# WHAT IS LEAN CONSTRUCTION - 1999

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**ABSTRACT**

The origins of lean production are reviewed and a claim made that it is a new form of production management, that is neither mass nor craft. Then the applicability of lean production in construction is considered and nature of lean construction discussed in comparison with current practice.

**KEY WORDS**

Lean construction, lean production, production management

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## INTRODUCTION

Lean construction much like current practice has the goal of better meeting customer needs while using less of everything. But unlike current practice, lean construction rests on production management principles, the "physics[1]" of construction. The result is a new project delivery system that can be applied to any kind of construction but is particularly suited for complex, uncertain, and quick projects.

## HISTORY OF LEAN PRODUCTION

Lean production was developed by Toyota led by Engineer Ohno. He was a smart if difficult person dedicated to eliminating waste. The term "lean" was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production (Womack et al. 1991). Engineer Ohno shifted attention to the entire production system from the narrow focus of craft production on worker productivity and mass production on machine. Ohno followed the work of Henry Ford and continued the development of flow based production management. But unlike Ford who had an almost unlimited demand for a standard product, Ohno wanted to build cars to customer order. Starting from efforts to reduce machine set up time and influenced by TQM, he developed a simple set of objectives for the design of the production system: Produce a car to the requirements of a specific customer, deliver it instantly, and maintain no inventories or intermediate stores.

Waste is defined by the performance criteria for the production system. Failure to meet the unique requirements of a client is waste, as is time beyond instant and inventory standing idle. A morning cup of coffee serves as an example. Instant delivery is possible but we must either have an intermediate inventory, coffee in the pot, or accept a cup of "instant" which hardly meets requirements of someone craving a low-fat double latte.

Moving toward zero waste, perfection, shifts the improvement focus from the activity to the delivery system. Engineer Ohno and other Japanese engineers were familiar with mass production of cars from their plant visits in the United States. Where US managers saw efficiency, Ohno saw waste at every turn. He understood that the pressure to keep each machine running at maximum production led to extensive intermediate inventories he called "the waste of over production." And he saw defects built into cars because of the pressure to keep the assembly line moving. Production at all costs meant defects were left in cars as they passed down the line. These defects disrupted down stream work and left completed cars riddled with embedded defects. Where the US approach aimed to keep the machines running and the line moving to minimize the cost of each part and car, Ohno's system design criteria set a multi-dimensioned standard of perfection that prevented sub-optimization and promoted continuous improvement.

Zero time delivery of a car meeting customer requirements, with nothing in inventory required tight coordination between the progress of each car down the line and the arrival of

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[1] The idea of a "physics" of production is borrowed from "Factory Physics", an excellent text on production management (Hopp and Spearman 1996).

parts from supply chains. Rework due to errors could not be tolerated as it reduced throughput, the time to make a car from beginning to end, and caused unreliable workflow. And coordinating the arrival of parts assigned to a particular car would be impossible if the movement of the car was unreliable.

Engineer Ohno went so far as to require workers to stop the line on receipt of a defective part or product from upstream. (Only the plant manager could stop the line in US plants.) Working to eliminate rework makes sense from a system perspective, but stopping the line looks very strange to people who are trying to optimize performance of a single activity. Stopping the line made sense to Ohno because he recognized that reducing the cost or increasing the speed could add waste if variability was injected into the flow of work by the "improvement."

Requiring workers to stop the line decentralized decision making. He carried this further when he replaced centralized control of inventory with a simple system of cards or bins which signaled the upstream station of downstream demand. In effect, an inventory control strategy was developed which replaced central push with distributed pull. Pull was essential to reduce work in process (WIP). Lower WIP tied up less working capital and decreased the cost of design changes during manufacture as only a few pieces needed to be scrapped or altered. Large inventories are required to keep production in push systems because they are unable to cope with uncertainties in the production system. And large inventories raise the cost of change.

Ohno also decentralized shop floor management by making visible production system information to everyone involved with production. "Transparency" allowed people to make decisions in support of production system objectives and reduced the need for more senior and central management.

As he came to better understand the demands of low waste production in manufacturing, he moved back into the design process and out along supply chains. In an effort to reduce the time to design and deliver a new model, the design of the production process was carefully considered along with the design of the car. Engineering components to meet design and production criteria was shifted to the suppliers. New commercial contracts were developed which gave the suppliers the incentive to continually reduce both the cost of their components and to participate in the overall improvement of the product and delivery process. Toyota was a demanding customer but it offered suppliers continuing support for improvement.

Lean production continues to evolve but the basic outline is clear. Design a production system that will deliver a custom product instantly on order but maintain no intermediate inventories. The concepts include:

- Identify and deliver value to the customer value: eliminate anything that does not add value.
- Organize production as a continuous flow.

- Perfect the product and create reliable flow[2] through stopping the line, pulling inventory, and distributing information and decision making.
- Pursue perfection: Deliver on order a product meeting customer requirements with nothing in inventory.

Lean production can now be understood as a new way to design and make things differentiated from mass and craft forms of production by the objectives and techniques applied on the shop floor, in design and along supply chains. Lean production aims to optimize performance of the production system against a standard of perfection to meet unique customer requirements.

## LEAN CONSTRUCTION

Lean construction accepts the Ohno's production system design criteria as a standard of perfection. But how does the Toyota system, lean production, apply in construction? The construction industry has rejected many ideas from manufacturing because of the belief that construction is different. Manufacturers make parts that go into projects but the design and construction of unique and complex projects in highly uncertain environments under great time and schedule pressure is fundamentally different from making tin cans.

Lean production invites a closer look. Certainly the goal of a delivering a project meeting specific customer requirements in zero time sounds like the objective for every project, and the evidence of waste in Ohno's terms is overwhelming. Waste in construction and manufacturing arises from the same activity-centered thinking, "Keep intense pressure for production on every activity because reducing the cost and duration of each step is the key to improvement." Ohno knew there was a better way to design and make things.

Managing construction under Lean is different from typical contemporary practice because it;

- has a clear set of objectives for the delivery process,
- is aimed at maximizing performance for the customer at the project level,
- designs concurrently product and process, and
- applies production control throughout the life of the project.

By contrast, the current form of production management in construction is derived from the same activity centered approach found in mass production and project management. It aims to optimize the project activity by activity, assuming customer value has been identified in design. Production is managed throughout a project by first breaking the project into pieces, i.e. design and construction, then putting those pieces in a logical sequence, estimating the time and resources required to complete each activity and therefore the project. Each piece or activity is further decomposed until it is contracted out or assigned to a task leader, foreman or squad boss. Control is conceived as monitoring each contract or activity against its schedule and budget projections. These projections are rolled up to project level reports. If

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[2] Reliable workflow was a consequence of stopping the line rather than a stated objective.

activities or chains along the critical path fall behind, efforts are made to reduce cost and duration of the offending activity or changing the sequence of work. If these steps do not solve the problem, it is often necessary to trade cost for schedule by working out of the best sequence to make progress. The focus on activities conceals the waste generated between continuing activities by the unpredictable release of work and the arrival of needed resources. Simply put, current forms of production and project management focus on activities and ignore flow and value considerations (Koskela 1992, Koskela and Huovila 1997).

Managing the combined effect of dependence and variation is a first concern in lean production. Goldratt (1986) illustrates the effects on production in "The Goal" and the application to construction is demonstrated by Tommelein et al. (1999) in "Parade of Trades. The problem of dependence and variation can be illustrated by what happens in heavy traffic on a freeway. If every car drove at exactly the same speed then spacing between cars could be very small and the capacity of the freeway would be limited by whatever speed was set. Each car would be dependent on the one ahead to release pavement and variation would be zero. In effect, there would be no inventory of unused pavement. In reality of course, each car does use the pavement released to it from the car ahead but speeds vary.

Under the pressure to get to work or home, gaps between cars close and any variation in speed demands immediate response from following cars. As the gaps close, small variations in speed propagate along and across lanes. One small hesitation can lead to a huge standing wave as traffic slows to a crawl. Recovery is difficult because it is impossible to get everyone to accelerate smoothly back up to the standard speed and interval. High speed at any one moment does not assure minimum travel time in conditions of dependence and variation. The idea that you do not get home any faster by driving as fast and as close to the car ahead is counter intuitive (at least to teenagers). Certainly the system itself does not function as well when dependence is tighter and variation greater.

Managing the interaction between activities, the combined effects of dependence and variation, is essential if we are to deliver projects in the shortest time. Minimizing the combined effects of dependence and variation becomes a central issue for the planning and control system as project duration is reduced and the complexity increases. (Complexity is defined by the number of pieces or activities that can interact.) The need to improve reliability in complex and quick circumstances is obvious. New forms of planning and control are required.

The first goal of lean construction must be to fully understand the underlying "physics" of production, the effects of dependence and variation along supply and assembly chains. These physical issues are ignored in current practice which tend to focus on teamwork, communication and commercial contracts. These more human issues are at the top of practitioner's lists of concerns because they do not, indeed cannot see the source of their problems. It is not that these people are stupid, but that they lack the language and conceptual foundation to understand the problem in physical production terms. The development of partnering illustrates this point.

Partnering makes great sense from an activity perspective. But few realize Partnering is a solution to the failure of central control to manage production in conditions of high uncertainty and complexity. In these circumstances, representatives of each activity (or contract) must be able to communicate directly with out relying on the central authority to control message flow, and so Partnering works. From the lean understanding of the physics of production, Partnering is evidence of a failure in production management but it provides the opportunity for collaborative redesign of the planning system to support close coordination and reliable work flow.

Lean supports the development of team work and a willingness to shift burdens along supply chains. Partnering relationships coupled with lean thinking make rapid implementation possible. Where Partnering is about building trust, lean is about building reliability. Trust is the human attitude that arises in conditions of reliability. We are not likely to trust one another very long if we do not demonstrate reliability. Reliability is the result of the way systems are designed. Of course people manage systems and in current terms they do a fine job. The problem is that production systems just do not work well when every person tries to optimize their performance without understanding how their actions affect the larger web.

The problem of matching labor to available work offers a good example of the difference between the contemporary view of the workplace and lean. "Matching labor to work" means having the resources on hand for a crew to work steadily and without interruption. Current practice views the assignment to the crew as a sort of "mini contract" which is more or less independent of other assignments, and sets the person in charge responsible for the organization of resources and direction of the crew. To be fair, companies have logistics systems that try to get the resources close to the crew and a few actually try to assemble and assign packages of work. But the majority of foremen are responsible for the final collection of resources and assuring that their crews can work continuously. When this approach fails to produce acceptable results, when the numbers are bad, management assumes the foreman or crew is not performing.

Companies typically maintain elaborate cost control systems to measure this performance. These systems are the manifestations of the cause and effect theories operating in the company. At the heart of this model is the belief that the crew is essentially independent and that all costs charged to an account arise within from the effort necessary to complete the assignment by the crew.

The lean construction view is different as it views the problem in physical production terms. The crew works at variable rates using resources supplied at varying rates. Matching labor to available work is a difficult systems design problem with a limited number of "solutions." Lean works to isolate the crew from variation in supply by providing an adequate backlog (a safe distance between cars) or tries to maintain excess capacity in the crew so they can speed up or slow as conditions dictate. On occasion, people acting on intuition apply these techniques. (They drive to work on freeways.) Unfortunately neither resource nor capacity buffers reduce the variation in supply and use rates of downstream crews.

These problems are solved by long and predictable runs in the factories (and along the highways of our dreams). In these stable circumstances managers can predict the work content at each station and shift labor along the line to minimize imbalance. Such factories are mostly dreams that have little to do with construction where we only have some idea of the labor content of activities from previous projects.

People holding current practice dear sometimes say they are helpless victims of fate when faced with managing uncertainty on projects. Their view is that uncertainty arises in other activities beyond their control. The lean approach is to assure we do not contribute to variation in work flow and to decouple when we cannot get it under control. In lean construction as in much of manufacturing, planning and control are two sides of a coin that keeps revolving throughout a project.

- **Planning:** defining criteria for success and producing strategies for achieving objectives.
- **Control:** causing events to conform to plan and triggering learning and re-planning.

Often the first question we are asked when describing a project to people unfamiliar with lean thinking is, "What kind of contract was in force?" Next come organizational and systems issues: "Was supervision by area or craft? Union or not? Were designers on site? Did the owner know what they wanted?" These questions are reflections of contracting or activity centered thinking. Lean construction rests on a production management mind. We ask about the way work itself is planned and managed. We want to know the whether the planning system itself is under control, the location of inventories and excess capacity, and the extent to which the design and construction process itself supports customer value.

Lean construction embraces uncertainty in supply and use rates as the first great opportunity and employ production planning to make the release of work to the next crew more predictable, and then we work within the crews to understand the causes of variation.

*Where current practice attacks point speed, lean construction attacks variation system wide.*

Under lean, labor and work flow are closely matched when variation is under control and activities de-coupled through capacity or resource buffers when variation is not under control and work content unbalanced. These solutions are directed by the physics of the situation. Where current practice assesses and attempts to control individual performance, we see the planning system as the key to reliable work flow. Construction is different from manufacturing in the way work is released to the crew. Work is released, moves down the line, in manufacturing based on the design of the factory. In construction work is released by an administrative act, planning. In this sense, construction is directives driven and so measuring and improving planning system performance is the key to improving work flow reliability. Measuring planning system performance reflects our understanding of cause and effect. This is a different mind, a new novel. Once we understand physics problems at the crew level, we see all sorts of new issues and opportunities.

Our first objective is to bring the flow of work and production itself under control. This effort pays immediate dividends and demands the project delivery system be changed to better support reliable work flow. These include changing how work is structured early in design, and the organization and function of both the master project plan and lookahead process (Ballard and Howell 1997).

Research proposed by the Lean Construction Institute follows this path. We start with working to understand the physics of production at the task level, and then to design the underlying systems to support high performance in Ohno's terms. The planning system is the logical first target, but other design, procurement and logistic systems must also be considered. We understand that it will be necessary to change the organization to support these redesigned systems. Here we take another page from Ohno and expect to see distributed control replace current reliance on central control. Research efforts now underway explore the application of pull techniques both on site and in design. Finally, we expect new forms of commercial contract to emerge that give incentives for reliable work flow and optimization at the deliverable-to-the-client level. In this way we move from task to system to organization to contract.

Human issues come into play on implementation. Systems, teams, organizations, communication and contracts do not change the physics. Their design does limit what can happen just as physical rules place other limits. For example, the need for upstream investment to reduce downstream variation is in conflict with current practices of buying each piece for the lowest cost, or of pushing each crew to work quickly as opposed to reliably. Uncertainty in work flow places great demand on communication channels as people attempt to find some way to keep the project or their crew moving in the face of uncertainty. But flexibility defined in this way requires slack resources and injects more uncertainty into the flow of work. Where we see uncertainty as the consequence of the way we manage work, they see uncertainty as environmental and beyond their control. We operate on different theories, we tell different stories.

A pattern is beginning to emerge in implementation. Managers in most companies and on most projects have an inflated view of the reliability of their planning system. This attitude changes once the decision is taken to make assignments to criteria and the results come in. New opportunities are revealed and new demands arise in all directions. Upstream changes typically include changes in the timing and size of deliveries from fabricators. Horizontally, coordination with other specialty contractors shifts from a central controlled push functions to decentralized pull. Downstream, the effect of reliable work flow may be to change the way labor is managed. One contractor now shifts labor between nearby projects because it is possible to predict the actual demand for labor in coming weeks. Hoarding labor is reduced and fewer workers can service more jobs.

"Value" is one area of our work that does not rest so directly on some underlying physics. Here we are trying to understand how value is created. We believe our work will help organize and frame the conversation between ends and means so that the implications of early decisions are more explicit. We expect to change the design process so it will better cope with the contending demands of uncertainty and speed, and respond to the explosion in available technology.

## RESEARCH AND THE LEAN CONSTRUCTION INSTITUTE

The Lean Construction Institute (LCI) is theory driven and theory seeking. We think nothing is more practical than a good theory, as it explains what happens and why. For example, in current practice a delay is often attributed to morally deficient subcontractors[3].

Our theory is that such delays may be due to the combined effects of dependence and variation working over a long supply chain and period. We can test this theory by experimenting with techniques that reduce dependence and variation and observe the results. New theory, that is new cause and effect models, are invisible to those holding current theories dear. We approach problems related to production in construction first in physical and then systems terms believing that issues of organization and contract can only be resolved by assuring they best manage the "physics" of production. This approach is in contrast with efforts that start with issues of motivation and contract and never to come to grips with the work itself.

In each case we first want understand the current state of knowledge, and then form our theories. In this stage we must understand how the function is accomplished in current practice and the underlying mental model or theory that supports that practice. We cannot improve what we don't understand [insert comma] so accurate description is the first step in solving the puzzle. Other pieces may be found in the literature, current practice, theory or practice in related fields or the application of logic while taking a shower. Once we assemble the pieces a new theory is revealed and we can design experiments and refine our thinking.

Common sense teaches us to break large problems into parts small enough to be solved. We are taught "the devil is in the details", and he often is. Traditional research and science, like contemporary forms of project management, is built on this reductionist approach. The LCI research agenda does not ignore the details or the resulting common sense. But LCI is aligned with new forms of enquiry that are attempting to understand how and why "The whole is more than the sum of its parts." It is here in complex uncertain and quick circumstance that we expect to make explicit the roots of conventional wisdom, make our contributions, and redefine common sense.

## CONCLUSION

Lean construction results from the application of a new form of production management to construction. Essential features of lean construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design to delivery. Significant research remains to complete the translation to construction of lean thinking.

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[3] Of course the contractor may be, but we cannot know unless the contractor is embedded in a principle based production system. By contrast we often see that behavior considered immoral is in fact a logical response to the failure in the underlying production system. Failure to provide labor to a project can be understood as evidence of bad upbringing.

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