

CONSTRUCTION SUPPLY CHAIN MODELING: A RESEARCH REVIEW AND INTERDISCIPLINARY RESEARCH AGENDA

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ABSTRACT

Supply chain management has emerged as a popular and useful concept in the construction industry and research community since the mid 1990s. Research in construction supply chain management draws from a broad range of disciplines, notably: (1) industrial organization economics to better understand market structure and forces and their effect on firm and supply chain behavior and (2) Analytic modeling of supply chains to improve supply chain performance along metrics such as speed, cost, reliability, quality, etc. Both industrial organization and analytic modeling provide useful but ultimately incomplete perspectives and prescriptions for construction supply chain management. As such, this paper proposes development of an interdisciplinary research agenda that draws from both fields. Towards that agenda, a review of research is presented to introduce the main ideas, relevant literature, and theory and methods in each of the two areas. From these independent reviews, applications that could benefit from a combined perspective are identified and used as a basis for development of an interdisciplinary research agenda.

KEY WORDS

Construction supply chain management, research agenda, industrial organization economics, transaction costs analytical modeling

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INTRODUCTION

Concurrent with the development of lean approaches in construction, there has been increasing interest and research in supply chain management as a field of study and application. Supply chain management focuses on understanding and improving the coordination of multiple firms that compose a supply chain. The explicit identification of firms separates supply chain management from approaches that focus more narrowly on production processes. As noted by Cox and Townsend (1998), there is a relationship between improving supply chain management on construction projects and understanding the inherent behavior of firms in markets and the structural characteristics of those markets. Thus the central thesis of this paper is that a research and modeling approach for supply chains is needed that combines elements of process modeling with understandings of market forces and constraints.

In support of this thesis, the authors propose a research agenda combining elements from operations management/analytic modeling/logistics research (hereafter noted as analytic modeling) and industrial organization theory. Analytic modeling addresses normative aspects of the behavior of individual supply chains or components thereof. In contrast, industrial organization theory addresses descriptive aspects of the behavior of firms in markets and the nature of market structure. Whereas analytic modeling typically addresses managerial decisions, industrial organization has typically addressed guiding government policies. The policy-management division is not strict, and there are many instances of applications to both areas. For example, Porters' (1980) "five-forces" model is perhaps the best-known application of market generated theory applied to managerial practice.

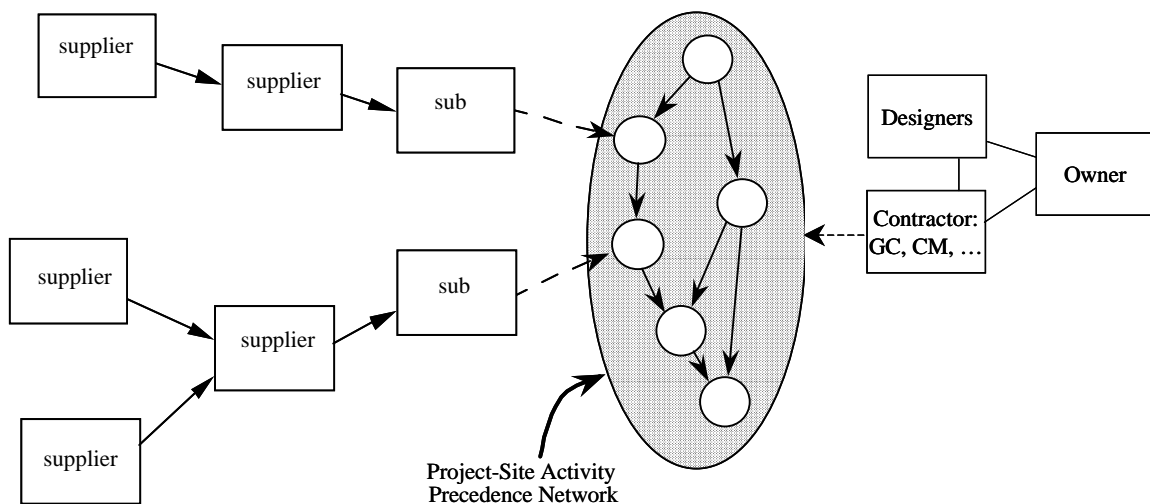


Figure 1: Conceptual view of the project supply chain

The need for synergy between analytic modeling and industrial organization theory is shown by explicit consideration of the complexity of the construction supply chain structure. Figure 1 describes a conceptual view of a construction supply chain. While somewhat simplified, figure 1 does give an indication of the complexity of supply chain production operations. Figure 1 also depicts the large number of firms that compose a construction supply chain, suggesting that there will be a wide range of incentives and

market forces operating on those firms. There is a clear role for both analytic modeling and industrial organization theory to provide insight into supply chain behavior. Further, given the complexity of the construction supply chain, prescriptions for performance improvements are likely best served by an inter-disciplinary perspective.

Towards development of a multidisciplinary approach to modeling supply chains, this paper discusses both industrial organization economics and analytic modeling as applied to supply chains. The authors provide a review of the current capabilities and research directions in each field, and note that considerable research needs to be performed in each field to model the complexity posed by construction supply chains. There does exist enough knowledge in each field, however, to inform research in the other field. Thus the authors conclude with a proposed research agenda in interdisciplinary modeling from industrial organization and analytic modeling perspectives.

INDUSTRIAL ORGANISATION ECONOMICS THEORY

The theory of industrial organization economics which is often simply termed industrial organization is a useful framework to explain primarily firm behavior within markets and inter-firm behavior between markets. Broad definitions suggest that it is a branch of microeconomics that deals with the performance of firms and especially with the effects of market structures on firm conduct (for example, pricing policy, restrictive practices, and innovation) and behavior i.e. how they are organized, owned and managed (Bancock et al. 1998). According to Martin (1998) “*contemporary industrial organization economics concerns itself with the analysis of market structure, firm conduct and market performance in oligopolistic markets.*” This preoccupation with analysis of those particular markets where there are a few large suppliers was explained as such; “The most interesting and important applications in industrial organization economics concern primarily oligopolies; the type of market in which firms are neither monopolists nor perfect competitors, but something in between. By and large these are the kinds of firms and markets that we find in the real world (Martin 1998). Microeconomics in general has focused upon simple market structures – competition and monopoly. The most important elements of market structure in this field are identified and the relevance of these characteristics to the construction supply chain concept are explored in Table 1.

Table 1: Market structure elements related to supply chain concept

Market structure	Relevance to supply chain concept
1. the nature of the demand (buyer concentration, number and size of buyers),	Buyers’ market ie upstream supply chain markets, impacts upon volume of work for downstream construction supply chain firms. This can affect procurement practices and tendering and pricing for individual project contracts or longer term agreements; which for eg in turn impacts upon incentive for downstream firms to be involved in buyer supply chain management initiatives
2. existing distribution of power among rival firms (seller concentration, number and size of sellers),	Construction supply chain market structure impacts upon firms’ nature of response to buyers, in construction in particular the number and size of sellers impacts upon competition and whether or not there is an incentive to change supply chain processes
3. entry/exit barriers	Movement of firms also impacts upon degree of competition and ability to develop innovative products and processes and make long term technological improvements

4. government intervention	Regulation affects competition 'rules' within a market In many countries governments can intervene as a major construction buyer
5. physical structuring of relationships (horizontal and vertical integration)	For example, the degree of vertical integration increases the length of chains and can impact upon flow of information and product/ lead times/prices/profit margins Horizontal integration blurs firm boundaries within markets and alters nature of competition within the market

There are two main contributions that the industrial organization methodology can make to management of the supply chain. Firstly it can serve to assist in understanding why certain behaviors are taking place in markets and thereby the nature of supply chain inter-firm relationships. Research in this arena primarily seeks to understand what is taking place, that is, it is descriptive initially and then explanatory.

Secondly the industrial organization economics literature can assist in a more prescriptive manner; in developing an understanding of better performing behaviors of firms and their suppliers. Research in this arena seeks to establish causal relationships between types of behavior and outcomes. This is more useful to, although not exclusive to, individual firms when taking a prescriptive approach to supply chain management.

QUANTITATIVE METHODOLOGIES

The study of industrial organization economics in its modern form has transcended its former rigid attachment to 'structure-conduct-performance' models and it now demonstrates a wider choice of method and scope. The core field has accommodated at least three main methodologies to study markets; case study of particular sectors, cross sector econometric work and panel data econometrics. The most widely used is case studies of sectors and this has tended to be much more quantitative.

These type of studies rely heavily upon sector wide firm level data to develop measures across the sector. There are various applications of various econometric models from industrial organization economics and many have focused upon measures and indexes that describe quantitatively market structure, in particular buyer and seller concentrations. Numerous other econometric models have been developed in an attempt to describe firm behavior derived to explain pricing rules and game theory:

- Market structure analytical measures: indexes of degree of market power
- Firm behavior models: pricing rules and game theories

Much of this could inform the reason why firms behave in a certain manner and where supply chain management can be more effective. The approach in these types of studies typically focus upon the larger and leading firms within the sector who have the greatest market share.

Various supply chain management models have emerged in the last two decades in the manufacturing industry that have explicitly drawn upon core industrial organization economic concepts. A review by London and Kenley (2001) attempted to map selected supply chain management models and events across four main streams of research; production, distribution, strategic procurement and industrial organization economics. It is acknowledged that this is a vast field and there are even more streams that could be covered. The intention of this paper is to attempt to grapple with the manner in which logistics (distribution & production) /analytical modeling and industrial organization economics can inform each other. One of the significant contributions by those using

concepts *derived* from the industrial organization economics literature is the attempt to describe and analyze the structuring and interdependency of relationships in the system of supply chains.

Selected supply chain research published in mainstream management literature, has studied the complex system of supply chains through inter-organizational structure and particularly networks of supply. These are important models that merge the field of industrial organization and supply chain theory and explore supply networks (Hines 1994, Nishiguchi 1994, Harland 1996, Hobbs 1996, Lambert et al. 1999).

Although Hines (1994) and Nishiguchi (1994) are clearly advocates of the *lean* system of supply, some of the more significant contributions of their research were the descriptions of the historical, organizational and economical structure of the Japanese system of supply across automotive and electronics industries. In many ways this has provided a *richer* picture of *lean* production and supply chains than other writings of the apocalyptic posturing of the field's success. They embedded much of their research within an industrial organization economic approach and considered sector wide quantitative measures to describe the market contexts for lean production and supply chain management

Carassus (1998) developed a meso-economic systems approach to describing the construction industry and its 'production chain' which was firmly placed within the industrial economics field. It was an alternative framework for the economic analysis of the construction sector and its activities that relied upon four assumptions:

- It is a system which operates upon various levels (local, regional, national and international).
- Various forms of inter firm relationships exist both collaborative and competitive.
- There are informal and formal regulations and rules defined by participants in the system.
- It is a system of risks and rewards and participants create various configurations to better position themselves in these strategic stakes.

In a similar vein the Australian Expert Group for Industry Studies (AEGIS) developed a model for the Building and Construction Industry Cluster based upon a holistic view of the industry based loosely upon an industrial organization approach (AEGIS 1999), for the national government. The model discussed the industry as a 'chain of production' and conceptualized the industry through five main sectors: onsite services; client services; building and construction supplies and products and fasteners, tools, machinery and equipment. Existing statistics were used to describe the sectors in terms of industry income. However the authors note that this is contrived, as sufficiently detailed data is not available. This is one of the difficulties of the industrial organization field of study – the aggregation of data about firms and the access and availability to such data. Both models have identified the need for empirical work to further refine the concepts.

It is conventional wisdom to accept that the construction sector is composed of a large number of players with numerous project supply chains and various markets. Unraveling this complex web of buyer-supplier inter-enterprise relationships that makes up the bulk of the industry has proven difficult because the majority of parties involved within this environment are small to medium enterprises. What is more conventional when exploring

supply chain management and industrial organization economic related concepts is to attempt to isolate smaller clusters of firms and develop an understanding of the nature of individual chains or a small number of relationships. Case studies such as these tend to develop a detailed view of relationships between key firms and the methodologies tend to be more qualitative. In some cases this often blurs the boundaries between the fields of strategic procurement and industrial organization economics.

QUALITATIVE CONSTRUCTION SUPPLY CHAIN STUDIES

The mapping of the structure of firms involved in project supply chains can assist towards understanding the complexity of the organization of construction supply chains. Many of these studies aim at describing supply chain networks and the value of various forms of strategic alliances, supply chain management, supplier coordination and development to report upon better performing supply chains. Seminal industrial network literature builds upon the industrial networks movement of the 1980s (Piore and Sabel 1984) – suggesting that close knit inter-organizational networks produce superior economic performance and quality, and that there should be a move away from the large, vertically integrated firms (Alter and Hage 1993). Another case study of a constellation of some 20 small to medium enterprises that leveraged their combined capacity to enter international construction markets identified a variety of strategic initiatives to develop inter-organizational networks (London 2001)

Callaghan (1998) discussed a number of concepts related to supply networks including; environment, strategy, structure, process, network evolution, and product/service dimensions. He concluded that there are few empirical cross-comparisons of supply networks between industries. There is a growing body of empirical studies in construction to draw from.

Lambert, Cooper and Pugh (1998) also provide insights for mapping supply chain structure through three primary attributes: members of the supply chain, structural dimensions, types of process links; indicating the structure of different supply chains and the interconnection between a number of focal organizations' supply chains and the resultant *networks of supply*.

An early exploratory study using Lambert et al's conceptual mapping as a starting point by London and Kenley (2000) reported largely on simple descriptions of horizontal and vertical structure, i.e. 'who' supplies to 'whom' along the supply chain and potential numbers of alternative suppliers within the tiers. The two 'chains', for in actual fact they were clusters of chains, that were described were aluminum framed windows and concrete within a small Australian construction market. This study concluded that there was scope to examine further the competitive environment within each tier and the nature of the relationships between organizations along the tiers. There is also scope to further develop the methodology for larger, complex markets and to give consideration to the measurements used within the conventional industrial organization model.

There is potential for future research to develop a more detailed map of the industry through the industrial organization of the supply chain. This exploratory study served to highlight that the development of a supply chain industrial organization methodology provides an extra dimension to our understanding of a complex and layered industry. It is useful in two ways; firstly to the supply chain management field and secondly in a broader economic sectoral analysis. Figure 2 was adapted from Lambert et al. (1998) and used as a means to explore project and market supply chains.

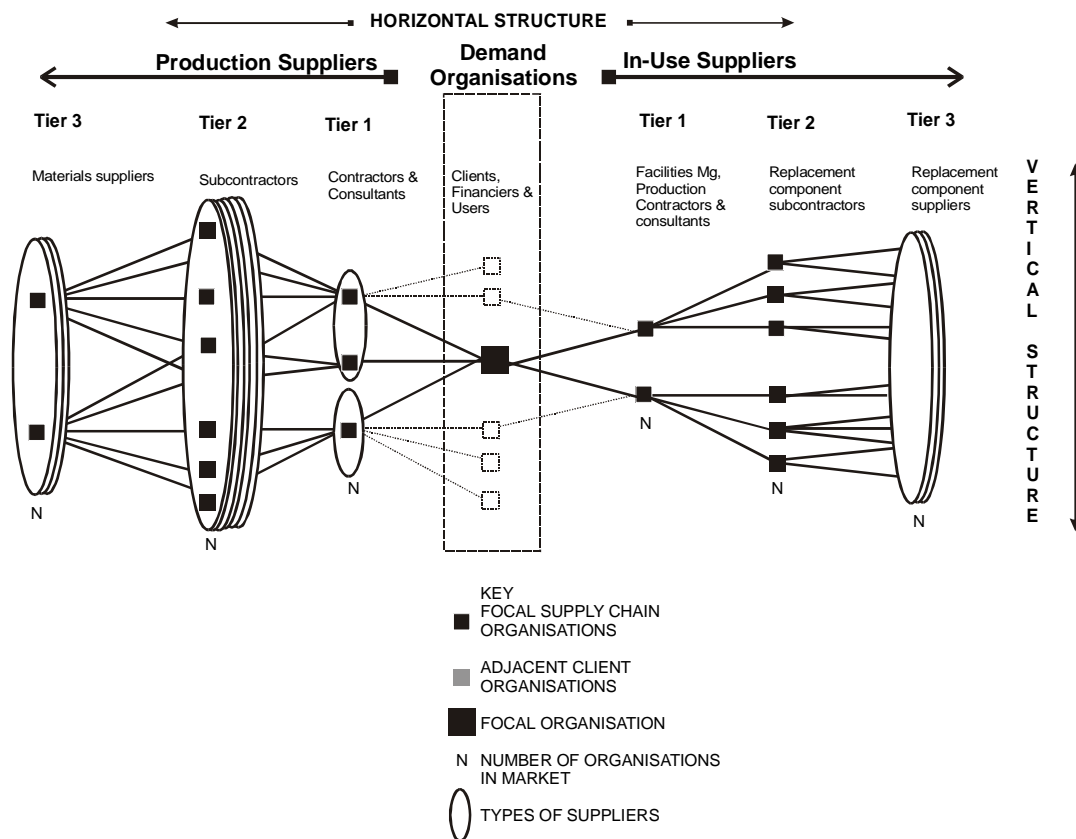


Figure 2: Construction project supply chain structure from an industrial organization perspective (London et al. 2000, after Lambert et al. 1998)

Figure 2 describes the contractual relationships between firms in the supply chain that are embedded within markets. There are a number of approaches to consider when exploring the nexus between industrial organization economics and analytical modeling. Figure 2 is largely focused upon bringing the industrial organization model closer to the strategic procurement environment for an individual firm. The fundamental assumption in this model is that the supply chain in this instance is ‘owned’ by the client, who is the focal supply chain organization. If the focal organization that procures and manages a supply chain shifts then this may shift the perspective of what is analytically modeled.

TRANSACTION COST THEORY AND SUPPLY CHAINS

Ellram (1997) took an industrial organizational perspective, although from a single organization’s ability to manage the supply chain. She suggested types of competitive relationships that firms undertake from transaction, short-term contract, long-term contract, joint venture, and equity interest to acquisition. These involve increasing commitment on the part of the firms. She described the key conditions under which supply chain management relationships are attractive according to an industrial organization perspective. The main thrust was that supply chain management is ‘simply a different way of competing in the market’ that falls between transactional type relationships and acquisition and assumes a variety of economic organizational forms (Ellram 1997). This was one of the first discussions to explore the implications of Williamson’s transaction cost economic theory (firm theory), and industrial organization

economics related to supply chain management. Situations conducive to supply chain management included:

- recurrent transactions requiring moderately specialized assets,
- recurrent transactions requiring highly specialized assets,
- operating under moderately high to high uncertainty.

The choice for a particular governance structure is not just dependent on transaction cost minimization. Exchange of knowledge, access to information, mutual trust, power relations, combined competencies, and production and communication control are important factors (Voordijk et al. 2000, Kornelius and Wamelink 1998).

The co-operation between main contractor (assembler) and subcontractors and suppliers are subjects of supply chain management, and development of these relationships within the supply system towards arrangements of lean supply and partnerships (e.g. Lamming 1996, Dainty et al. 2001a). In addition, supply chain management is about integrating subcontractors' and suppliers' skills and competencies in order to achieve performance improvement, and to overcome barriers to implementing supply chain management arrangements with small to medium enterprises (Dainty et al. 2001b).

It has been argued that short-term project collaboration must evolve towards long-term strategic partnering that supports and enables organizational learning ("cooperative learning alliances"), and develop a culture for "reflective and mutual learning", and knowledge and communication management, beyond merely project management and performance improvement (Love et al. 2002a). In this way the learning and improvement capacity of firms can be embedded in cooperative relationships in the supply chain, and cultivate a climate for mutual learning and continuous improvement, and build trust and competitive advantage as alliance objectives (Love et al. 2000a, 2002b). Much of this depends on the commitments between firms in the supply chain and the activation of commitments; how is further action assured and how are the execution and completion of actions controlled and communicated, and laid down in the supply chain as a network of commitments (Vrijhoef et al. 2001). The development of such long-term arrangements then relies upon understanding the structural and behavioral characteristics of supply chains and particularly the construction industry structure (London 1998).

Further to this Hobbs (1996) viewed transaction cost analysis (TCA) as a framework to understand and explain the structure and coordination of supply chains. Transaction cost reduction is viewed as one objective of SCM. Inter-organizational cooperation and improved data interchange aims to reduce transaction costs. TCA is a way to assess and understand transaction costs within supply chain relationships, and find ways to reduce the transaction costs through closer relationships in the supply chain (Hobbs 1996, Loader 1997). Transaction cost economics (TCE) has been used as a conceptual framework to analyze construction supply chains, to improve efficiency and reduce coordination costs, and to explain governance of the construction process (Winch 2001).

Such prescriptions should be considered with caution, 'arguments designed to prove the inevitability of this or that particular form of organization are hard to reconcile, not only with the differences between the capital and socialist worlds, but also with the differences that exist within each of these (Richardson 1996). Transaction cost economics theory has just as many critics as supporters (London and Kenley 2001).

One of the main criticisms being that it has tended to assume a market and hierarchy dichotomy (Richardson 1996). Theorists have found it difficult to explain contractual relationships between firms where clearly the transaction costs were high and yet firms did not vertically integrate. There are a variety of institutional arrangements between the two extremes of market versus hierarchy, which do not fall neatly into the transaction cost model and clearly demonstrate that markets are not the only way prices are coordinated (Alter and Hage 1993). Furthermore, the application of the TCE approach to construction supply chains has been criticized from other perspectives, including the fact that optimizing production costs (e.g. transaction costs) doesn't necessarily improve the production organization itself (Koskela 2000).

FUTURE RESEARCH ON INDUSTRIAL ORGANIZATION

The role of the supply chain concept in construction will soon move beyond the rhetoric that it is a management tool to improve the performance of the industry. Future research may include optimization of supply chains and will enable more credible discussions of advantages of different types of networks, clusters or chains. To do this an interaction between industrial organization modeling and analytical modeling is one methodological approach.

Various construction studies have widened the perspective and have introduced industrial organizational concepts, for example vertical integration (Clausen 1995, Tommelein and En Yi Li 1999), design specialization and fragmentation (Tombesi 1997), subcontractor/contractor dependence and the 'quasifirm' (Eccles 1981), buyer concentration or pooled procurement (Taylor and Bjornsson 1999), and SME constellation of supply (London 2001). Much of this work is oriented to the project as the unit of analysis and is not approaching the research problem from an industry or market perspective (although London's single case study is market oriented). The results are difficult to generalize and are quite focused. There is a lack of work that approaches the research problem from a wider industrial context. A deeper and more detailed understanding of industrial organization theory and supply chains would further this debate (Carassus 1998, London and Kenley 1998).

There is a need to develop this further and explore the explicit inter-firm supply chain relationships and various attributes and properties of these relationships on the firm and market level of analysis within the field of industrial organization economic theory.

ANALYTIC MODELING OF SUPPLY CHAINS

In his review of supply chain models and applications at Hewlett-Packard, Davis (1993) noted that "without an adequate analysis tool, opportunities for change might be lost for want of a credible argument." (p. 37) Davis' statement refers to the goal of analytic modeling of supply chains: Providing the necessary insight and numerical results that help managers improve supply chain design and operation. Thus, analytic modeling may help construction managers make decisions about how to structure a supply chain to enable rapid construction or to improve operational responses to changed conditions.

SUPPLY CHAIN MODELING IN OPERATIONS MANAGEMENT: A BRIEF REVIEW

Production researchers have formally modeled elements of supply chains at least since Clark and Scarf's seminal paper on optimal policies in a multi-echelon (or tiered) inventory system (Clark and Scarf 1960). Multi-echelon methods developed rapidly over

the next few decades, but these methods were generally limited to analysis of inventory distribution systems. Methods of analyzing production systems (principally from a queuing perspective) developed separately. Significant work linking production and inventory systems – early methods of integrated supply chain analysis before the term supply chain became popular – occurred in the 1980s. Examples from this period include Cohen and Lee 1988; Federgruen and Zipkin 1984; Federgruen and Zipkin 1986; Mukstadt et al. 1984; Schmidt and Nahmias 1985; Schwarz 1981; and Yano 1987. These models represent a broad range of approaches but for the most part are limited in their applicability and focus on idealized elements of supply chain production.

The 1990s saw an explosion of supply chain activity in both research and practice. Within the manufacturing community, much work was inspired by developments in lean production/JIT systems (e.g. Womack et al. 1990), and concurrent developments in systems thinking applied to (non-lean) production-inventory systems in practice (in particular, at Hewlett-Packard (Davis 1993, Lee and Billington 1992) and at DEC (Arntzen et al. 1995)). The volumes edited by Geunes et al. (2002) and Tayur et al. (1999) provide excellent state of the art reviews of capabilities and research directions. Bowersox et al. (2002) provide a more practical review with a focus on logistics

Drawing from Davis' (1993) paper, figure 3 depicts a manufacturing supply chain composed of production, inventory and transportation functions serving a (typically random) demand function for a single product (or closely related product family). For such a demand function, analysis techniques provide guidance both how to structure and operate the supply chain. Structuring or strategic analysis supports decisions choices about where to place production in the supply chain for faster response time or for reduction in system inventories. (Risk pooling and delayed differentiation are two such strategies; see Simchi-Levi et al. (2000) for a review). Strategic analysis also supports selection of suppliers based on their capabilities and location. Analysis also supports operational or tactical decisions about the supply chain; largely these are decisions about sizes of various inventory buffers for a given supply chain structure.

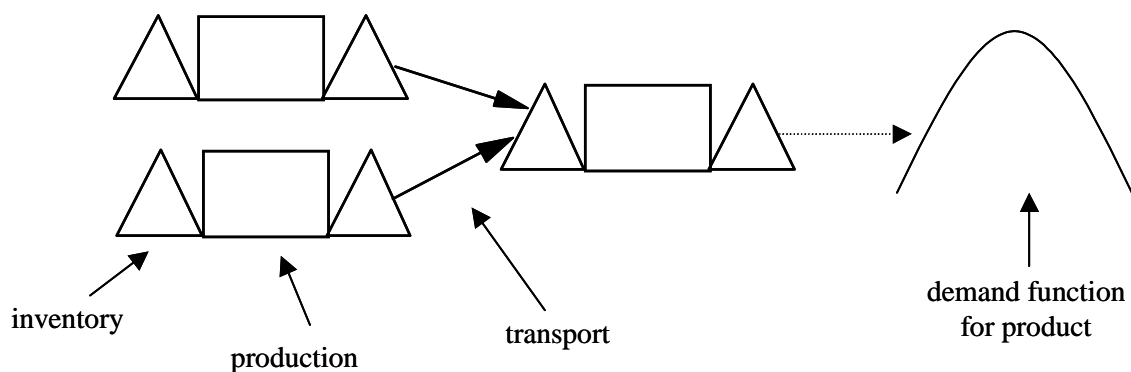


Figure 3: Modeling perspective and scope of manufacturing supply chain analysis

Analysis techniques for supply chains in figure 1 are powerful but capture only limited aspects of supply chain operations and constraints. The research frontier in supply chain analysis has grown to encompass business concerns, including:

- The impact of information and incentives in decentralized supply chain structures (Lee et al. 1997; Tsay et al. 1999).

- Managing product variety and product families (Garg and Lee 1999; Lee et al. 1993).
- International operations and exchange rate risk (Cohen and Huchzermeir 1999).
- Production in heterogeneous production environments or in environments not characterized by high-volume, repetitive production (Mahoney 1997; Raman 1999).

MODELING CONSTRUCTION SUPPLY CHAINS

Research directions in the operations management literature towards supply chain analysis for low volume and/or heterogeneous production environments suggest that analytic modeling tools will begin to accommodate the complexity posed by production in construction. While figures 1 (construction supply chain) and 3 (manufacturing supply chain) are conceptually similar, the conditions posed by construction are more complex as there is low volume production and coordination of many components.

The past decade has seen the development of supply chain research as a field in construction. While Koskela's (1992) seminal paper broadly introduced lean thinking to construction, the earliest literature in construction explicitly considering supply chains is the case study by Bertelsen (1993) and the paper by O'Brien and Fischer (1993). From these beginnings, construction research has roughly paralleled supply chain research in manufacturing, albeit with a strong emphasis on lean applications and an associated focus on operational decisions. In particular, there has been a focus on tactical or operational decisions such as sizing of buffers relative to performance (e.g. Howell and Ballard 1997, Al-Sudairi et al. 1999). There also exist models and techniques to analyze a given construction process from a flow perspective and improve it (e.g. Tommelein and Weissenberger 1999). Buffer and flow modeling has typically focused on operations across a small section of the supply chain, such as the supplier-subcontractor interface for a given technology. The complexity of the construction environment has to-date limited larger scale quantitative analysis. Empirical studies have similarly been limited in focus (e.g. Wegelius-Lehtonen and Pahkala 1998)

Due to complexity, much construction research has employed qualitative analysis based on quantitative models and concepts drawn from the manufacturing management and operations management literature. For example, Vrijhoef and Koskela (2000) analyze the construction supply chain as a make-to-order supply chain, and identify four major roles of construction supply chain management as: Focusing on developing the interface between the supply chain and the construction site, focusing on developing the supply chain itself, focusing on transferring activities from the construction site to the supply chain, and focusing on the integration of the supply chain and the construction site. (It is important to note that Vrijhoef and Koskela, like many construction researchers, make a distinction between site production and production in the off-site supply chain). Vrijhoef and Koskela qualitatively analyze supply chains using time buffer measurement, cost and price analysis, and problem sequence analysis through the supply chain. They find that problems typically exist at the interfaces between parts of the supply chain, and appear to be interdependent to a large extent, similar to previous studies of make-to-order supply chains in other industries (e.g. Luhtala et al. 1999). In a more focused study, O'Brien (1995, 1998) qualitatively studies the performance characteristics and distribution of

benefits in a supply chain consisting of off-site suppliers, a transportation/distribution firm, and on-site production under different production disciplines. O'Brien suggests a qualitative typology of supplier types based on production technologies, and demonstrates how supplier types can be combined to produce qualitative models of larger supply chains with associated performance predictions (O'Brien 1998).

Construction supply chains are subject to business constraints as are manufacturing supply chains. Thus while continued research in process evaluation remains a priority, the research frontier in construction supply chain management has extended to include considerations of:

- The impact of decentralized information and decision making in supply chains (O'Brien et al. 1995; Taylor and Bjornsson 1999).
- The impact of contracts and incentives on supply chain performance (O'Brien 1995).
- The link between design and supply chain performance (Singh et al. 1999).

Analytic modeling can only currently address subsets of the larger construction supply chain. Similarly, extensions of analytic models to address business and design issues are limited in descriptive and prescriptive abilities. There is no framework or theory to fully relate focused improvements to overall supply chain performance or to design overall supply chain structure.

Given these limitations, a promising research area is to decouple components of the supply chain from a production and managerial perspective, identify/prescribe performance parameters, and predict aggregate supply chain performance from the components. For example, Christopher and Towill (2000) suggest a hybrid supply chain model, dependent on the decoupling points for material flow and information flow. The proper location of decoupling points is determined by how lean (upstream) or agile (downstream) a supply chain and the "order fulfillment process" should be (see also Lin and Shaw 1998). The issue here is to bring together the best of different lean and flexible/agile paradigms, towards a "leagile" model (see also Naim et al. 1999). In construction supply chains, the decoupling point is located relatively downstream, compared to many other industries, e.g. manufacturing. In fact, construction supply chain management can be characterized as a postponement strategy for delayed differentiation in the order fulfillment process, similar to "pulled production" (Vrijhoef et al. 2002).

Whatever the power and promise of analytic modeling, its limitations in addressing overall supply chain structure may never be fully overcome by development within the field. In general, as complexity increases, the predictive and prescriptive power of analytic modeling tools decreases. Thus there is a need to include other perspectives such as those provided by (neo)-industrial organization models of supply networks.

SUMMARY: TOWARDS A SYNTHESIS AND COMBINED RESEARCH AGENDA FOR INDUSTRIAL ORGANIZATION THEORY AND ANALYTIC MODELING OF CONSTRUCTION SUPPLY CHAINS

Industrial organization economics and analytic modeling have had only limited impact on the other's research focus. It is the view of the authors, however, that a combined perspective will be useful (and necessary) to adequately provide normative theory and methods to improve construction supply chains from both a policy and managerial level.

Such a combined perspective is presaged by recent developments in each field: Industrial organization theory is attempting analysis of networks of organizations and is increasing relying on detailed contextual data about transactions between firms. Analytic modeling of operations provides insight into these transactions, particularly from a normative perspective that can aid industrial organization policy prescriptions for market interventions and contracts. Similarly, knowledge of market forces will aid analytic models as they move to inclusion of incentive and information structures.

As with any multidisciplinary perspectives, there needs to be development of shared understandings of epistemologies and ontologies within and across the fields of industrial organization theory and analytic modeling. It is the hope of the authors that the reviews above provide a useful first step in defining the general approaches, capabilities and research agendas of these two fields. However, more research needs to be conducted to better formalize the epistemology and ontology of each field from a construction supply chain perspective. Rather than conduct such research abstractly, however, the authors anticipate that advances in theory and knowledge will be driven by practical applications at either the managerial or policy level. Thus below we propose a (necessarily incomplete) research agenda focused on applications that can benefit from both industrial organization and analytic modeling approaches:

- Sourcing and make-versus-buy decisions: Analytic modeling can provide tools to assess supplier performance and, for critical suppliers, inform choices about making products in-house. However, such decisions can benefit from expectations about market structure and evolution of market structure, particularly if firms plan to invest in long-term associations and partnerships.
- Related to sourcing are managerial decisions about supply chain structure. Analytic approaches, for example, suggest decoupling the components of the supply chain around different production philosophies and related demand profiles. This is an incomplete perspective, however, as technically driven decoupling and associated clustering may not be compatible with larger market forces. This is particularly so in construction where individual supply chains are not large enough clients to effectively force decoupling points on supply chains.
- Development of improved incentive structures from an analytic modeling perspective can benefit from better knowledge of the market forces and constraints that firms operate under. In particular, it is hoped that industrial organization theory can make reference to the nature of the supply network firms operate in, providing contextual understanding and identification of specific forces and constraints (that in turn can improve modeling). A particular application here is the role of owner organizations and governments as construction clients. By choice of contract and managerial style, they set much of the tone of construction incentives, culture and governance throughout the supply chain.
- Conversely, analytic modeling can suggest behavioral actions and properties of firms from a normative perspective that is missing in industrial organization theories. Government policy applications (such as tax law promoting investment in new production technologies or supporting joint ventures and related long-term relationships) could improved with better

understanding of the inner workings of supply networks and which forms and behaviors should be promoted.

The construction supply chain field is maturing as it grapples with the development of theories and models and refinements of those theories and models. The two distinct fields of industrial organization and analytical modeling have been explored in detail in terms of their contributions to the supply chain concept. There is the danger inherent in this of course, which is dealing with the complexity of numerous concepts and techniques, however it is suspected that the competing and contributing fields can really only assist the development theory for the supply chain field.

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