Construction Supply-Chain Management:
A Vision for Advanced Coordination, Costing, and Control

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Overview

Construction supply-chain management offers new approaches to reduce the cost of and increase the reliability and speed of facility construction. Supply-chain management takes a systems view of the production activities of autonomous production units (subcontractors and suppliers in construction) and seeks global optimization of these activities. Applications of supply-chain management techniques in manufacturing environments have saved hundreds of millions of dollars while improving customer service (Arntzen, et. al, 1995). As subcontractor and supplier production comprise the largest value of project cost, supply-chain approaches may have similar benefits. Limited studies in construction suggest that poor supply-chain design regularly increases project cost by ten percent (Bertelsen, 1993), and this estimate is probably conservative. Project duration may be similarly affected.

The promise of supply-chain management comes from its system perspective on production activities. Such a perspective allows improved understanding of firms' production costs and capabilities (particularly under the uncertain and changing conditions that characterize modern construction sites). This provides a rational basis to improve coordination and control on construction projects. Production activities can be better planned and adjusted and, by linking to costs, contracts can be formed that promote optimal supply-chain performance. Similarly, enhanced understanding of production allows analysis of the impact of facility design on supply-chain performance. The systems discipline of supply-chain management contrasts sharply with traditional methods of planning, controlling and contracting for projects that, taking a hierarchical, decomposition approach, seek at best to optimize individual activities. Thus whereas current construction methods tend to support the fragmentation that plagues construction, supply-chain management promises an engineering basis to design, plan, and manage construction projects in a collaborative manner.

Practice today

Limitations of current practice can be seen in two case studies:[2] The Durand Centre project which is an example of the limitations of traditional approaches (particularly under changing conditions), and the Buchhaugen project which demonstrates the shortcomings of our understanding when applying new techniques.

The Durand Centre is a £100 mn ($150 mn) shopping mall built in the London area in the early 1990's. It followed a traditional contractual form where the general contractor held contracts with each of the subcontractors and did not self-perform work. Standard penalty clauses for liquidated damages were in place. The project completed on time and placed second in a national project manager competition. On the Durand Centre project there was a delay to steel fabrication that resulted in a six-week delay to steel erection on-site. This delay was not anticipated and did not become apparent until it occurred on-site. To avoid liquidated damages and complete the project on time, the contractor directed an acceleration of

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[2] Details of both case studies can be found in O'Brien (1998) and the Buchhaugen case also in O'Brien (1995).

following trades at a cost of £231 thousand. Subsequent investigation found that an alternative acceleration may have been possible at a savings of ~£70 thousand. This analysis came from investigation with the affected subcontractors and suppliers. Conditions that affected cost and capability were both site conditions that affect productivity and resource availability given the demands of other projects under changing schedule.

Several lessons can be drawn from the Durand Centre case:

- It reiterates that changes in schedule and scope are a common occurrence on construction projects, even on well-run projects. Production in construction is transient in nature.
- Resource availability (capacity constraints) and poor site conditions pose real costs and limits on subcontractors and suppliers. Subsequent investigation (O'Brien 1998) has found that these conditions are generally applicable beyond the Durand Centre case. These costs are particularly important given frequent changes in schedule and scope.
- Existing methods to manage changes in schedule and scope (in particular the time-cost tradeoff for network scheduling techniques) do not account for the costs of capacity constraints or site conditions. More broadly, construction costing and control methods do not take these influences into account. This may account for the failure of managers on the Durand Centre project to explore lower cost alternatives to their acceleration.
- Construction contracts that penalize for problems and contract solely for specific work at specific times retard information sharing and provide no mechanism to explore costs and capabilities in a dynamic environment. This may explain why the delay to steel fabrication was not known until it resulted in delays on-site and partially explains the lack of examination of alternatives by the general contractor.[3]

Another recent case study is the Buchhaugen project (a NOK 25 mn multi-unit residential project located in Trondheim, Norway), which utilized a Just-In-Time style delivery system inspired by both the Toyota assembly system and an earlier Danish project (Bertelsen, 1993). Specifically, the project employed a unit-order system where the project was split into small packages of material ("units") that are to be delivered to site where they are needed, just as they are needed. Each unit was to be ordered on a rolling three-week order system, where each unit would have a three-week lead-time to be prepared by suppliers before delivery to site. In theory, the unit-order system would lead to increased reliability, improved productivity, and lower costs for all firms involved on the project. In practice, project management had great difficulty predicting demand for units on-site with any certainty and more than half of the units ordered had deviations from the planned three-week order period. While many of the firms involved in the unit-order system saw it as a positive experience, they were troubled by the uncertainty in production progress on-site and had difficulty quantifying savings. At least one firm (an intermediary materials handler/supply depot) found an overall increase in costs with the unit order system.

Several lessons can be drawn from the Buchhaugen case:

- As with changes in schedule and scope as seen in the Durand Centre project, uncertainty in production schedules on-site is a common occurrence in construction. This uncertainty, because it requires shifting resource allocation on the part of suppliers and subcontractors, is a major driver of project costs and savings under the unit order system or other disciplines.
- There is a need for integrated analysis across the entire supply-chain (from supplier to subcontractor). As a naïve application of Just-In-Time principles, there was an expectation of benefits accruing to every firm. This is clearly not the case as one firm had an increase in costs and supplier costs are

[3] The scheduling manger noted that under existing contracts where he had no true knowledge of costs, he had no incentive to explore alternative because he believed the affected trades would charge as much as they could for the changes.

greatly influence by the degree of uncertainty in the unit-order system (O'Brien 1998, 1995). A systems perspective is required to evaluate performance.

- ✍ There is a link between facility design and supply-chain performance. Some suppliers choose not to participate in the unit order system because their production technology would be adversely affected. As production technology is largely driven by design, in theory design choices can be made to select technologies compatible with the desired production discipline. Some examples of "design for supply-chain management" exist in the manufacturing literature (Lee, et. al., 1993).
- ✍ Contracts need to promote system optimization. Given a need for integrated analysis and the problems of finding systems in which every party gains, ways to equitably share the benefits of improved supply-chain systems are required. Similarly, there need to be incentives for improved operating performance, particularly with regard to uncertainty. On the Buchhaugen project, the general contractor paid a fixed price for each unit without regard to uncertainty in its demand. A penalty for uncertainty may have produced better performance on its part.

Vision for future practice

Improved coordination, costing, and control offered by construction supply-chain management is an achievable vision. A better understanding of firm's production costs and capabilities – in particular their ability to manage their resources across projects given changes in schedule and scope – affords several opportunities for improvement. It provides a background for improved production control within each subcontractor and supplier. Such an improved understanding of costs and capabilities also allows improved design of supply-chains composed of those subcontractors and suppliers, providing and engineering basis for improved coordination. Moreover, the link between cost and production allows new forms of contracts that promote system optimization.

Consider how improved supply-chain knowledge would change practice on the Durand Centre and Buchhaugen projects. On the Durand Centre, practitioners would:

- ✍ Better be able to predict risks of disruption to production and design buffers to guard against those risks. Such buffers would include both schedule buffers and sequencing of production to mitigate the impact of problems should they occur. More broadly, they could use supply-chain knowledge to design schedules to meet project goals for speed, flexibility, and risk.
- ✍ Understand subcontractor and supplier production costs should there be changes in schedule and scope such as the delay to steel erection. Such knowledge would allow a directed search of alternatives to find optimal responses to these changes.
- ✍ Implement contracts that specify an equitable basis to pay for the true costs of changes, enhancing trust and information sharing among firms.

On the Buchhaugen project, practitioners would:

- ✍ Use analysis techniques to design supply-chains and determine which disciplines are appropriate (e.g., Just-In-Time vs. batch orders) to the needs of the project.
- ✍ Use the knowledge of costs to promote optimal performance, both in terms of system design and control. Rather than looking to individually optimize each contract, managers would have a rationale to pay some firms more so that system performance is improved. Similarly, contracts could be designed to give incentives to improve supply-chain operation. Non-linear price schedules (Wilson, 1993; O'Brien, 1995) could be designed to penalize poor performance, especially for uncertainty. Also, concrete knowledge of costs could quantify savings if certain supply-chain disciplines are adopted; these savings could be used to reward firms if targets are achieved. (The insurance industry already uses such rewards to promote safety.)
- ✍ Design the facility to improve supply-chain performance. Designers could select materials and components that can be manufactured and installed according to the desired supply-chain discipline;

alternately, facility design could be altered to allow different on-site assembly sequences that would enable efficient groupings of project activities.

Research needs

The vision for improved construction supply-chain performance suggests four complimentary research areas:

1. Cost and performance modeling of subcontractor and supplier production.
2. Econometric measures of firm and supply-chain performance.
3. Game theoretic design of contracts to support supply-chain performance.
4. Generation of design criteria to improve supply-chain performance.

The need for improved linking of costs to production performance places priority on research area one – more work must be done in this area before progress can be made in research areas three and four. There must be a knowledge of payoffs to design practical contracts in research area three and the production knowledge necessary to evaluate design criteria will come from further research in area one. Research area two is the only area not specifically derived from discussion of the Durand Centre and Buchhaugen projects. However, econometric measures are necessary to complement cost and performance modeling. Such measures serve to generalize more specific models and test the propositions of those models. More generally, such measures allow generation of an empirical database that can demonstrate the gains possible by supply-chain techniques. This should help to speed adoption of these techniques across the construction industry.

Due to the priority of research areas one and two, I have detailed at some length below proposed contributions to practice, current status, and proposed benchmarks as knowledge progresses:

1. Cost and performance modeling of subcontractor and supplier production.

Contributions	✍improved scheduling methods, particularly with regard to the design and placement of buffers against uncertainty and changes ✍improved subcontractor coordination methods by linking site production to resource management ✍improved accounting and production control systems
Current status	Definition and problem formation;[4] conceptual models
Proposed benchmarks	✍supplier/subcontractor specific model(s) ✍generic models/models for classes of firms ✍accepted calibrated models ✍rules for accounting/production control systems ✍improved design rules for schedules and buffers

[4] It is important to note that the existing manufacturing research in supply-chain management, while useful at a high level, does not translate to a construction environment. The transient nature of production on construction projects contrasts sharply with manufacturing models that focus on average production characteristics. Hence, relatively little is known about construction supply-chain management and we are currently at early research stages.

2. Econometric measures of firm and supply-chain performance.

Contributions	✍development of quantitative methods to measure firm performance in a multi-project, multi-resource environment ✍benchmarking of firm performance, including management policy ✍construction of cost indices to improve estimating
Current status	Methods of single activity/project productivity measurement; non-construction specific, non-parametric data envelopment productivity models (Fried, et. al., 1993)
Proposed benchmarks	✍case studies to test/adapt data envelopment models to construction environment ✍generalized measurement model(s) ✍Generation of large data sets; cost indices ✍Test of research propositions; benchmarking of firms

Because research areas three and four are dependent on success in research areas one and two and are longer-term areas, I do not project their research contributions and benchmarks in as comprehensive a manner. In general, it should be possible to design contracts that promote systems behavior. Myerson (1989) describes theoretical approaches to contract design while more practically Wilson (1993) describes both simplification concepts and application of pricing schemes in practice. O'Brien (1995) finds that Wilson's criteria for application of contracts is compatible with the construction environment. Research area four, design for supply-chain management, is more speculative but builds off existing work in constructability as well as manufacturing examples (Lee, et. al., 1993). An early contribution in this area should be case examples of the relationship between facility design and dependence among production units. At the least, research in this area should provide case studies that enhance and broaden the experience of practitioners.

Personal background and motivation

I have been interested and involved in promoting improved collaboration among construction firms for 10 years. As a practitioner, I have been closely involved in the development and application of Internet collaboration tools, where I have developed an appreciation of the complexities and nuances of implementing new techniques and processes. This has shaped my approach to supply-chain research. I believe in the necessity to provide both improved processes and the rationale to adopt them; thus my emphasis on understanding costs and creating contracts that promote the adoption of new techniques. As an academic, I believe I have contributed the first doctoral dissertation on construction supply-chain management (O'Brien 1998). This work, based on empirical studies with subcontractors and suppliers, demonstrates the inability of existing construction costing and planning techniques to account for the true costs of changes such as those on the Durand Centre. This work also contributes qualitative models of supply-chain performance that ground much of the proposed research in cost and performance modeling. I have also contributed subcontractor productivity models that link site conditions to resource allocation; this work ties supply-chain resource allocation models to the site coordination work currently underway by other researchers, in particular that of Riley & Sanvido (1997, 1995), Thabet & Beliveau (1994), and Tommelein & Ballard (1997). More broadly, my contributions contribute to an understanding of subcontractors in the areas developed by Bennett & Ferry (1990) and Gray & Flanagan (1989).

Combining personal interest, practical experience, links to existing research thrusts, and detailed knowledge of subcontractor and supplier production uniquely qualifies me to develop new knowledge in this area and work with industry to implement it.

Recap: Impact of research on practice

Supply chain management offers a way to work that can fulfill the promise of a collaborative construction environment. At least since the early '80s (Business Roundtable, 1983) there has been dissatisfaction with the fragmented nature of the construction process and the often associated poor productivity. Since the Business Roundtable report there have been several movements to cope with the deleterious effects of fragmentation, notably partnering to cope with the adversarial nature of the process and more recently design-build to work towards unification of a significant part of the project delivery process. Supply-chain management offers a systems focus on production that furthers these collaborative initiatives. By focusing on production, supply-chain management promises a concrete engineering discipline; by focusing on the subcontractors and suppliers that comprise the largest value of project costs, supply-chain management promises substantial impact on project performance.[5]

Moreover, while supply-chain management will be developed in conjunction with practitioners, it offers unique scope for academic research to make a contribution. The improved coordination, costing, and control of the activities of many firms is difficult for any individual firm in a supply-chain to conceptualize, let alone generate the trust to implement on a project-wide basis. Academics are able to generate the models and provide the empirical evidence of supply-chain opportunities and pitfalls. The collaborative efforts of industry will eventually lead to improved supply-chain efforts; as academics we have a position to speed and shape these efforts.

[5] And more so in the future as an increasing value of project production occurs off-site. For example, a Norwegian study shows an increase in the value of materials as a percent of project cost from 59% in 1970 and 67% in 1992 (Albriktsen, et al., 1993).

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