A Qualitative Analysis of Construction Projects From Supply Chain Management Perspective

민 정 웅*
Min, Jung-Ung

Abstract

This paper presents an analysis of construction project management from supply chain management perspective to gain insight from all constituents and to identify areas of improvement. In order to suggest opportunities for improvement, interviews with the members of a typical urban office building project in US were held. Based on that, a qualitative analysis of construction projects is presented. Focusing on electrical and mechanical sub-systems, this study illustrates the roles of subcontractors, suppliers, distributors, and manufacturing representatives as well as the complexity that a general contractor faces in managing its supply chain. The author°Øs recommendations are focused on process restructuring and automation, which include some quantifiable performance measures, incentives, and their alignment with each other

·**Keywords** : Construction Projects, Supply Chain Management, Qualitative Analysis, Interview

1. INTRODUCTION

A construction supply chain is a network of facilities and distribution options that performs the function of procurement, transformation, and the installation of construction components for an end customer. Specifically, a general contractor (GC) contracts/engages subcontractors, who in turn, procure materials from suppliers and distributors and contract trade labor from local union halls (Clough and Sears, 1994). The supply chain can become very complex with a multitude of subcontractors, who may also engage multiple sub-subcontractors, suppliers, and distributors of construction-related materials. The construction supply chain, from the GC' s perspective, includes trade labor, construction/building materials, and hardware which can be tracked and measured; it also includes the detailed drawings, specifications, construction know-how, and expertise that are much less easily quantifiable. The opportunities to standardize practices, to improve information sharing among the members of the vast network, and to reduce material and labor lead-time are motivational to the industry.

Based upon interviews with a general contractor and its supply chain partners in United States, this paper describes current practices of project management from supply chain management perspective, including its organization, procedures, performance measures, and possible areas for improvement.

2. SCOPE OF THE STUDY

Cooper et al. (1997) suggested a conceptual framework of supply chain management that consists of three major and closely related elements: business processes, the structure of supply chain, and management component. Among these, this study focuses on the process perspective of supply chain management. The motivation for this focus is that there is still lack of empirical research addressing the entire scope of the supply chain for understanding, describing, and analyzing it (London and Kenley, 2001).

The interviews and their analysis presented in this paper were

* 학생회원, 미 스탠포드대 박사과정

captured from Swinerton & Walberg(S&W) and its supply chain partners in a project. The representative project that is examined in this study is an urban office building, one of the typical construction projects for S&W. Figure 1 depicts an extended supply chain for an urban office building project.

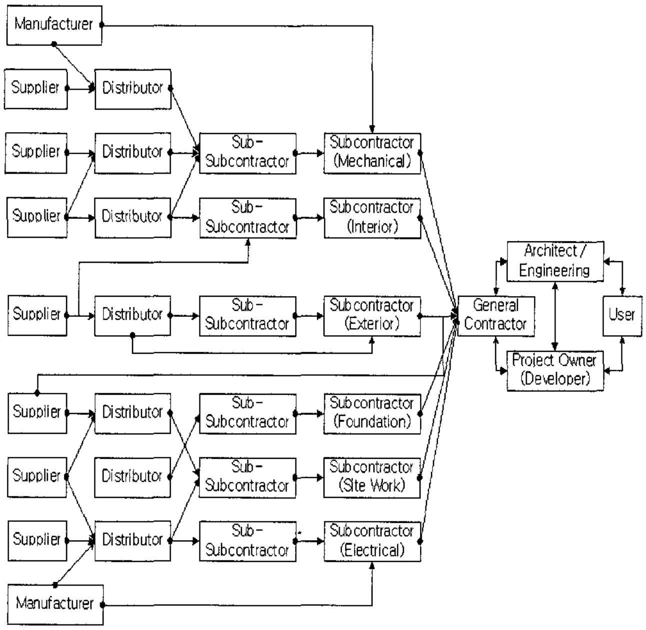

Figure 1. Extended Supply Chain/Network for a Typical Urban Office Building Project

The general approach of this study is to drill down to gain particular insights and to provide specific examples of how the supply chain operates within these elements. Rather than trying to describe the entire construction process involved, this study focuses on key components on a critical path: electrical and mechanical. For the electrical and mechanical sub-systems, this study specifically focuses on the procurement of trade labor and materials from subcontractors, suppliers, distributors, and manufacturers.

3. DESCRIPTION OF THE SUPPLY CHAIN

This section presents the general description of a construction supply chain in terms of different roles and processes based on interviews with practitioners.

3.1 Roles in a Construction Supply Chain

In general, a construction supply chain consists of an owner, architect/engineering firm, a general contractor, subcontractors, and their suppliers and sub-subcontractors. The interview results turned out that the general roles of downstream members were typical that can be found on literature (Barrie and Paulson, 1992; Clough and Sears, 1994); the owner' s role is to set the operational criteria; the architect and engineering firm (A/E) produce design alternatives, specifications, and drawings; and the GC oversees that contracts are in place with its subcontractors to secure the necessary materials and labor on time. However, as it goes upstream, it becomes complicated such that it involves key supply inputs including material procurement and trade labor.

The subcontractor secures material from its distributors and suppliers. Distributors provide certain types of products that can be made by a multitude of manufacturers. Generally, distributors are used by subcontractors for raw materials and commodity product. On the other hand, suppliers typically represent a line of products from a single manufacturer, where manufacturer' s direct sales force sells more expensive items such as structural steel and passenger elevators.

3.2 Processes in a Construction Supply Chain

The typical life cycle of a construction project consists of the following four phases: Concept and Feasibility Studies, Engineering and Detailed Design, Procurement, and Construction (Barrie and Paulson, 1992). In this study, interviews were focused on the procurement phase which includes the following: (1) bidding and awarding contracts to subcontractors in order to secure materials; and (2) commitments for trade labor to perform construction-related activities. Here, the construction activities appear to resemble those of manufacturing firm such that each subcontractor is responsible for on-site inventory management as well as securing materials as necessary in order to reduce possibility of work stoppage or delays in other activities.

(1) Material Procurement

Materials that have long lead-time become key elements of the building' s construction path. Typically, the committed lead-time is not known until a firm purchase order is placed with the manufacturer' s representative.

With the exception of certain commodity items (e.g., lumber), the GC typically will not procure materials. Unless the incentive scheme (material cost avoidance) is sufficiently large to entice the GC, it will place the ordering function on its subcontractors. The burden of on-time delivery and risk management will be borne by the subcontractor. For materials and systems not on the critical path, the GC will determine when each key system or sub-system is required and will write contracts with its subcontractors to order and to install with flexibility stipulations attached. This allows the GC to align the timing of critical and non-critical path activities and to more effectively control the cash flow of the project since payments are made based on percentages of work completed.

The materials are procured via purchase orders issued by subcontractors (e.g., Rosendin Electrical, Marelich Mechanical) to their suppliers, to their distributors in the area, and to manufacturer's representatives in and out of the local region.

(2) Trade Labor

As for the trade labor, the foremen and key specialists work directly for the subcontractors. However, the majority of the craft labor and journeymen are members of local union halls that have arrangements with the large electrical and mechanical subcontractors in the area. Larger subcontractors, such as Rosendin and Marelich, are able to effectively engage craft labor at multiple sites depending on the required person -loaded resource schedules. Thus, many craft laborers will have worked and will continue to work on projects managed by Rosendin or by Marelich regardless of the particular GC's that engage Rosendin and/or Marelich.

(3) Expediting/Submittal Process

As a part of procurement process, the GC tries to receive acknowledgment such that purchase orders have indeed been placed with the supplier, manufacturer, or distributor. This allows the GC to ensure that the order is placed and prevent surprises. Similarly, the GC requests a production schedule (e.g., from suppliers); it wants to have details available (e.g., raw material procurement, machining, finishing, packaging, and shipping).

4. PERFORMANCE MEASURE

One of the challenges facing the construction industry today is the ability to measure performances across projects and corporate's boundaries (Fisher et al., 1995). There are many links in the supply chain for the construction industry and each link evaluates the others using a variety of measures in a multilateral way. In general, these measures are not quantified nor are they directly used to select business partners. However, the interview results tell us that most are considered qualitatively through experience and word of mouth to influence business related decisions. Table 1 summarizes performance measures that were observed to be used in practice from interviews.

Table 1. Observed Performance Measures Used in Practice

Target	Evaluator	Performance Measure
Subcontractor Sub-subcontractor	GC	- Bid amount - Punctuality - Flexibility, Quality - Responsiveness
GC	GC	- Profitability per capita - Employee retention rate - Repeated customer
GC	Subcontractor	- Prompt payment
Subcontractor	Subcontractor	- Profitability - On-time delivery
Supplier	Subcontractor	- On-time delivery - Flexibility, Quality - Responsiveness
GC, Subcontractor Sub-subcontractor	Supplier	- Prompt Payment - Quality
Other Suppliers	Supplier	- On-time delivery - Quality, Price - Degree and availability of engineering help
Supplier	Supplier	- Profitability - On-time delivery

4.1 Performance Measures of the Subcontractors and the Sub-subcontractors by the GCs

When considering bids for a job, the GC uses dollars as the primary decision factor. Other measures may be used to rule out specific bids, or give some higher bid an edge, but only in limited capacity. Ability to meet the schedule and the flexibility to adjust when others lag are good examples of measures considered qualitatively by the GC. A long list of other measures can be generated and these include quality, workmanship, attitude, responsiveness, and effective dealings with other subcontractors, sub-subcontractors, and suppliers. Though these listed measures can strongly affect project profitability, it was observed that they are seldom used in practice.

4.2 Performance Measures of the GC by Itself

Like most businesses, the GC measures itself on the bottom line. For instance, in order to evaluate the value of the San Francisco branch, S&W uses dollars per capita, showing high productivity as well as the market opportunity in the Bay Area. Other measures of success include employee retention rate and repeated customers including both clients and architects. The observation from interviews is that S&W and other GCs do not measure their own performance in managing the supply chain beyond project profitability. S&W also tracks the percentage of bids that it successfully wins and the bid rate by subcontractors on projects that it leads.

4.3 Performance Measures of the GC by the Subcontractors

The primary measure of downstream members of a supply chain is prompt payment because it is most likely to have an effect on profitability and cash flow. To ensure the organization is efficient, the subcontractor desires GCs to hold the project to the original schedule. This allows the subcontractor to get in and out of a site quickly and to maximize its use of capital and labor. The subcontractor also looks for quick and effective problem solving for similar reasons. As is typical in the GC, the subcontractors do not quantify these measures as well.

4.4 Performance Measures of the Subcontractors by Itself

Profitability is the primary measure of self for subcontractors. Many subcontractors also gauge their effectiveness by their own ability to deliver products and services on time.

4.5 Performance Measures of the Suppliers by the Subcontractor

On-time delivery is an important and quantified measure used by subcontractors to evaluate suppliers. Other measures include quality, flexibility, and responsiveness.

4.6 Performance Measures of the Subcontractors, Sub-subcontractors, and GCs by the Supplier

When suppliers work directly with these groups, their measures of performance are similar. As is usual for measuring downstream partners, the most important measure is prompt payment. For most companies, this is measured often by the accounting department. When payments are not met, the GC can be held accountable, even for subcontractor liabilities. However, legal proceedings cost money and are often unsuccessful, so this is not a desirable way to ensure payment.

Centria, a manufacturer of wall panels, has a list of qualified erectors for its product. These erectors were chosen largely based on the quality of workmanship. They are also evaluated on their ability to bid and gain works.

4.7 Performance Measures of Other Suppliers by the Supplier

Manufacturers have suppliers of raw materials used in production. The standard supply chain measures of delivery, quality and price are used. Degree and availability of engineering help are also considered. Centria does little measuring of supplier performance, and has moved to a single supplier model, having developed confidence in their suppliers to meet quality and delivery requirements.

4.8 Measures of the Supplier by Itself

Like the subcontractor, the supplier evaluates itself on its ability to hold down cost and make on-time deliveries. As with most manufacturing organizations, these are measured regularly.

In general, upstream links are measured on price and quality while downstream links are measured on project management performance in terms of maintaining timelines and making payments. Though the measures outlined above are used qualitatively to rule out some particularly bad companies, decisions are generally made based on straight dollars.

5. UNCERTAINTY AND RISKS IN THE SUPPLY CHAIN

The risk and uncertainty that an individual in the value chain sees depend on where he sits. Although many of the participants face the same risks, the severity and level of importance of these risks are extremely dependent upon its location. In general, the further down

Table 2. Typical Risks Faced by Project Participants

Participants	Risks and Uncertainties
Manufacturers Suppliers Distributors	- Profitability, Schedule, Labor - Payment, Supplier selection - On-time delivery, Lead-time - Material availability - Relationship with customers
Subcontractors	- Lead-time, Payment - Relationship with customers - Material availability, Labor
GC	- Schedule, On-time delivery
Owner/Architect	- Schedule, On-time completion

the supply chain that one is, the larger the magnitude is when something occurs upstream (Lee et al., 1997). The risks encountered throughout the construction supply chain are very similar to those seen by other high tech and consumer product supply chains as described below. Table 2 summarizes typical uncertainties and risks faced by the members of a construction supply chain observed from interviews.

5.1 Manufacturers, Suppliers, and Distributors

The main risks for this group are profitability, schedule, and prompt payment. Others include labor, supplier selection, lead-time, on time delivery, availability, and the risk of having a bad relationship with others throughout the value chain. Since many components are customized on the design document, the suppliers rarely hold inventory of such finished goods.

The schedule is of major concern to this group for the following two reasons. First is associated with the uncertainty pertaining to the capability of on time product delivery from the suppliers. Second is the risk of change in the schedule. If the schedule changes, the distributor will have the inventory on their books for a longer period of time, incurring extra inventory holding costs. Otherwise, as Holzemer et al. (2000) pointed out, the distributor may ship the product and compel the subcontractor to hold the product at the work site until it is installed.

Payment from individuals further along in the value chain is important because of the lag between when the supplier/distributor purchases goods and when payment is received. This can also add significant costs.

5.2 Subcontractors

Subcontractor' s main risks are lead-time of purchased parts, relationships with other supply chain participants, and prompt payment, of which relationship management is most important. Since bids are strongly influenced by the relationships previously established, a bad recommendation can severely damage a company. The same reasons shown for suppliers hold true for subcontractors.

Lack of materials on time at a job site is one the biggest problems for subcontractors because it could directly associate with expensive labor and equipments rentals.

5.3 General Contractor

A GC' s main risk is remaining on schedule. It typically has less of a problem with prompt payment from owners as long as it maintains the overall project schedule. However, it is ultimately responsible for integrating everyone' s efforts to ensure the final project is done on time. When trying to determine what might go wrong with the schedule, the theories of Six Sigma can be applied. Most US companies today operate at a level of around 4 sigma[1]. This implies that company makes 6,210 mistakes out of every 1,000,000 operations they do. If we assume that there are 20 companies are involved in a critical path item, simple statistics show that nearly 120,000 mistakes will occur for every 1,000,000 operations performed. This means that 12% of the time, the operation that originated at other supply chain partners will be delayed before reaching the final step.

5.4 Owner and Architect

The owner and architect worried about the same thing with the GC: the on-time completion of a project. The owner, architect, and GCs usually have huge financial incentives to ensure the schedule is met. For example[2], imagine that Charles Schwab wanted to move into its new 440,000 sq ft office facility. The cost of money of foregone occupancy was calculated to be worth $440,000 per week to Schwab (= $1/sq ft per week). Assume that a $40,000 contract with a subcontractor included a specific $2,000 labor component was holding up the completion and handoff to the owner (Schwab). Even if the subcontractor is at fault, the GC would be claimed by the owner for lost time and opportunity costs. The GC would pay the $2,000 itself and deal with the subcontractor later. Liquidated damages, a specified penalty per unit time, for the GC being late on handoff to customer was $440K per week on the Schwab project; this figure is computed by the customer as his appropriate opportunity cost. The incentive bonus clause to the GC for completing early is typically the same figure as the liquidated damage penalty.

6. DISCUSSIONS AND RECOMMENDATIONS

Based on the interview results described above, this section presents discussions and subsequent recommendations for

1) Estimation from Charles Kuffner, Senior Vice President and Regional Manager of Swinerton & Walberg.

2) This example is adopted from CIFE (Center for Integrated Facility Engineering) Summer Program 2000 at Stanford University, presented by Charles Kuffner.

construction supply chain management process in two perspectives: process restructuring and automation.

6.1 Process Restructuring

(1) Performance Measures and Incentive System

As can be seen from survey studies conducted in construction (Plemmons and Bell, 1995) and manufacturing (Wisner and Tan, 2000) as well as this study, on-time delivery of materials and services is the key requirement in this industry.

However, there is no incentive system in place to drive on time performance across the supply chain. There is a contract penalty for being late, though, and avoiding this may be an incentive, but in practice, everybody puts forward a somewhat valid reason for being late. Though the industry is plagued with law suits, all players want to settle amicably, especially when subsequent relationships are important. Incentive of potential repeat business works to some extent but a better reward system should be in place. One way of doing this is to offer faster payment for work completed on time. The delay in payments from the GC is a continuing problem with cash starved channel partners and thus such an incentive should be appropriate. To ensure this, the GC should have a self performance measure, e.g.,

Further, there is no incentive system for safety performance. The employees of the subcontractors and union labor usually do not show adequate regard for safe working practices. Since they do not directly report to the supervisors appointed by the GC, it becomes difficult to ensure safety.

This is a major on-site project implementation concern and can be overcome by using suitable performance measure that reflects safety related ones, e.g., .

Productivity per capita is yet another very important concern for the GC. They should improve productivity with the objective to improve the factors such as how well the project is supplying the basic elements of work (e.g., information, materials, and equipments) to the crews.

Finally, in the construction industry, there are no quantitative performance measure except for financial measures like inventory turns and profits. In order to align the measures with the incentive system and desired improvements, additional measures are recommended as shown in Table 3.

Table 3. Recommended Quantitative Performance Measures

Category	Performance Measures
Sub's Performance	- Work Injury Cost / Project Cost - (Actual-Scheduled) time - Ratio of missed deadlines - Rework time / Total on site time - Total invoice amount/# time missing info.
GC's Performance	- (Payment-Completion) time - # Bids accepted / # bids received - Project duration / # time missing info. - On site time / # time missing items
Channel-wide Performance	- Cash-to-cash cycle time - Channel lead-time - # of handling points - Channel inventory cost to revenue ratio - Dynamics of order(Zice, 1999)

(2) Use Bidding for Forecasting

Since the whole industry works on the basis of bidding for a project, it is difficult to predict demand. The whole issue is further complicated by wide and unpredictable customer choices. The channel players wait to place an order till the bid is accepted. Almost the whole supply chain bids for a project, though, and this can be leveraged to create some ground level forecast and estimation of capacity needs. In the absence of data, however, it is impossible to test any model. In the author's view, correlating project category for which bidding was taken up, number of bids in each category, and items ordered annually based on historical data may be a good model.

6.2 Process Automation

Web-based technologies are well established now for cross-enterprise automation, information sharing, and project management. Large scale civic projects require extensive B2B collaboration but the construction industry has been very slow in adapting to the Internet. Exploiting channel wide efficiencies through Internet suffers because of the lack of standards (Behrman, 2002). After standardization, there are tremendous opportunities for automating business processes: front end process (pre-project planning), design process (design effectiveness, constructability, and design for safety), procurement (material management, lead time planning, supplier relations, and bidding), and project management (change management, cost and schedule control, resource management, and dispute resolution).

More specifically, the automation of process in construction can be subdivided into the following:

① Information sharing: current order status, work status, deadlines, request for information (RFI), drawings, request for quotation (RFQ), delivery confirmation, purchase orders.

② Project management: document approvals and routing, work schedule management, cross team communication, project status, access control, compliance checking (Han et al., 1998), time line adherence, on time personnel availability, impact of changes on schedule and cost, expediting (Min, 2004) if required.

③ Collaborative planning: resource scheduling, design collaboration, collaborative forecast and capacity planning.

④ E-procurement: supplier rating (Ekstrom and Bjornsson, 2003), market making, identifying the suitable suppliers (Taylor and Bjornsson, 2002).

⑤ Electronic construction archives: Electronic records of all documentation from original drawings to changes made and to building closeout specifications during the project.

Some benefits of process automation for the construction industry may include the following:

① Lower costs: Overhead costs can be reduced by eliminating drawing duplications and shipping costs, and schedule delay overruns are avoided by electronically communicating delivery plans and changes to all parties.

② Reduced cycle times: Electronic collaborative environment means faster approvals for any changes, instant access to drawings and schedules by all parties, and the resolution of conflict documentation before construction is halted.

③ Less risk: Reducing delays and mitigating cost overruns limits risks for owners. Architects and general contractors now have more predictable schedules and can better manage the impacts of changes. Recording and documenting change approvals as they occur will reduce all-too-common post- construction litigation over deviations from drawing specifications.

④ Lower costs drive open bidding: Reduced administrative costs mean firms will compete on construction efficiency, opening the door for smaller contractors.

⑤ Shorter cycle time drive purchasing over the Web: Compressed project schedules will push contractors to use the Internet at the job site to order building materials for next-day delivery.

⑥ Lower risk changes services: Smart insurers will use this lower risk to expand margins. Similarly, financing will be easier to get for a lower risk building project.

7. CONCLUSION

In this study, the author looked at typical construction supply chain and interviewed each participant in hope of gaining insight from all constituents and providing feedback for areas of improvement. The goal was to identify these areas of improvement without altering the existing supply chain. In order to analyze the supply chain for the construction industry, an urban office building was selected as a representative project and interviews were concentrated on electrical/mechanical systems.

It was observed from the interviews that in construction, many of the deals are based on responsiveness, quality, and personal relationships but not strictly on price. Also, the sheer variety of construction projects and nature of associated services make it difficult to obtain data. For these reasons most of the information provided in this paper is based on a qualitative study instead of a typical quantitative approach.

This paper provided insights for the general supply chain of the construction industry and the relative complexity that a typical construction company in US faces in managing its supply chain. The performance measures used at each node of the supply chain and the uncertainty seen by each participant were examined. The author also probed how management incorporates the results and the reactive measures to deal with these issues. The recommendations are focused on the restructuring and automation of construction supply chain management process. The author suggested quantifiable performance measures, incentives, and their alignment with each other. The improvements in the efficiency of the supply chain in terms of communication, bullwhip effect (Lee et al., 1997), integration, and cost are also suggested based on information sharing, collaborative planning, bidding based forecasting, and project management.

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Company Name	Location	Type
Swinerton & Walberg	San Francisco, CA	General Contractor
Centria	Pittsburgh, PA	Mechanical Manufacturer
Rosendin Electric	San Jose, CA	Electrical Subcontractor
City Electric Supply	Oakland, CA	Electrical Supplier(Commodity)
WESCO Distribution	Pittsburgh, PA	Electrical Distributor
Scott Co. Mechanical	San Leandro, CA	Mechanical Subcontractor
Norman S Write	Brisbane, CA	Mechanical Supplier
Marelich Mechanical	Hayward, CA	Mechanical Subcontractor

요 약

본 연구에서는 건설 프로젝트에 대한 공급사슬 관리 측면에서의 분석을 통하여, 프로젝트를 구성하는 전반적 구성 요소들에 대한 심층적인 이해와 이의 개선 방안을 다루고 있다. 이러한 건설 공급사슬 관리 차원의 효율성 향상을 도모코자, 본 연구에서는 미국의 일반적인 고층 사무 빌딩 프로젝트에 참여하는 실제 공급사슬 구성원들과의 인터뷰를 통하여, 건설 프로젝트 관리에 대한 공급사슬 관리 맥락에서의 정성적인 분석을 시행하였다. 본 연구는 전기 및 기계 분야 공급사슬을 중심으로 하여, 공급사슬을 구성하는 하도급 업체, 공급자, 제조업체 및 유통업자의 역할을 조사 하였고, 아울러 원도급 업체가 프로젝트 관리 상에 직면할 수 있는 문제점들에 대하여도 파악하였다. 이를 토대로 본 연구에서는 크게 프로세스 재구성(restructuring)과 자동화(automation)라는 개념에 의거한 개선 방안들을 제안하였으며, 인터뷰를 통해 조사된 현황 파악 척도 및 인센티브 제도와의 조율 방안을 제시 하였다.

키워드 : 건설 프로젝트, 공급사슬 관리, 정성적 분석, 인터뷰