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LEAN METHODS IN CONSTRUCTION

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ABSTRACT

The Construction Industry has traditionally been one of the largest in the United States; employing approximately 6.7 million people in November 2000, with a new construction value of over $800 billion dollars. While other industries have greatly increased their levels of quality and performance, the majority of construction work is based on antiquated techniques, attended by supply-chain deficiencies and high defect rates resulting in wasted labor and materials. Estimates indicate that up to 30% of construction costs is due to inefficiencies, mistakes, delays, and poor communications. As global competitiveness increases, so will the expectation of higher levels of quality and productivity in constructed facilities, placing the U.S. construction industry at a competitive risk. This paper describes the obstacles to high performance, productivity and quality initiatives and describes how lean techniques may be applied to overcome these shortcomings. A framework is proposed for providing technical support for lean methods application, and for continuous improvement in the associated activities.

KEYWORDS

Supply Chain Management, Lean Construction, Just-in-Time, Quality, Value Stream

1. INTRODUCTION

The US Construction Industry includes more than 2 million architectural firms, general contractors and construction management firms in the US alone. US construction productivity declined by 0.79% in the period 1995 to 1999, signaling the need to utilize new approaches for increasing the value added by workers in the construction process.

Although both manufacturing and service industries have emphasized the importance of competitiveness and implemented quality and performance improvements, the majority of construction work is based on antiquated techniques. Research has pointed to a significantly high level of wasted resources in the construction industry – both human and material. An article titled "Construction and the Internet" in The Economist of January 15, 2000, noted that up to 30% of construction costs is due to inefficiencies, mistakes, delays and poor communications.

Clearly, new approaches are urgently required to address the construction industry's ills.

As was stated in a recent Berkeley-Stanford conference, construction research needs a greater sense of mission, focus and industry support. The industry was said to need more research and development, and to move beyond a reliance on historical surveys to identify new approaches to get the job done.

As a whole the US construction industry has lagged far behind other industries in terms of the standards for quality achievement represented by the Malcolm Baldrige National Quality Award. A diverse group of world-class companies have won that award since its initiation in 1987, yet no awards have been made to construction organizations to date.

The need for innovative methods to improve construction performance is underscored by the ongoing and anticipated shortage of skilled labor in an industry that is highly labor-intensive. The traditional sources of workers - vocational school programs and apprenticeships have not been keeping up with the demand. In the area of technicians and equipment operators alone there is a projected shortage. The Associated Equipment Distributors of Oak Brook, Ill. projects a shortage of 15,000 technicians over the next five years.

According to Maeda and Maeda, (1997), the construction industry differs from mass production manufacturing in several major ways. Products are made in response to individualized orders and the same design is infrequently used more than once. The location of production is not constant and differs from one project to the next. Owners often commission architectural design and construction separately; the working relations between the architect/engineer, contractor and subcontractors vary on a case-by-case basis. The organization of and facilities for production are dispersed after project completion. In addition, at completion, different people appraise each structure in different ways

2. CHALLENGES FACING THE CONSTRUCTION INDUSTRY

The concept of construction performance does not emphasize productivity and quality initiatives. The work of many researchers has revealed an industry tendency to measure performance in terms of the following: completion on time, completion within budget, meeting construction codes. Very little attention has been directed to owner satisfaction as a performance measure.

There is a growing emergence of subcontracting. The subcontractors are often priced in a manner that does not reflect the contract with the owner - even if the owner pays a high price, the subcontractor may still have to work with inadequate budgets, often compromising quality as a result.

Poor communication. Communication tends to be via the contract. Essentially, the designer is paid to produce a design expressed in the form of specifications and drawings. The contractor is expected to use these as a means of communication, and produce the completed facility. This communication often does not work as well as it should.

There are large gaps between expectations and results as perceived by construction owners. Symbolically, Value (V) = Results (R) minus Expectations (E). Consequently, since expectations often outweigh the results, construction owners feel that they receive less value than they should. Forbes, 1999, quantified the "gaps" or dissonance zones between the three parties to construction, i.e., owners, designers, and contractors in health care facilities projects. In the area of owner satisfaction factors for example, public owners and designers differed on 7 of 9 criteria, owners and contractors differed on 5 of 9 criteria, while designers and contractors disagreed on the relative importance of 2 criteria.

Slow adoption of innovation - small contractors often lack the expertise or financial resources to adopt technological advances - adoption is inhibited further by fear and uncertainty. Roofing contractors, for example, tend to use the same time-honored methods to ensure that supplies and equipment are on site each day. Expediters, at additional cost, deliver items that are frequently forgotten.

Needed training often does not get to the decision-makers in the construction industry. Construction management programs around the country have been providing higher levels of training for managers - however, this training has not reached the ultimate decision-makers in the industry. Efforts to enhance quality and productivity are likely to be frustrated under this scenario.

Owners have not specifically demanded productivity and quality. There is a general lack of productivity/quality awareness in the industry among all parties, including owners. Owners have come to accept industry pricing - they have not been able to influence the productivity of the industry - prices have simply become higher on a per unit basis. By contrast, manufacturing activities have become cheaper over time on a per unit basis.

Architect/Engineer contracts are said to be unclear with respect to professional standards of performance, often leading to unmet expectations. Construction owners feel that typical A/E contracts protect designers at the owner's expense. For example, prevailing contract language relieves designers of any role in the case of a lawsuit or arbitration between an owner and contractor. An outgrowth of this is the practice of "substantial completion" where a job is usable but has 5% of the remaining work in the form of a "punch list". An owner often has a very difficult time in persuading a contractor to finish that work.

Few large companies, and virtually no small companies have implemented the concept of a quality or productivity manager - cost cutting trends have resulted in such a position being viewed as an unjustifiable luxury.

There is little, if any, benchmarking - many manufacturers and service organizations have become pre-eminent by adopting the best practices of benchmarked organizations. - Construction has done very little of this -due to distrust, fear of losing competitive advantage, but more likely, simply by being anachronistic.

2.1 Proposed Solutions to Construction Performance Problems

Many interrelationships exist in a number of techniques that represent significant potential for improving construction processes. Lean construction maximizes value and reduces waste and applies specific techniques in an innovative project delivery approach including supply chain management and Just-In-Time techniques as well as sharing of data in a consistent format. Lean manufacturing is an outgrowth of the Toyota Production system that was developed by Taichii Ohno in Toyota in the 1950s. Ohno had observed mass production at Ford and recognized that there was much waste everywhere. Ohno identified seven wastes in mass production systems – overproducing, waiting time, transporting, processing itself, having unnecessary stock on hand, using unnecessary motion and producing defective goods. The Toyota Production System was based on the "Just – In – Time" (JIT) philosophy; its three tenets were: Minimizing waste in all forms, continuous improvement of processes and systems, and maintaining respect for all workers. Its benefits are reduced inventories (and space) higher human productivity; better equip product and utilization, shorter lead times, fewer errors, and higher morale. In the mid – 1970's Toyota reduced the time needed to produce a car from fifteen days to one day, using JIT. Omark Industries, one of the earliest US companies to adopt the Toyota Production system was able to reduce machine setup time from 8 hours to 1 minute and 4 seconds. Overall, JIT facilitates lower costs, shorter lead-time and cycle time, while quality is improved.

Supply Chain Management (SCM) emerged as part of the Just in Time delivery system developed by Toyota; its primary focus was logistical to control the interface between suppliers to Toyota, to provide supplies precisely on time, in needed quantities. SCM effected major economies by reducing inventories. SCM has been developed further as a management concept beyond its logistical roots and incorporates features of JIT.

JIT is best used in a repetitive production system, such as a flow shop. The Japanese concept is to make goods "flow like water", to provide low cost and consistent quality. This is more difficult with a job shop like construction, but several benefits are still possible - – the concept calls for raw materials and components to reach a production operation in small quantities when needed and not before – supplier and customer have to work closely for this to occur. The result is fewer inventories of raw materials, less work in process and better lead times. However, according to Besterfield et. al. 1999, inventories may fall to critically low levels, so it requires suppliers with outstanding quality products and services.

Whereas mass production is a push system that dictates production volume based on market forecasts, Just in Time is a pull system that responds to actual customer demand. In essence, products are "pulled from " the JIT system. JIT only commits the resources needed to meet the customer's needs

2.2 Construction Application of JIT

Construction poses special challenges to the application of JIT. Whereas in manufacturing many products are generated repeatedly, most construction involves a single, unique product that is made only once. (Manufactured housing may be more similar to the manufacturing environment in that regard). The variability in construction may be high- due to the large numbers of participants as may be seen in a typical construction project, changing customer wants may emerge in the form of change requests, large numbers of components, lack of standardization

JIT, as applied in manufacturing, eliminates safety stock between stages (or work stations) in a process. A failure in any stage requires a work stoppage to investigate the root causes of problems and resolve them, instead of passing on defective work to the next stage. This leads to better processes with less waste between them. As described by Howell et al 1994, construction variation may be reduced with two types of buffers: plan buffers and to a lesser extent schedule buffers. Schedule buffers may take the form of equipment or materials, which require time to execute. They allow time to be used productively, but do not address the root causes of variation. On the contrary, plan buffers are planned assignments that prepare for succeeding stages; they delineate the assignment of the workforce to specific jobs

Howell et al recommend placing schedule buffers immediately following processes that have a variable output, such as between engineering and fabrication. This allows design adjustments to be made. On the contrary, a schedule buffer should not be placed between fabrication and installation.

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2.3 Lean Methods in Construction

Lean production or lean thinking is based on a philosophy of making improvements that stress cost effectiveness, reducing "muda" or waste (Womack and Jones, 1996). Ohno's system coordinated the flow of materials on a day-to-day basis so that the parts would only be produced at each step to meet the immediate demand of the next step. Howell (2000) describes Lean construction as a new way to design and build capital facilities. Lean theory, principles and techniques, jointly provide the foundation for a new form of project management. It uses production management techniques to make significant improvements particularly on complex, uncertain, and quick projects. Lean methods have reduced office construction costs by 25% within 18 months, and schematic design time from 11 weeks to 2 weeks (Garnett et. al. 1998).

Lean construction departs significantly from current project management practice. Processes are actively controlled, and metrics are used in planning system performance to assure reliable workflow and predict project outcomes. Performance is optimized at the project level. Whereas current project management approaches reduce total performance by attempting to optimize each activity, Lean construction succeeds by optimizing at the project level, as opposed to the less effective current project management approaches, which reduce total performance by attempting to optimize each activity.

Lean methods focus on value, i.e., what is important to the customer. This value may be identified through the use of techniques such as Quality Function Deployment (QFD). The value stream shows when and how decisions have to be made. Process flow charts can be used to represent the value stream map by starting at the project level and then reducing to the activity level, showing where waste exists in a process. Lean methods may call for portions of construction work to be packaged so they can proceed without the completion of other work. This approach therefore eliminates areas where value-adding work is interrupted.

2.4 Construction Supply-Chain Management

The term supply chain encompasses all the activities that lead to having an end user provided with a product or service – the chain is comparable to a network that provides a conduit for flows in both directions, such as materials, information, funds, paper, and people. Studies by Bertelsen, 1993, indicated project cost increases of up to ten percent because of poor supply-chain design. Supply Chain Management (SCM) analyzes the impact of facility design on the construction process and enables superior project planning and management, avoiding the fragmented approach of other methods. Through SCM, all parties are kept aware of commitments, schedules, and expedites – all work as a virtual corporation that can source, produce, and deliver products with minimal lead time and expense. SCM application needs to be tailored to the conditions in the geographic area and environment in which projects are executed. Construction supply chains are subject to inefficiencies caused by interdependency with causes in various stages of the chain, primarily due to self-serving actions by individual companies and organizations, as well as divisions of the same organization.

Three case studies were examined in the Netherlands and Finland, to apply different methods of analysis. (Vrijhoef and Koskela 1999). The breakdown of the cases was as follows:

Case 1 – the installation of concrete wall elements in residential construction. Time buffers in the supply chain were quantitatively assessed.
Case 2 – the façade elements in residential construction. The control systems in the supply chain were qualitatively evaluated.
Case 3 – a study of the cost impact of the contractor's method of materials acquisition.
The results were informative. Large time buffers developed that were 70 – 80% of the total lead-time. Controllability problems were caused by the parties near the beginning of the chain separate from the activities being studied. This

excessive value was caused by adversariness between the parties, and lack of goal congruence. These results pointed to self-interested actions by the parties.

(Vrijhoef and Koskela 1999) propose a 4-stage approach similar to the Deming Cycle to improve organizational performance: Supply chain assessment, supply chain redesign, supply chain control, and continuous supply chain improvement. This involves first evaluating a supply chain to identify waste and problems and determine root causes. The supply chain is then redesigned to address shortcomings, using analytical and feedback systems to monitor system performance, measure waste and apply corrective measures. This is followed by continuous improvement.

2.5 Information Technology

The knowledge economy provided by the Internet, the intranet, and the extranet, is expected to have an explosive impact on the construction industry over the next twenty years. Veeramani and Russell, 2000, visualize five business areas that will be affected by these media, i.e., what impacts there will be on products, processes, organization, a supply web and complementary partners, and the life cycle in time for the foregoing four factors. The authors anticipate that business model optimization of these five dimensions will lead to competing actions between maximization of wealth, quality/safety, responsiveness, sustainability, asset utilization, and minimization of time and risk. Veeramani and Russell point out, very importantly, that academia and the industry will need to collaborate in developing an appropriately trained workforce to meet future needs.

2.6 Post Occupancy Evaluation (POE)

Post Occupancy Evaluation involves a review of completed facilities to identify how well they meet the original design intent, and also to determine how well they serve the users. This technique is far from new, but it needs to be revisited and utilized in order to provide learning from previous projects. POE represents the STUDY phase of Deming's PDSA Cycle. Without that critical step, the construction industry is denying itself of the important feedback that is needed for continuous improvement. A national survey of Health Care Facilities' construction by the principal writer indicated that fewer than 5% of projects involved Post Occupancy Evaluation, even though other respondents agreed that the technique was beneficial as a continuous learning tool. POE information could be maintained in a centralized database for research purposes; it would identify specify project success factors for future consideration.

2.7 Implementation Issues

For effective deployment of corrective measures, the following inhibitors need to be borne in mind:

Many projects have waste and problems in the supply chain. However, this is often invisible as separate parties focus on their immediate responsibility and act in their own self-interest.

Problems tend to arise in early phases of supply chain, and waste is caused mostly by parties to construction that often are not alerted to the consequences of their actions.

Comparisons with previous research (Jarnbring (1994) on supply chain management of construction projects in Sweden indicated a potential for cost savings of 10% to 17% - due to inefficiencies caused by lack of coordination between contractors and suppliers.

Koskela and Leikas 1997, observed a typical shortcoming in the industry resulting in excessive variation – construction components often ordered with incomplete or missing information

Several researchers posit that collaboration between contractors and suppliers would yield significant savings as it would reduce the tendency of each to include a buffer, resulting in large cumulative effects, but this is counteracted by an industry tendency to hire contractors on the basis of price as determined by Wegelius et al, 1996, Jarnbring, 1994.

The following proposed techniques have been well established in the manufacturing and service industries, and have been proven to be highly effective. For successful implementation in the construction arena, a support system will need to be provided. This support system must include professionals who have a thorough understanding such techniques as supply chain management, Just-In-Time principles, value stream mapping, quality-based continuous improvement, and Post

Occupancy Evaluation. Most of these techniques lie within the skill set of industrial engineers. It is therefore proposed that one or more industrial engineer(s) or related professionals be appointed to the position of Lean Methods Expert (LME).

2.8 Structure of the Proposed Framework for Lean Methods Implementation and Management.

Organizational relationships

Figure 1 illustrates the proposed framework. The parties to construction projects, i.e., owners, designers, and contractors (as well as their suppliers). The success of lean methods approaches is highly dependent on having a cohesive team working toward congruent goals and objectives. To accomplish this, a partnership relationship would be needed; it could be formalized with a binding legal agreement, or at least, the parties could informally resolve to maintain an amicable relationship. Given that background, the parties would be depicted as a "Construction Delivery Partnership", shown in the large oval. Both information and transactions would flow between the parties, as represented by the arrows. A web-based, or web-enabled information system would be required. Such a system would provide far more rapid information flow than is available in most prevailing construction management systems. In such systems, the parties typically have local or wide area networks to serve their immediate organizations. Web-based systems, on the other hand, are able to provide seamless intercommunication with other organizations' information systems without the interconnection problems posed by hard-wired systems. The reporting relationship would need to be determined by the parties, as the Lean Methods Expert provides support that benefits all of them. A large owner that has a large ongoing construction program could have a permanent staff LME. Also, since many of the activities directly benefit the contractor, that party could also have an LME function that could serve more than a single project at any one time.

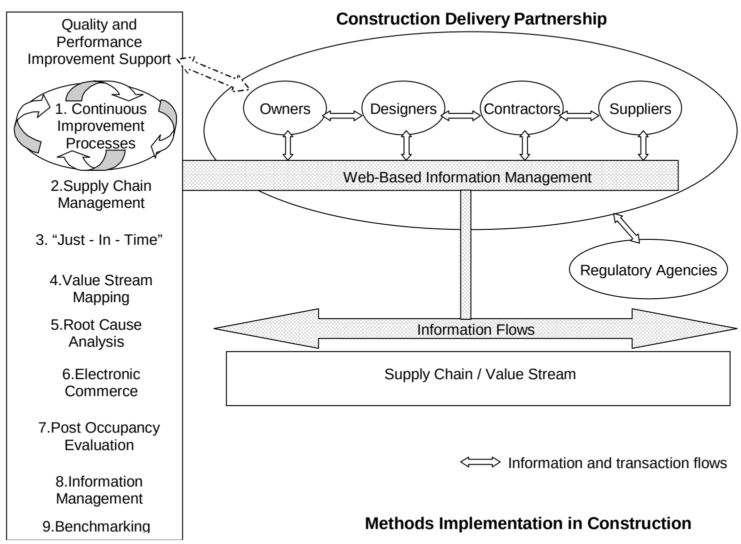

Figure 1: Proposed Framework for Lean

2.9 Information Flows

Information flows occur between the main parties; a hierarchy of security levels could be built in to keep a small number of items of privileged information under careful control. Contractor-supplier communication, for example, would make material delivery dates and quantities available to all of the other parties, although cost information would not necessarily be divulged. Nevertheless, Value Stream Mapping would be conducted with the unit prices recorded in the contract. Lean construction techniques would be deployed based on an analysis of the value stream.

Continuous improvement is required for the Supply Chain Management System – it needs to be analyzed for root cause analysis of problems, redesigned for improvement, and monitored for measurable results.

The design of the supply chain will need to be reconfigured, as sustainable construction becomes increasingly adopted. This will increasingly involve recycled construction debris.

2.10 Cultural Issues

A quality culture is needed for successful application of such techniques as Just-In-Time, Lean Construction, and Supply Chain Management to function. JIT, in particular, demands discipline, as there is no room for unreliable suppliers. JIT does not work in atmosphere of suspicion, distrust and internal competition. Consequently, all parties need to come together and share a unified mission for a project. In addition, training has to be carried out to familiarize participants with concepts and techniques. Overall, a comprehensive approach similar to Total Quality Management may be modified to fit the time frame of a project, in order to secure "hearts and minds" commitment to lean methods-based initiatives. In the prevailing industry climate, subcontractors pose a special challenge, as they need to be provided with Lean methods support; this approach surpasses the knowledge base of most of these small organizations.

3. CONCLUSIONS AND RECOMMENDATIONS

- Each member of the construction supply chain should be made aware of its influence on the overall project
- Partnering should be promoted to maximize team building and development of trust.
  Members should be empowered in decision-making to make these partnerships meaningful.
- Information systems should be upgraded to make maximum use of Just in Time techniques by providing instantaneous information to all involved parties. Internet-based technology should be used to provide seamless communication regardless of differences in hardware and location. State of the art software should communicate supply chain info, dates etc.
- A team approach is needed to bring together architects, engineers, contractors, so that all technical information is available for acquisition in the supply chain.
- Emphasize Total Quality Management approaches in the design process to improve design accuracy, contract document information to contribute more effectively to the value adding process in the construction supply chain
- Facility design should be performed with supply chain performance in mind as design factors drive performance. Design choices should favor appropriate technologies. Materials and components should be selected that best meet the needs of the supply chain discipline.
- The design of the supply chain will need to be reconfigured, as sustainable construction becomes increasingly adopted – logistics will include redeployment – on site – of recycled material.
- Require suppliers to establish quality assurance programs, including a Zero Defects program- analytical techniques must be taught and utilized to eliminate defects, as buffers are minimized

3.1 Issues for Future Research

A number of issues need to be considered for future research:

- Who should employ the Lean Methods experts?
- Can the Construction Delivery Partnership function without formal partnering?
- How can a contract be enforced with penalties when the parties are expected to share information openly?
- How can ground rules be established to identify project-appropriate disciplines such as JIT versus batch orders?

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