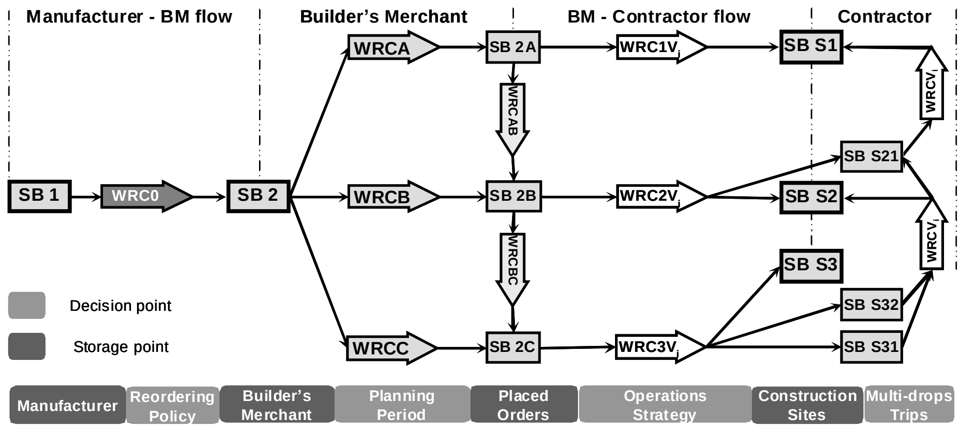
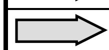
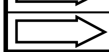


Figure 2: A simulation model for the logistics of a single product

Multiple runs of the simulation, and changes to system conditions, reveal variable interrelations driving the model. Table 2 contains a short description of the basic simulation objects and their role in the model, i.e. their control over certain model parameters.

Table 2: Simulation objects and functions

Simulation object	Role	Parameters
	Inventory	Material type / Loading time
	Manufacturer - BM Link	Order point / Batch size / Replenishment time
	Time period	Contract commencement / Network spec / Demand characteristics
	Vehicle	Vehicle capacity / Transport & Turnaround times / Multi-drop trips

RESEARCH METHODOLOGY

The research detailed in this paper utilises a grounded theory approach since it seeks to establish a theoretical logistics model. Given that at this stage of the research, the author is at an early phase of PhD study, conceptual understanding of the problem at hand is pre-eminent. Thus it was decided to utilise pre-existing data as a means of creating a theoretical construct to validated through further investigation. In essence the research detailed in this paper is grounded theory stage of a process which envisions a two stage triangulation study, validating the model with UK based basic research (Easterby-Smith et al, 2002). Input data for the model are taken from research by Shakantu (2005) associated with vehicle movements and material deliveries in South Africa. Data collected during the field study (7 sites and 910 vehicle movements) indicated 62.6% of vehicles movements to sites were material deliveries, with a loading efficiency calculated to be 46%. Wegelius and Pahkala (1998) acknowledge logistics costs are related to the nature of materials. They recognise that materials differences are significant, and costs of logistics varied from 5% to >50% of purchase price. This does not forbid the generation of a single model that involves more than one type of materials. In that case, a logistics system could be simulated straightforwardly by the use of mixed materials' loads and multiple inventories for each product. To limit complexity, a specific product type has been selected. Variations in logistics costs result from

BM practices for storing, handling and packaging materials but these are not incorporated into the general model described, since these costs are considered to be negligible to transportation and inventory costs.

Inventory cost is a major component of logistics cost including capital, storage, taxes insurance and obsolescence. Although variable, estimated figures (Coyle, 2003; Bowersox and Closs, 1996) are 25% of average inventory value annually. Demand over the simulation period is based on deliveries of bricks in the UK during 2004 (Monthly Digest of Statistics, 2005). In order to simulate uncertainty of market demand, a different construction site is added to the model every ordering phase, allowing for including multi-drops trips which occur each time the phase changes. Simulation time is defined by that needed for all demand to be satisfied. The model is tested under five different demand levels and 12 vehicle mixes. Ordering phases and site locations are in table 3 and fig 3. Model requirements are listed in Table 4. To introduce various vehicles operating costs according to vehicle loading capacity, RHA cost tables were used (RHA, 2005), derived from annual surveys of RHA members.

Table 3: Functional parameters

Site	Ordering phase	Start	Duration (t.u)	Distance (m)
1	1	0	9600	3.5
2	2	9600	9600	5
3	3	19200	9600	5

Figure 3: Sites layout

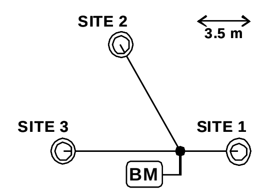


Table 4: Functional parameters

Parameter	Remarks
Multi drops trips	When more than one site is undergoing, priority is set to the site starting earlier (60:40). Vehicles of 3.5 and 7.5t deliver to two sites, while 13t are allowed 3 deliveries.
Vehicles costs	Taken from the RHA's cost tables (RHA, 2005)
Reordering policy	Order point and lot size selected in order BM not to stock out during the highest demand.
Product unit (p.u)	Pack of 50 bricks
Average petrol price	70.67 pp litre = 321.3 pp gallon (15.11.04)
Value of bricks	£158.00 (pack of 1000)
Vehicles available	3.5; 7.5; and 13 tonne gross vehicle (diesel)
Vehicle travel time	Normal distributions – relevant to specific sites
Turnaround times	20 min for a vehicle of 3.5t. Then follow the increase of carrying load (minus 20% when moving to bigger vehicle). Turnaround time is reduced to 50% when unloading half load.

SIMULATION RESULTS

Initial tests show composition of BM fleets determine system performance as a result of high time-related costs (i.e. ownership costs like wages, depreciation, licences, overheads etc). To deal with variability the introduction of different mix of vehicles was necessary. The results of the simulation are divided in cumulative and typical outcomes. The first group refers to the total of 12 mixes of vehicles incorporated while the second represents a typical outcome.

Cumulative outcome

Cumulative results occur from simultaneous study of the models as they represent a system of different BMs acting under the same conditions. Fig 4 shows level of demand influences logistics costs, and an exponential relation between costs and demand i.e. 70% cost increase with 12% higher demand. The individual models show the significant increase is due from:

- Low demand or/and low fleet capability result in high inventory costs;
- High demand requires a significant investment in vehicles.

Although the cost of material is relatively low, high inventory costs are possible since the model was studied for 3 months, allowing identification of demand generating minimum cost and the requirements of the system for a specific demand. Moreover, the diagram of costs vs. movements shows as expected an exponential relation between costs and vehicle movements (since movements are analogous with demand). This implies a relation between costs and vehicle movements significant for construction. Construction materials are generally of low value and high volume, requiring large numbers of deliveries. Thus it is essential to minimise total vehicle movements. By induction, operational systems using high numbers of deliveries (i.e. JIT), are inappropriate for construction. The cumulative results are useful, but the long term aim of the work in this paper is a general logistics model for construction supply chains. Additionally, the study of a typical model gives a better description of the relation between the parameters listed above and facilitates practical interpretation of cumulative outcomes.

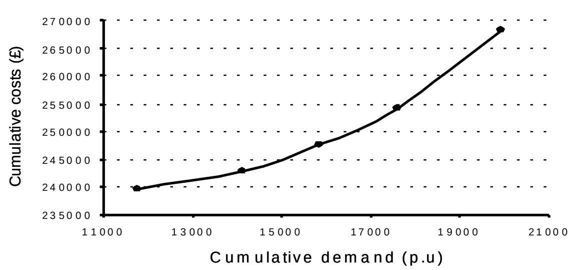


Figure 4: Costs - Demand

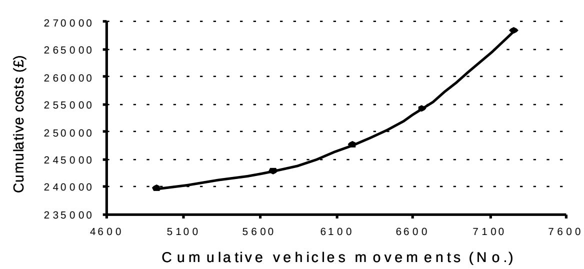


Figure 5: Costs - Movements

Typical outcome

Cumulative results indicate the expectation of a typical model. Fig 6 shows the relation between system costs from the combination of models under varying demand. The exponential model that best fits this data was found to be: $Y = a + b\exp^{cX}$, where a = 1.95E+04, b = 2.70E+01, c = 2.57E-03, while the coefficient of determination (r^2) = 0.99. The analysis was performed on the LAB Fit (Silva and Silva, 2006), developed for analysis of experimental data. The model is used to predict further values for different levels of demand. The final curve and sales are depicted in fig 6, which are analogous to demand (if no quantity discounts are included). Subtracting the cost of operations from the sales the generated profit is calculated. From the profit curve it becomes apparent that there is no profit generated for the lower and the higher levels of demand. Simultaneously, the curve allows for identifying the range of demand levels that the BM should act in, in order to maximise profit. The physical interpretation of the model is that BM bears a minimum cost for maintaining the fleet; even there are no sales. On the other hand, high vehicles' operation costs and BM's investments exceed profit.

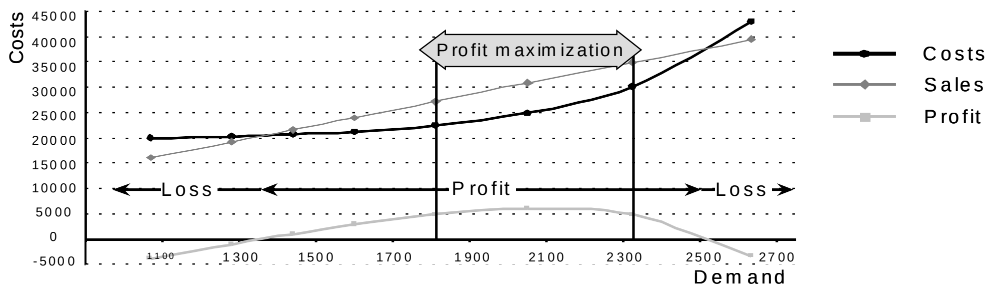


Figure 6: Costs vs. demand, sales, and profit for a specific logistics system

Regarding the cost and vehicles movements relation an exponential model also seems to fit this data very well. The model given by LAB Fit is Y = c + aexp$^{(bX)}$, where: a = 2,59E+06, b = -4,21E+03, c = 1,99E+04, while the coefficient of determination (r^2) = 0.99. The models that have been found demonstrate that construction supply chains' instability and complexity can be managed. However, there is a requirement that certain aspects of supply chains have to be matched with construction special characteristics. This is achievable by understanding the functions of the various players of a construction supply chain and the role of logistics in integrating supply chain operations.

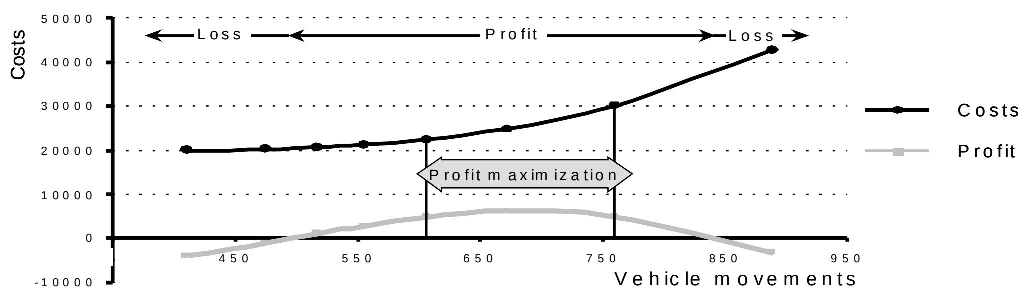


Figure 7: Costs vs. vehicle movements for a specific logistics system

CONCLUSION

The paper presented critical aspects and functional information that is required in order to develop a model for construction logistics. The involvement of BMs was highlighted in an attempt to balance the contractor-centric approach that governs current research and adopt the holistic character of SCM in construction. The nature, complexity and instability associated with construction supply chains was the main consideration for the model development. Conceptual functions of logistics had to be matched with construction special operational characteristics in order to carefully address logistical problems within the industry. The long term aim of the work presented in this paper is to develop a general model for construction supply chains which assess the effect of industry's special characteristics to any strategic decisions and lead to effective logistics planning. Reconfiguration of the logistics systems within construction will help the industry to benefit from huge savings in materials' acquisitions and provide better value for money for construction clients.

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