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Lean Construction Principles, Prerequisites, and Strategies for Implementation

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Abstract

The construction industry's inefficiencies and need for improvement are well documented. Research has pointed to an incidence of waste in the vicinity of 30%, due to a variety of losses including workforce underutilization, cost overruns, late delivery, safety-related incidents, and construction defects. As the annual value of construction worldwide is approximately US$4.0 trillion, the potential for savings in that industry is indeed great. Several researchers (Howell, Ballard, O'Brien et al) have shown that lean construction techniques reduce supply chain losses, reduce construction costs and shorten project delivery schedules. This paper addresses lean principles, the prerequisites for a lean construction environment, and provides specific strategies for successful lean projects. It will explain how these strategies improve projects in terms of cost, schedule, safety, and quality.

Keywords

Lean construction, Quality, Waste, Relational contracting, Lean project delivery

1. Introduction

In the past 20 years, manufacturing industries have greatly improved their competitiveness through the use of lean manufacturing methods and Just-In-Time techniques. These organizations have improved their production processes to satisfy customers' needs, improve product quality and maximize operational productivity. These approaches have also been implemented in the service sector. Despite the advances in innovation seen in the manufacturing and service industries, the majority of construction work is still based on time-honored techniques, attended by fragmentation (due to increasing sub-contracting), supply-chain deficiencies and high defect rates. These factors typically result in wasted labor and materials. Research studies attribute waste in the construction process to inefficiencies, mistakes, delays, and poor communications. 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. Studies by the Construction Industry Institute identified that 10% of project cost is typically spent on field rework.

Waste in the construction process occurs mostly in the interaction between trades, and in the hand-offs of work from one trade to another. In effect, each member of the supply chain acts in self interest to obtain local optimization; yet this action does not ensure that the overall project is optimized. Construction industry practitioners have been continually seeking to apply better technologies and processes to improve project delivery, but change has come very slowly because of the lack of a unified strategy, and because there is little incentive to change. Most construction contracts place the parties to construction in adversarial roles, although approaches such as "design-build" and "partnering" have diminished this challenge to a limited extent. Most recently, initiatives such as Lean Project Delivery (LPD) and Integrated Project Delivery (IPD) have been adopted successfully on a relatively small number of projects. This success has been largely attributable to the interest of willing project owners who have set the stage for the close integration between all parties that is needed to create a so-called Lean environment. Although the parties to a construction project are interdependent, they tend to make decisions independently, based on their own requirements. Nam and Tatum (1992) point out that industry specialization has separated designers from the management of the production process, and that this situation is perpetuated by the potential legal ramifications of apportioning project risk.

2. Lean Construction

Lean construction is a new construction approach based on the lean production methods that have been used successfully in the Toyota Corporation for many years (Howell, 2000). 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 the open sharing of information and close collaboration between all the parties involved in the production process. Lean manufacturing is an outgrowth of the Toyota Production system (TPS) that was developed by Taichii Ohno in the 1950s (Womack *et al.*, 1990). Ohno had observed mass production at Ford Motor Corporation's manufacturing facilities in the U.S. and recognized that there was much waste (muda) everywhere. Ohno and Shigeo Shingo, an industrial engineer at Toyota identified 7 wastes in mass production systems:

1) Overproducing
2) Idle time waste - waiting time/queue time
3) Transporting/conveyance waste
4) Processing waste – waste in the work itself
5) Inventory waste - having unnecessary stock on hand
6) Wasted operator motion - using unnecessary motion
7) Producing defective goods – waste of rejected production.

Ohno sought to develop a delivery process that met customers' needs with very little inventory. However, working without inventory meant that the production line had to speed up, and every person involved it in that process had to improve their skills in order to accomplish the production targets.

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. It is important to note that Ohno's improvement of Toyota's production process was not necessarily a new technology, but rather the result of involving all participants in a new philosophy of avoiding waste of any type.

A hallmark of the Toyota Production System (TPS) was that it was able to produce a wide variety of vehicle types – luxury cars, small fuel-efficient cars, large trucks, and small trucks. This was done with a much smaller customer base, and with a much shorter average model life cycle – four years versus ten years. In essence, the TPS was demonstrated to be the world's most competitive automotive producer.

a) Koskela (1992) addressed the application of manufacturing techniques to construction. His study, titled "Applications of The New Production Philosophy to Construction" drew parallels between both fields by characterizing construction as a form of production. He looked to the manufacturing industry for a new direction for construction. Koskela (1992) proposed a new approach that was not based on technology, but rather on the principles of a production philosophy - . Tools, such as kanban and quality circles, a manufacturing method, a management philosophy (Lean production, and JIT/TQC etc.).

He noted its evolution through three stages:

b) Tools, such as kanban and quality circles

c) A manufacturing method

d) a management philosophy (Lean production, JIT/TQC, etc)

Koskela inferred from a number of productivity- based studies on US and European manufacturing plants that the most successful methods were based on the JIT philosophy. Howell *et al.* (1993) addressed the combined impact of work flow variability and dependence, and their implication for the design of operations. Howell *et al.* (1993b) discussed uncertainty in project ends and means. In 1994, Ballard and Howell (1994) published measurement data on work flow variability.

The Last Planner system was developed by Ballard (1994), and further refined in 2000 (Ballard, 2000). This refinement focused on managing flows in the construction process, involving the use of buffers to limit the impacts of variability in the process, using the principles embodied in the Toyota Production System (TPS).

Lean design and construction involve the application of lean methods/techniques to the design and construction processes, in order to derive the benefits that have been clearly established in manufacturing operations. Howell (2000) explains that Lean theory, principles and techniques, jointly provide the foundation for a new form of project management. Lean construction 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. The benefits include lower costs, fewer delays, less uncertainty, and less waste.

3. Principles of Lean Construction

The Lean construction philosophy views a project as a promise delivered by people working in a network of commitments (Howell and Macomber, 2005). Smooth work flow is dependent on having the parties to construction make promises to carry out assignments, and keep their promises. Reliable promises downstream enable others, especially upstream to make reliable promises as well, in anticipation of predictable workflow. When all the parties keep their promises, waste is reduced, productivity is increased, and projects can be completed more rapidly.

Five Lean principles described by Womack *et al.* (1996) apply to any organization. These principles are:

1. Value: It is critical to identify the value actually desired by customers, and provide it.
2. Value stream: Mapping the value stream for each product or service exposes waste and facilitates its removal; establishing cooperation between the participants and stakeholders results in lean processes.

3. Flow: Business, job site, and supply flows depend on the value stream analysis and their own nature.
4. Pull: Under the lean transformation, the efforts of all participants are to stabilize pulls during the construction process.
5. Perfection: Strive for perfection, although it may never be achieved. Develop work instructions and procedures, and establish quality controls.

Value-adding activities transform materials and information into products and services needed by the customer. Value is not necessarily economic; in the process environment it is obtained when desired products and services are delivered.

Promise-keeping by the parties is an essential behavior for lean construction. It is a critical requirement in the Integrated Form Of Agreement (IFOA) for Lean Project Delivery (Lichtig, 2005). At the level of weekly work plans the trades in question must be aware of the scope of upcoming assignments. They must use this knowledge to determine the resource requirements – labor, equipment, materials, information, etc. Above all, they should ensure they can deliver on their promises.

The Last Planner System is one method for applying lean techniques to construction. Control is defined as "causing events to conform to plan" as opposed to the construction tradition of monitoring progress against schedule and budget projections.

Supply chain management is an important support function for facilitating lean construction. It is an integral component of the TPS. The construction 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. 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. Through SCM, all parties are kept aware of commitments, schedules, and expedite – all parties work together as a virtual corporation that can source, produce, and deliver products with minimal lead-time and expense.

Howell (1999) stresses the importance of reliability as a requirement for building trust in the members of without interruption. As opposed to traditional practice, lean isolates workers from variability by providing a workable backlog.

4. Prerequisites for Lean Construction Implementation

a) A willingness to change is essential: Lean methods are a departure from conventional methods and their adoption requires changing the behavior of people. Cultural change is the most compelling quest along with the physical transformation of an organization. One cannot force change on people – They have to be engaged so that the intrinsic satisfaction of outstanding performance will motivate them. In a lean culture, people have to be treated as the only appreciating asset. Lean enables organizations to have responsiveness, reliability and relevance.

b) A commitment to training and learning: Stakeholders at all levels need to be trained in lean techniques in order to become successful participants in lean projects. Lean implementation also requires that completed assignments have to be continually examined as a source of learning for future improvements instead of being a search for sources of blame.

c) A quality-oriented 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.

d) A “Shared vision” is essential to have all stakeholders on the same page. Macomber and Howell (2005) promote the importance of a “shared vision” in which a work force aligns itself with the direction set by a leader. This alignment is far different from carrying out orders. It is based on a sharing of beliefs and a common view of a future state that benefits everyone and makes them receptive to the changes necessary to reach that future state. In the case of lean construction the shared vision would lead to a “Lean mind”. A Study Action Team ™ (SAT) is recommended to develop the shared vision. Members start as a reading group and focus on learning as much as possible in order to bring about change. The SAT members would be volunteers from various groups involved in construction.

e) A commitment to reducing or eliminating waste is a fundamental principle of lean construction (Polat and Ballard 2004). A commitment to improving safety is critical to lean implementation as construction accidents are rivalled only by mining; In 2003, there were 1131 fatal accidents and 408,300 nonfatal injuries and illnesses in the construction industry.

f) A commitment to cost and performance measurement. These measurements are important indicators of the impacts of lean in construction projects. Benchmarking is based on comparing performance with other organizations (Alarcon *et al.*, 2001). Measurements of percentage projects complete (PPC) are essential as a foundation for continuous improvement.

g) A willingness to implement lean during the design stages: The Lean Project Delivery System LPDS is an integrated model that links designers with constructors and that enables them to go beyond the norms of traditional practice to include elements of construction process design in their scope of work. Lean designers also engage in “Target Value Design” to meet the client’s value proposition within a defined budget. This early commitment of additional design resources improves constructibility and overall project performance.

h) Collaborative relationships: Lean requires close collaboration between the parties. The standard forms of contract are adversarial in nature. Relational contracting is a transaction or contracting mechanism that apportions responsibilities and benefits of the contract fairly and transparently, based on trust and partnership between the parties. It provides a more efficient and effective system for construction delivery in projects that require close collaboration for execution. Working relationships between the stakeholders are improved, and the improved efficiency and reduction in conflict lead to improved financial returns. The most significant factors that underlie relational contracting are co-operation and dependency between the parties.

i) Information technology makes it possible to effectively manage the construction process to transform physical resources such as money, materials, manpower and equipment. Integration is greatly improved by the sharing of information between the parties. Building Information Modeling (BIM) is a technology that affects many economies in construction projects (Eastman *et al.*, 2008). It makes a reliable digital representation of the building available for design decision-making, high-quality construction document production, construction planning, and performance predictions, and cost estimates. Having the ability to keep information up-to-date and accessible in an integrated digital environment gives architects, engineers, builders, and owners a clear overall vision of all their projects, as well as the ability to make informed decisions faster.

5. Strategies for Implementation

There are several subsets and components of lean that can be incorporated in an implementation strategy. Lean design concurrently defines the facility to be constructed and the method or process to be used in building it. It comprises conceptual design, process design and product design. Whereas traditional practice excludes contractors from the design process and obstructs valuable product design information, lean construction advocates simultaneous product design and process design. Cross-functional teams – including architects/engineers, contractors, and subcontractors are brought together in that scenario. BIM enables contractors to minimize or eliminate conflicts between various building systems, reducing one major source of waste. BIM design information can also enable contractors to generate procurement information to meet material supply requirements.

Target costing involves building to a specific budget. The budget is allocated to various facility systems and cross-functional teams collaborate to work within those limits. A critical requirement is for cost estimating to keep up with the design work as it progresses – with very frequent real time updates.

Designing to a target cost or value is not intuitive to the construction industry – the "thermostat" approach is typical, where deviations result in corrective action. Given the sequential approach to design development, it is not unusual for cost projections at various design phases to exceed budgets. Historically, designers have sought to make modifications to reduce cost – such as value engineering, often to the detriment of earlier design efforts.

Set based design - a design management approach that defers design decisions to the "last responsible moment" to allow for the evaluation of alternatives for the construction process that improve constructability.

Relational Contracting enables lean construction and provides a platform for lean project delivery, integrated project delivery and other lean initiatives. Two contract types have some similarity to Relational Contracting, but have significant differences. Partnering has been used both as an individual project mechanism and as a long tem strategy. Alliancing links the owner/client with the contractor and supply chain, usually in a long term relationship. Relational contracting differs by being based on the linking of interdependent parties to improve the value chain.

There are many possible scenarios to describe the interaction between the parties in relational contracting. In the case of the Lean Project Delivery Method (Matthews and Howell, 2005) the basic requirements can be met by: a) creating a business entity that incorporates designers, contractors, and subcontractors. A contractual agreement binds the members of the business entity together. In effect, it is a design-build team, but it is held together by a single "pact". b) having the parties serve as business entities in their own right and held together through a relational contract or Integrated Form of Agreement (IFOA).

The parties are "Core Group" Members (CGMs). There may be other subcontractors that are not CGMs and they are selected by the CGMs. The client has a single prime contract with the IPD team. This contract may be of the traditional type that defines scope, design and specification requirements, cost and schedule. The Integrated Agreement is also based on "Pull Planning" based on the Last Planner system or equivalent. Financial risk is apportioned between team members such that profits and losses are shared between team members without any focus on sources of blame.

With Integrated Project delivery, a single business entity is created, that may comprise the architect/engineer, the general contractor, and primary subcontractors (Lichtig, 2005). These parties are termed Primary Team Members (PTMs). There may be other subcontractors that are not PTMs. The client has a single prime contract with the IPD team. This contract may be of the traditional type that defines scope, design and specification requirements, cost and schedule.

The Last Planner is based on three levels of schedules and planning tools:

- The master "pull" schedule serves as the overall project schedule, as contrasted with the detailed critical path schedule that is the more traditional management tool. In some cases, a critical path chart may also be used
- The look-ahead schedule reflects major work items that need to be completed for the milestone dates in the master pull schedule to be met. This schedule is usually based on a six to eight week time frame, and uses items "pulled" from the master pull schedule; they are carefully reviewed to ensure that they are free of constraints that cannot be removed within a given time.
- The weekly planner schedule delineates the work activities or assignments "pulled" from the look-ahead schedule that must be initiated to meet the completion dates in that schedule. Eligible activities or assignments are those that have no current constraints, and that have resources available and assigned.

The so-called Last Planner is the foreman or other professional who prepares the weekly planner schedule. This schedule also includes a buffer of work activities based on future work. The weekly accomplishment is measured as "Percent Planned, Complete (PPC). The pact between the PTMs ends when the project is completed and all terms and conditions of the prime contract are fulfilled, including warranty obligations. At that point, the profits are determined, adjusting for any cost overruns that may have occurred. The resulting profits are distributed to the PTMs based on the previously agreed-upon formula.

The reliability of the Last Planner System and Lean Construction in general, hinges on informed commitments in order to maintain the trust that is essential for avoiding waste. If subcontractor, Sub. B depends on Sub. A to have a work area available by a given day, then Sub. B should be able to mobilize crews for that day without the reservation that Sub A might not keep its promises. Should that occur, Sub. B could incur significant waste by having workers report for duty without being able to carry out the scheduled tasks? This waste would not only penalize Sub B., but would contribute to an ongoing spiral of distrust that characterizes traditional construction. Each trade schedules hesitantly, cautiously optimistic that other supporting trades may keep to the schedule, but often anticipating that that they not.

6. Conclusions and Recommendations

It is critical to break away from the tradition of treating project design and production as separate functions. Once production (construction) starts, it quickly becomes obvious that factors that have not been considered in the design phases are of major significance in the field. The concept of design for production should be implemented, using design consultants with relevant expertise.

The benefits of lean construction techniques have been demonstrated by the improved performance of many projects at each and every project phase. Lean construction may require more time in the design and planning phases, but this attention eliminates or minimizes conflicts that can dramatically change budgets and schedules.

Each member of the construction supply chain should be made aware of its influence on the overall project. Efforts should be made to gradually change the cultural approach to projects to improve effectiveness. For example, Fiallo and Revelo (2002) observed that in Ecuador it is difficult to introduce new construction planning and control systems. Contractors have a tendency to focus on finishing tasks as opposed to devoting more time to planning that would avoid the waste and misuse of resources in the overall project. This is probably true of some professionals in other regions as well.

Partnering should be promoted to maximize team building and development of trust. Team members should be empowered in decision-making to make these partnerships meaningful. An Integrated Form of Agreement (IFOA) should be adopted to make these collaborations legally enforceable.

Information systems should be upgraded to make maximum use of Just in Time techniques by providing instantaneous information to all involved parties. BIM technology should be enabled in order to facilitate the beginnings of lean design, involving contractors working in concert with designers. Internet-based technology should be used to provide seamless communication regardless of differences in hardware and location.

A team approach is needed to bring together owners, architects, engineers, and contractors, so that all technical information is available for acquisition in the supply chain.

Total Quality Management approaches should be introduced in the design process to improve design accuracy and contract document information to contribute more effectively to the value adding process in the construction supply chain

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