Design-Led Lean

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Abstract: Lean thinking is a concept begun in Japanese manufacturing that strives to eliminate all waste from a process while pursuing perfection in the finished product. Lean thinking has been applied to the construction process in the form of lean construction. However, traditional resistance by the construction industry to manufacturing ideas has limited the extent of lean construction. When used, lean thinking has been limited to only the design process or only the construction process. This paper introduces the idea of design-led lean as a method of improving construction performance by incorporating lean principles at the earliest stage of a project – design. The goal of design-led lean is to design a project in a way that avoids, reduces, or mitigates variability during the construction process in order to facilitate flow. Design-led lean builds on the constructability concepts identified by the Construction Industry Institute through the addition of flow considerations.

Key Words: Lean construction, lean production, constructability, design-build, design process, variability, flow

INTRODUCTION

The New Economy is creating unprecedented challenges and opportunities for the design-construction community. Owners of constructed facilities are demanding delivered projects in greatly reduced time frames (Koskeli et al. 1999, Songer et al. 2000, Strassman 1995, Tluazca and Daniels 1995).

Although owner demands may seem unreasonable, distinct competitive advantages are obtainable for companies responding to owner needs. Research conducted by the authors provides examples of companies finding ways to meet dramatically reduced project schedules without compromising quality or safety. These results combined with existing lean research documented at previous IGLC conferences suggest lean strategies as a mechanism for meeting the challenges of the New Economy.

Lean construction is a concept adapted from production management principles that strive for perfection while eliminating waste. The idea of lean production originated with Toyota in post-World War II Japan. The Toyota system of production was dedicated to eliminating waste, which Toyota engineers defined as mistakes, excess inventories, unnecessary processing steps, unneeded movement of people and goods, and idle workers (Womack and Jones 1996). In general, waste was any action or product that did not provide value to the customer.

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In its effort to eliminate waste, Toyota developed a production system that was comprised of five main principles – defining value, identifying the value stream, making production flow, pulling goods from the system, and pursuing perfection (Womack and Jones 1996). A key difference between the lean production model and the standard production models of that time period is that lean production shifted attention to the entire production system and away from craft and mass forms of production (Howell 1999). As it moved toward a zero-waste model, Toyota expanded improvement focus from production activities back into the design process and along the supply chains. Toyota engineers recognized that to develop a truly waste-free production system, they had to consider the design of the production process along with the design of the car (Howell 1999).

The general aim of lean production – optimize performance of the production system against a standard of perfection to meet customer needs – is also applicable to design and construction projects, including design-build, and traditional design-bid-build delivery systems (Ballard 1993, Howell 1999, Koskeli 1997, Tzortzopoulos 1999). In fact, some design and construction companies, like the Neenan Company, have accepted many of the principles of lean production and its pursuit of perfection. Historically, however, the construction industry has rejected many ideas from manufacturing due to the belief that construction is different than manufacturing. Design and construction is typically viewed as craft production of one-time designs, while manufacturing consists of mass production. Construction also differs from manufacturing in that each product is produced in a different location under uncertain environmental conditions. Manufacturing, by comparison, occurs in the same building under constant conditions.

How then, can lean principles be integrated into the design-construction industry? This paper suggests collaborative teaming approaches, which promote lean principles throughout the project life cycle. To accomplish this, the authors endorse a concept of design-led lean. Design-led lean is based on the concept that truly lean construction can only occur by designing the construction process concurrently with design of the building or facility. To achieve this end, design must be viewed as an integral part of the whole construction process instead of a separate product.

DESIGN AS AN END PRODUCT

Under traditional design-bid-build construction delivery and in many cases current design-build schemes, the design of the building is viewed as an end product. In the first step of this delivery process, the client contracts with an architect/engineer (A/E) to produce a complete set of drawings and specifications (the “design product”). The role of the A/E is viewed as highly creative to help the client achieve his or her vision of the final product (Gargione 1999). On the other hand, the construction phase is merely a transformation of the drawings into the final product.

The A/E is typically paid based on their ability to produce drawings and specifications that reflect the client’s vision. The value is defined as taking the client’s vision and transferring it to drawings and specifications. Therefore, most of the design time is spent creating unique, custom buildings specifically for each client. Little, if any, time is spent on analyzing how the building will be constructed, since most A/E’s (and client's) view this as part of the construction phase. The client, therefore, must pay for a design product before it is even known whether the constructed building will meet his or her needs. In this scenario, the true "value" to the client is at best an assumption that the final constructed building will meet his or her needs.

DESIGN AS A PROCESS FOR FLOW

By comparison, lean manufacturing relies on eliminating the barriers that require all products to go through the traditional system of product definition, design, and finally production. The reason lean manufacturing integrates design and production is to create an overall process that promotes flow (Womack and Jones 1996).

Once value has been defined and the value stream identified, the next step in the lean process is to make the value-creating steps flow. Flow is achieved when one works continuously on a product from raw material to finished product, with no waiting or batching at intermediate steps. To make a process flow requires a focus on the end product and its needs, rather than on the organization or equipment used in the production (Womack and Jones 1996). This concept of flow is radically different from the current transformation view of construction (Koskela 1999).

The separation of the design and construction phases in projects makes it difficult to create flow in the overall process. Because the A/E industry views design as a distinct process with its own product, there is little incentive to spend time and money on constructability issues. Instead, researchers have studied how to create flow within just the design process (Gargione 1999; Fabricio et al. 1999). Likewise, the construction industry has studied how to improve flow on the job site, but only after the initial design is completed (Ballard and Howell 1998; Ballard 1999).

However design-led lean in an interactive collaborative process creates a framework for creating life cycle flow. One example of design-led lean is the Neenan Company's construction of an addition to the American Water Works Association (AWWA) building in Denver, Colorado. At the start of this project, Neenan guided AWWA through the process of defining value and allowed AWWA to become the driving force during the design phase. The design team consisted of AWWA, subcontractors, and Neenan engineers and architects. All worked together identifying areas of waste, recommending design features and helping to ensure the defined value stream flowed efficiently. Because of the high level of information sharing, the design process was completed in two weeks, compared to a typical duration of eight weeks (Neenan 1999).

Implementation of the design was accomplished by continuing the application of lean principals started by the design team. One of the principles employed in the field was the concept of Last Planner (Ballard and Howell 1998). Last Planner allows the supervisors in the construction process to select the work schedule from workable backlog. This concept helped with overall flow by making it clear when each task would be completed. The results of this design-led lean process was a project that required no rework and was finished six weeks ahead of the original schedule. AWWA also estimated that it saved 11 percent on design and construction costs compared to a traditional construction approach (Neenan 1999).

The primary advantage of design-led lean is that it starts the lean thinking process early in the design, when it is less expensive to make changes and incorporate constructability concepts to reduce variability (Figure 1). Examples of variability at a construction site include inadequate design information, missing materials, and incomplete prerequisite work. Variability typically leads to increased costs, delayed schedules, and incorrect work. In all cases, variability does not add to the value of a project and often results in a project that does not meet quality requirements (Ballard and Howell 1998).

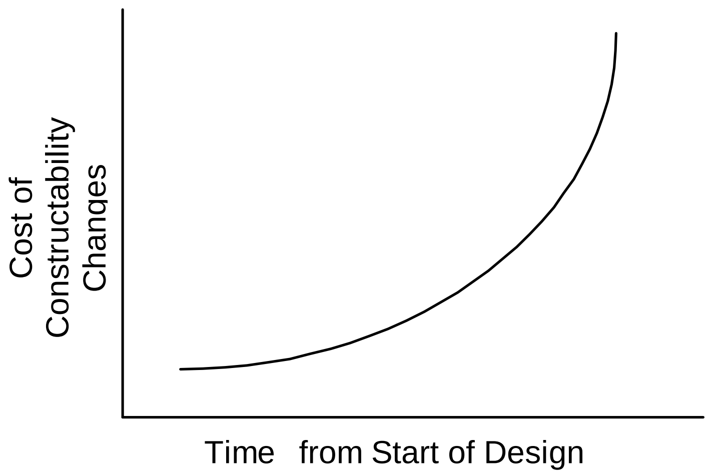

Figure 1 . Time versus Cost for Constructability

The importance of design considerations in overall project performance and quality was illustrated by investigating 30 projects whose performance dramatically exceeded traditional expectations.

IMPORTANCE OF DESIGN IN PROJECT PERFORMANCE

The authors' analysis of case study data of 30 exceptional projects indicates significant reduction in project duration and costs can be accomplished, when changes are made to traditional processes throughout the project lifecycle, including the design phase. These schedule and cost reductions were achieved with no negative effects on safety and quality. Schedule reductions ranged from 12 percent to 85 percent. For example, one exceptional project was completed in only 15 percent of the time (2 months) that a non-exceptional project would require (13 months). The cost reduction associated with the schedule reduction generally ranged from 40 percent to 52 percent.

Figure 2 illustrates the cost to schedule relationship for each exceptional project and each comparison project. Cost Fraction is the exceptional project total installed cost divided by the comparison (traditional) project total installed cost represented as a percentage. Therefore the vertical component on the graph illustrates the percent cost of the exceptional project compared to a traditional project of similar scope and complexity. The horizontal line represents 100 percent costs for a traditional project. Therefore, any project falling below the horizontal line on Figure 2 demonstrates a lower cost for the exceptional project than the comparison project.

Schedule Fraction is the exceptional project total duration divided by the comparison project total duration represented as a percentage. Therefore, the horizontal component of the graph illustrates the percent schedule duration of the exceptional project compared to a traditional comparison project. Note that all case study projects were completed in less time than their comparison traditional projects. A significant finding illustrated by Figure 2 is that 50 percent of all case studies demonstrated a DECREASE in cost with an associated DECREASE in schedule.

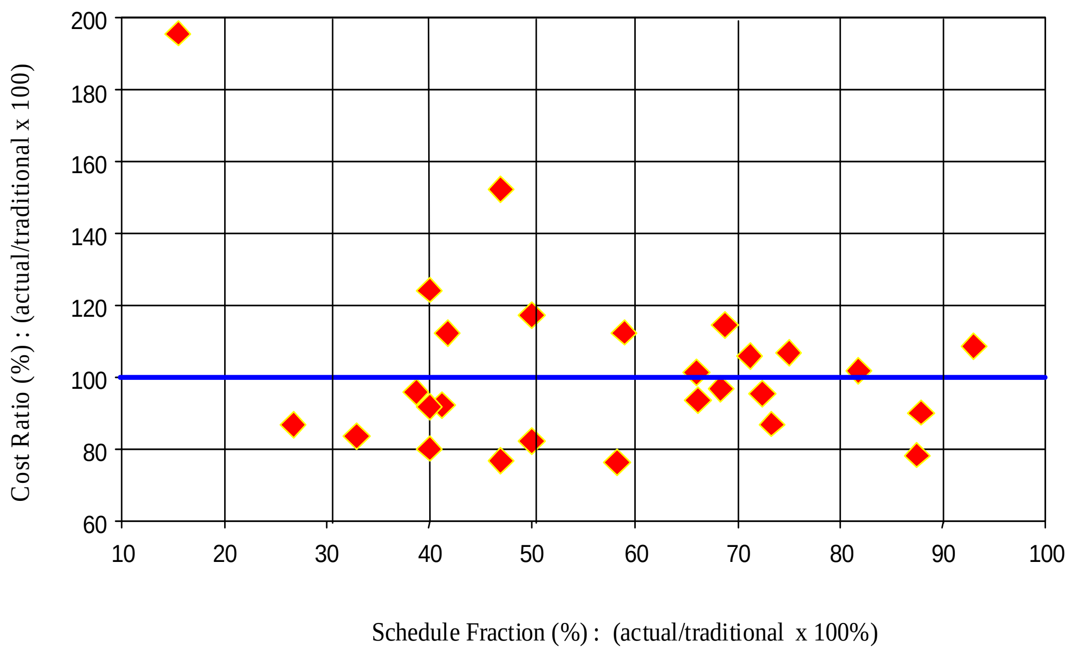

Figure 2. Decrease in cost with Associated Decrease in Schedule Demonstrated in 50% Cases

Determining why such dramatic schedule reductions occur on exceptional projects provides insight and suggestions for design-led lean. The research team investigated differences in work processes between exceptional and comparison projects. One interesting observation, which suggests to the researchers the important of design-led lean, was that 65 percent of process differences occurred in the early project phases (planning and design) of the projects. The significant schedule reductions reported, combined with the numerous work process differences observed in the planning and design phases, indicate that schedule reduction does not occur only from hard work but that it can result from decisions made during the early phases of a project.

Key planning decisions made on the exceptional projects established the organizational foundational for reduced project schedule. Decisions often involved policy changes such as using single contractors (design-build) or in some cases minimizing the bid phase by using a preferred contractor. Additionally, early planning decisions were made which focused authority and responsibility to the field level. These decisions were implemented by allowing greater authority of engineering and construction managers at the site as well as relieving engineers, constructors, and owner professionals of other “routine” responsibilities.

Differences between the exceptional projects and traditional EPC projects were also observed during other project phases. Differences in the engineering and design phases of the projects focused on improving communication and reducing traditional cycle times. Primary procurement phase process differences included the use of preferred subcontractors and vendors to eliminate the bidding process, locating engineers in fabrication shops to reduce submittal times by sequencing production schedules, placing purchasing agents at the field site, and using information technology to transmit information to project participants in a timely manner. Construction phase differences included multi-tasking by craftsmen, the use of alternate construction methods (i.e., mass excavation approach used in lieu of spot excavations), implementing separate teams to perform construction changes and not performing minor construction changes until the plant was constructed in conformance with original design. Start up differences included providing complete engineering teams to assisted the owner during critical start-ups, concurrent system start-ups and completing the project by "systems" for phased turnover. All of these changes suggest improvements in process flow. While no one work-process difference listed in the previous section was identified as the sole cause of significant schedule reduction, the cumulative impact of the engineer’s role and design process represented 30 percent of the schedule reduction. Figure 3 illustrates the impact of engineering and design on schedule reduction.

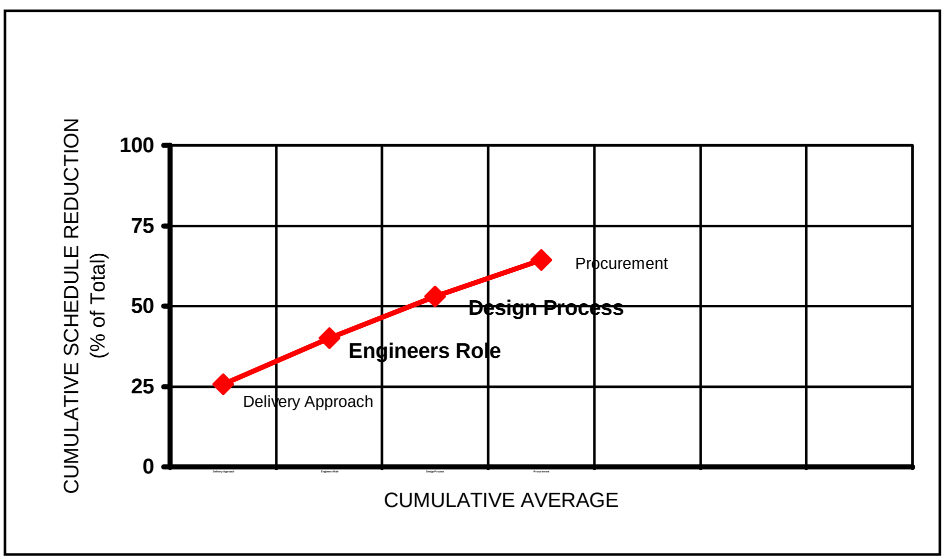

Figure 3. Top 4 Change Categories w/ Emphasis on Design

Engineer's Role - Exceptional projects are characterized by the establishment of engineering performed in the field or fabrication shops. Although the percent of designers re-located to field offices vary, the result of placing designers in the field is improved communications, reduced turn-around of reviews, reduced hand-offs, and rapid response to inquiry. To illustrate, one project located twenty of seventy-five designers at the field site whereas another project re-located 95 percent of its designers to the field. Yet another project placed an experienced engineer at the fabrication site 80 percent of the project duration. In addition to the above noted advantages, this action contributed to scheduling critical items to meet project needs, not fabricator schedule needs.

Such change from traditional designers at the home office contributes tremendously to schedule reduction. Although additional costs are involved in placing designers in the field, the net cost on the project is improved.

Design Process - Changes in traditional design processes contribute greatly to improved cost and schedule performance. Exceptional projects generally optimize use of pre-existing design, continuous reviews (vs. batch), reduction in design detail, and placing supplier personnel on the design team. For example, as reducing design detail was accomplished on one project by constructors "finger pointing" electrical runs to designers in the field. Designers were able to provide constructors with the appropriate level of detail required to install the wiring without excessive design detail.

One observation while investigating the exceptional projects was that in addition to the importance of a life-cycle view of process changes, an environment must exist within the project team, which promotes teamwork, empowerment, and no fear. This requires a fundamental overhaul of existing project organizations, which the authors suggest is essential to design-led lean.

IMPLEMENTING DESIGN-LED LEAN

The findings noted above suggest the importance of a full life-cycle approach for developing a lean design-construction environment. More significantly, designers and constructors can implement design-led lean through a process that focuses on creating flow in the value stream. In this manner, design-led lean is consistent with many of the themes of previous investigations on the constructability concepts (CII 1986). Although the inspiration and objectives of initial constructability research and lean production vary, many of the initial findings are relevant when considering a full life cycle design-led lean approach. Seven concepts of constructability that CII identified (many of which were seen in the exceptional project research) are as follows:

- Design and procurement schedules should be construction-driven;
- Designs should be selected to enable efficient construction operations;
- Standardization of design elements should be used;
- Designs that encourage modularity/pre-assembly should be sought;
- Designs should promote accessibility of all resources;
- Designs should facilitate construction under adverse weather; and
- Specifications should not impose unnecessary complex construction methods, building materials, installation tolerances, or other requirements that hamper field operations.

Each of the constructability concepts listed above are consistent with lean principles. The goal of constructability is to optimize the use of construction knowledge during planning, design, procurement, and field operations. Likewise, lean thinking also focuses on the entire process – from planning through construction. The second concept – designs should be selected to enable efficient construction operations – can be restated in a lean manner to read, “Designs should be selected to enable *lean* construction operations.”

Many of the other constructability concepts describe ways to enable lean operations, such as standardization of design elements, modularity, and pre-assembly. On another Neenan Company job site, a mechanical contractor effectively used pre-assembled ductwork to promote workflow and reduce the time to complete the task from two weeks to two days (Macomber 1999). In addition to improving workflow, the quality of the ductwork was much greater, having been assembled in the factory under a controlled environment as opposed to being assembled in the field.

In order to implement design-led lean, new teams consisting of owners, engineers, architects, general contractors, subcontractors, and even suppliers must replace traditional design teams. The challenge of communicating with so many participants will be great. However, advances in information technologies, including the Internet, can significantly improve decision-making and facilitate the design process (Betts 1997, Papamichael 1999, Rojas and Songer 1999).

CONCLUSIONS

Historical resistance by the construction industry to accept ideas from manufacturing has limited the acceptance and use of lean construction. The traditional transformation view of construction is contrary to lean principles, which shift the focus from craft production to the overall process (including design). The goal of lean construction is to make value-added activities flow, which can only be accomplished if lean concepts are included from the very beginning of the design process.

Design-led lean facilitates lean construction by considering constructability in the design in order to improve flow at the job site. Traditional constructability concepts developed in the 1980s still apply to lean construction and can be enhanced through the consideration of how to make the process flow. Standardization of design elements, modularity, and pre-assembly are all methods that can improve flow on the construction job site.

In addition to consideration of constructability concepts, design teams must be expanded to include contractors, subcontractors, and materials suppliers. Communication among all parties will be difficult; however, advances in information technology are making it easier to communicate. Through universal access, all key players can work cooperatively on a design instead of isolated from each other. With increased cooperation and collaboration, it is not difficult to incorporate lean principles into construction practices.

The implementation of design-led lean requires a radical shift from traditional construction methods. The benefits, however, far outweigh the initial costs by creating a process dedicated to pursuit of perfection.

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