14

The foundations of lean construction

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Editorial comment – Chapters 14 and 15

The creation of value in building and construction projects has a particularly strong place in the lean construction philosophy that lean construction is based upon. 'Lean' is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value. This chapter and Chapter 15 are an introduction to the ideas and techniques of lean construction. These chapters do not give detailed instructions for implementing lean construction, but they give a comprehensive overview of the philosophy and practice of lean as its applies to construction. Chapter 14 provides an overview of lean construction as a theory-based approach to project management, which is compared to current project management, and outlines the lean-based project delivery system and its implementation. Chapter 15 describes several tools and techniques that support this new approach.

This chapter starts with a discussion of a theory of production. Our understanding of systems of production and associated production theory and related tools can be classified into the transformation, flow, and value concepts. Lean production attempts to integrate these three concepts of production. The authors argue that current project management attempts to manage by scheduling, cost and output measures, but these are often not effective. By contrast, lean construction attempts to manage the value created by all the work processes used between project conception and delivery. Next, the phases of the Lean Project Delivery System[1] are explained, and how the inter-relationships between these phases can be managed. The chapter finishes with a discussion on organizational change and culture.

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Chapter 15 looks at the areas of production management, lean design, lean supply, and lean assembly. This is a thorough introduction to some of the techniques that distinguish lean construction from traditional project management. Importantly, the Last Planner[1] system of production control is clearly explained and the three components of this system are outlined. The Last Planner is one of the core ideas in lean construction. This is followed by a discussion that shows how the philosophy of value generation and waste reduction can be applied to design. The section on lean supply shows how lean thinking brings together the product design, detailed engineering, and fabrication and logistics aspects of construction projects. Finally, the tools and techniques used in addition to Last Planner for lean assembly are described.

14.1 Introduction

Since the mid-1990s lean construction has emerged as a new concept, both in the discipline of construction management and the practical sphere of construction. There are two slightly differing interpretations of lean construction. One interpretation holds that the question is about the application of the methods of lean production to construction[2]. In contrast, the other interpretation views lean production as a theoretical inspiration for the formulation of a new, theory-based methodology for construction, called lean construction. The latter interpretation has been dominant in the work of the International Group for Lean Construction, founded in 1993.

Here, the view of lean construction as a novel theory-based approach to construction is adopted. This does not mean, however, that the view of lean construction as a kit of methods is totally rejected; rather, methods and tools from lean production are introduced when justified.

14.2 Theoretical considerations

Let us first clarify the basic issues. What do we do with a theory of production? What do we require from it?

14.2.1 What is a theory of production?

An explicit theory of production will serve various functions (Koskela, 2000). A theory provides an explanation of observed behaviour and it thereby contributes to understanding. A theory provides a prediction of future behaviour. On the basis of the theory, tools for analysing, designing and controlling can be built. A theory, when shared, provides a common language or framework, through which the co-operation of people in collective undertakings (such as a project or a firm) is facilitated and enabled. A theory gives direction in pinpointing the sources of further progress. A theory can be seen as a condensed piece of knowledge: it empowers novices to do the things that formerly only experts could do. It is thus instrumental in learning. Once a theory has been made explicit, it is possible to constantly test its validity. Innovative practices can be transferred to other settings by first abstracting a theory from that practice and then applying it in target conditions.

The primary characteristic of a theory of production is that it should be prescriptive: it should reveal how action contributes to the goals set for production. On the most general level, there are three possible actions:

- design of the production system,
- control of the production system in order to realize the production intended, and
- improvement of the production system.

Production has three kinds of goal. First, there is the goal of getting intended products produced in general (this may seem so self-evident that it is often not explicitly mentioned). Second, there are goals related to the characteristics of the production itself, such as cost minimization and level of utilization (internal goals). Third, there are goals related to the needs of the customer, such as quality, dependability and flexibility (external goals). Furthermore, the theory of production should cover all essential areas of production, especially production proper and product design.

From the point of view of practice of production management, the significance of the theory is crucial; the application of the theory should lead to improved performance. Conversely, the lack of the application of the theory should result in inferior performance. Here is the power and significance of a theory from a practical point of view: it provides an ultimate benchmark for practice.

14.2.2 What theories regarding production do we have?

What have scientists forwarded as theories? What theories have actually been used in practice? Throughout the twentieth century, the transformation view of production has been dominant. In the transformation view, production is conceptualized as a transformation of inputs to outputs. There are a number of principles by which production is managed. These principles suggest, for example, decomposing the total transformation hierarchically into smaller transformations, called tasks, and minimizing the cost of each task independently of the others. The conventional template of production has been based on this transformation view, as well as the doctrine of operations management.

The transformation view has its intellectual origins in economics, where it has remained unchallenged to this day. The popular value chain theory, proposed by Porter (1985), is one approach embodying the transformation view. A production theory based directly on the original view on production in economics has been proposed by a group of scholars led by Wortmann (1992). However, this foundation of production is an idealization, and in complex production settings the associated idealization error becomes unacceptably large. The transformation view of production has two main deficiencies: first, it fails to recognize that there are phenomena in production other than transformations, and second, it fails to recognize that it is not the transformation itself that makes the output valuable, but, instead, that there is value in having the output conform to the customer's requirements. The transformation view is instrumental in discovering which tasks are needed in a production undertaking and in getting them realized, however, it is not especially helpful in figuring out how to avoid wasting resources or how to ensure that customer requirements are met in the best possible manner. Production managed in the conventional manner therefore tends to become inefficient and ineffective.

The early framework of industrial engineering introduced another view on production, namely that of production as flow. The flow view of production, first described in scientific terms by Gilbreth and Gilbreth (1922), has provided the basis for just-in-time (JIT) and lean production. This view was translated into practice by Henry Ford, however, his implementation was misunderstood. The flow view of production was further developed only from the 1940s onwards in Japan, first as part of war production and then in automobile manufacturing at Toyota.

The flow view is embodied in 'lean production,' a term coined in the 1980s by researcher John Krafcik to characterize Toyota's manufacturing practices. In the flow view, the basic thrust is to eliminate waste from flow processes. Thus, such principles as lead time reduction, variability reduction, and simplification are promoted. In a breakthrough book, Hopp and Spearman (1996) show that by means of queuing theory, various insights that have been used as heuristics in the framework of JIT can be mathematically proven.

A third view on production was articulated in the 1930s, namely that of production as value generation. In the value generation view, the basic goal is to reach the best possible value from the point of the customer. The value generation view was initiated by Shewhart (1931). It was further refined in the framework of the quality movement but also in other circles. Principles related to rigorous requirements analysis and systematized flowdown of requirements[3], for example, are forwarded. Cook (1997) recently presented a synthesis of a production theory based on this view.

Thus, there are three major views on production. Each of them has introduced practical methods, tools, and production templates. Nevertheless, except for a few isolated endeavours, these views – as candidate theories of production – have raised little interest in the discipline of operations management. As stated earlier, there has not been any explicit theory of production. Consequently, the important functions of a theory, as outlined, have not been realized either from the viewpoint of research or from the viewpoint of practice.

These three views do not present alternative, competing theories of production, but rather theories that are partial and complementary. What is needed is a production theory and related tools that fully integrate the transformation, flow, and value concepts. As a first step towards such integration, we can conceptualize production simultaneously from these three points of view: transformation, flow, and value. A number of first principles stemming from each view can be induced from practice or derived from theory. An overview of this integrated view, called the TFV theory of production, is presented in Table 14.1. These three conceptualizations remain partial, however, the ultimate goal should be to create a unified conceptualization of production instead.

The crucial contribution of the TFV theory of production lies in calling attention to modelling, structuring, controlling, and improving production from these three points of view combined. In production management, management needs arising from the three views should be integrated and balanced. In practice, the domains of management corresponding to the three views may be called task management, flow management, and value management. The constituents of the TFV theory of production are not new,

Table 14.1 TFV theory of production (Koskela, 2000)

	Transformation view	Flow view	Value generation view
Conceptualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfilment of his/her requirements
Main principle	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices	Work breakdown structure, MRP, organizational responsibility chart	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, quality function deployment
Practical contribution	Taking care of what has to be done	Making sure that unnecessary things are done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name of practical application of the view	Task management	Flow management	Value management

however, the TFV theory supports the new insight, that there are three fundamental phenomena in production that should be managed simultaneously.

14.3 Why conventional construction project management fails

Conventional project management in construction is inadequate because it does not rest on a TFV theoretical framework (Johnston and Brennan, 1996; Howell and Koskela, 2000; Koskela and Howell, 2001). From the first moments, construction projects are managed today by breaking them into pieces or activities, estimating the time and money to complete each, applying the critical-path method (CPM) to identify a logical order, and then either contracting externally or assigning internally to establish responsibility. In either case the pieces or activities are treated much the same. Project managers use the schedule to determine when each activity should start and push for work to begin on the earliest start date. Control begins with tracking and rests on the thermostat model[4]. Project controls determine if each activity and the total project are within their cost and schedule limits. Action is taken either to speed or re-sequence activities if delays threaten required completion. In many cases, additional workers are mobilized to speed completion but this then reduces productivity. Hard choices are made and risks shifted among participating organizations depending on commercial terms and other factors. While the project manager is struggling to achieve project objectives, those responsible for each activity work towards assuring or improving their estimated performance.

Why is it that this approach, which sounds reasonable, so often fails in practice? From the lean construction perspective, current practice rests on a defective model of the project, the work involved, and its control. Simply put, current project management attempts to manage activities by centrally applied scheduling and to control them using output measures. It fails even in the attempt to manage activities and misses entirely the management of work flow and the creation and delivery of value.

Projects today are complex, uncertain, and quick (CUQ) (Shenhar and Laufer, 1995). The pressure for ever-shorter durations will always be with us. Complexity and uncertainty arise from multiple contending and changing demands of clients, the market place and technology. The pressure for speed adds to the burden. In this dynamic environment, activities are rarely linked together in simple sequential chains; rather work within and between tasks is linked to work in others by shared resources and/or depends on work underway in others.

Co-ordinating work on CUQ projects cannot be assured even with highly detailed CPM schedules. These schedules portray the project as a series of activities and ignore the flow of work within and between them. The reliable release of work from one crew to the next is assumed or ignored. Project managers who rely on these schedules struggle with uncertainty but rarely see it arising within the project from their reliance on project level scheduling and control of activities (Tommelein *et al*., 1999).

Controlling by tracking activity completion and cost fails to assure reliable work flow (Howell and Ballard, 1996) because this type of control rests on the thermostat model applied to output measures. The thermostat model triggers when a variance is detected and it assumes that there are direct links to the cause of the variance. If the room temperature is above the set point, the thermostat turns off the furnace. Output measures based on estimated expenditures of work hours and duration are not linked to the 'furnace' on a project. At best, variances on a project trigger some investigation by supervisors but this is often aimed at justifying why the standard is incorrect for the circumstance. Given the circumstance, there is often little that supervisors can do to increase the production rate and/or reduce costs in the face of unpredictable release from upstream and poor co-ordination with adjacent crews or design squads.

Too often, steps taken by one supervisor to improve performance of the activity in his charge reduce total project performance by further reducing the reliable release of work to the next team. For example, this happens when crews choose to install the easier work first in order to improve their performance numbers; pipefitters call this 'showpipe'. Here we see a deeper problem in the way projects are managed: the attempt to optimize each activity inevitably leads to sub-optimal outcomes for the project. Despite efforts to build teamwork (e.g., through partnering) commercial contracts and cost/schedule controls lead to adversarial relations as managers responsible for interacting activities struggle to advance their interests by optimizing their activity with little concern for the problems this causes others. The business objectives of project-based producers and the client seem inevitably opposed as the project manager tries to complete the project.

Value to the client in this situation is understood as meeting the original design within cost, schedule, and quality limits – change is the enemy. Current project management certainly tries to deliver value to the client present at the beginning of the project. In the CUQ world, delivering value means increasing the ability of the customer at the end of the project to achieve their purposes. Circumstances change quickly when projects are CUQ, so completing a project that does not increase capability within schedule and budget limits set at the beginning is of little use. Change is certainly difficult to manage with current techniques that push for early decisions and local optimization.

The failures of current project management help define the requirements for a new approach. This new approach must rest on the expanded TFV foundation. In practice this means the management system must optimize performance at the project level in a complex and uncertain setting, always pressed for speed.

14.4 Lean project delivery in construction

The phrase ‘project delivery system’ has traditionally been used to indicate the contractual structure of the project, e.g., design–bid–build or design–build. ‘Delivery’ in this context is understood to be a type of transaction and a key question is how to structure the transaction. Design–build is seen as a means for providing a client with a single contracting entity with which to interact, as opposed to holding contracts with multiple players and thus inheriting the task and risk of co-ordinating their actions. By contrast, the lean construction community understands ‘delivery’ in terms of the actual work processes used to move a facility from concept to customer (Ballard and Zabelle, 2000a, b).

In the realm of construction, delivery involves designing and making capital facilities – buildings, bridges, factories, and so on. Construction differs from other types of project-based production systems by the type of products it produces, the differentiating characteristic of which is that they eventually become rooted in place. Construction’s products share with airplanes and ships the characteristic that, in the process of assembly, they become too large to move through workstations, so workstations must be moved through the products. Consequently, buildings, airplanes, and ships are made using fixed position manufacturing. Unlike airplanes and ships, however, buildings and bridges are rooted in place and are designed for a specific location, often both technically and aesthetically.

Traditional project delivery systems pursue the ‘task’ of project delivery and neglect both value maximization and waste minimization. This approach confuses the ‘task’ view with managing the project. A lean project delivery system is one that is structured, controlled, and improved in pursuit of all three goals, i.e., the transformation/flow/value goals proposed by Koskela (2000). While techniques are important, and such techniques as ‘kanban’[5] have become identified with lean production systems, all systems that pursue the TFV goals are, in principle, lean delivery systems, though some will be ‘leaner’ than others. Since it is impossible to achieve simultaneously the elements of the lean ideal (which is to provide a unique product to each customer, in zero time, with nothing in stores or any other kind of waste), techniques will come and go, but the goals will be pursued perpetually. The lean project delivery system[6], as currently conceived, incorporates many elements from advanced practice in construction today. However, they are integrated into a complete delivery system, rather than occurring in isolation. In addition, many similarities between lean and traditional practice prove, on examination, to be superficial. For example, design–build modes of structuring contractual relations might seem to share with the lean system characteristics such as cross-functional teams and integrated design of product and process. Design–build as such has nothing, however, to do with how things are designed and built, only with how a client procures its capital facilities. Design–build modes of delivery only pursue the transformation goal of production systems, and do not as such pursue the value or flow goals.

14.4.1 Lean Project Delivery System (LPDS[1]) Model

Projects have long been understood in terms of phases, e.g., pre-design, design, procurement, and installation. One of the key differences between traditional and lean project delivery concerns the relationship between phases and the participants in each phase. The model in Figure 14.1 represents those phases in overlapping triangles, the first of which is Project Definition, which has the job of generating and aligning customer and stakeholder values, design concepts, and design criteria. Those three elements are determined recursively. In other words, each may influence the other, so a conversation is necessary among the various stakeholders. Typically, like a good conversation, every person leaves with a different and better understanding than they brought with them. Traditionally, project definition has been done by the architect (or engineer, for non-building projects) working alone with the client. In Lean Project Definition, representatives of every stage in the life cycle of the facility are involved, including members of the production team that is to design and build it.

Alignment of values, concepts, and criteria allows transition to the Lean Design phase, in which a similar conversation occurs, this time dedicated to developing and aligning product and process design at the level of functional systems. During this phase, the project team stays alert for opportunities to increase value. Consequently, the project may revert to Project Definition. Further, design decisions are systematically deferred to allow more time for developing and exploring alternatives. By contrast, traditional design

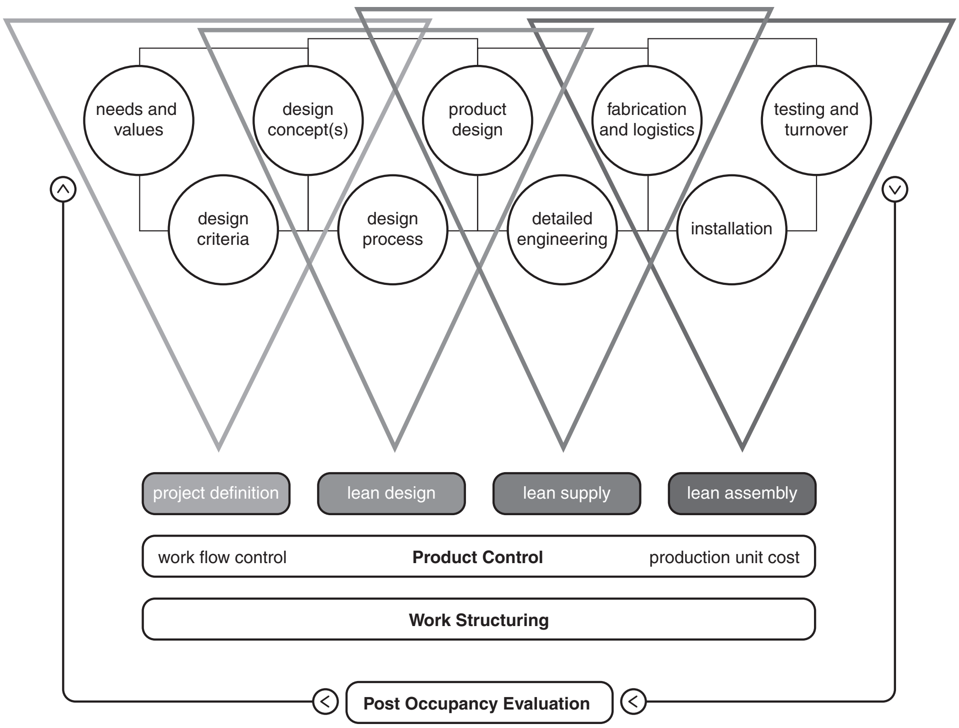

Figure 14.1 Triads of the Lean Project Delivery System (LPDS).

management is characterized by demands for a freeze of design and by a tendency to narrow a set of alternatives to a single selection very quickly. Although done in the name of speed (and often abetted by limited design fees), this causes rework and turmoil, as a design decision made by one specialist conflicts with the design criteria of another. The 'set-based' strategy employed in Lean Design allows interdependent specialists to move forward within the limits of the set of alternatives currently under consideration. Obviously, time is rarely unlimited on construction projects, so selection from alternatives must eventually be made. The practice in lean design is to select those alternatives at the *last responsible moment*, which is a function of the lead time required for realizing each alternative. Reducing those lead times by restructuring and streamlining supply chains allows later selection so that more time can be invested in designing and value generation.

The transition to detailed engineering occurs once the product and process design for a specific system has been completed and released for detailing, fabrication, and delivery. At least the latter two functions occur repetitively over the life of a project, hence the model shows Fabrication and Logistics as the hinge between Supply and Assembly.

Assembly completes when the client has beneficial use of the facility, which typically occurs after commissioning and start-up. The management of production throughout the project is indicated by the horizontal bars labelled Production Control and Work Structuring, and the systematic use of feedback loops between supplier and customer processes is symbolized by the inclusion of post-occupancy evaluations.

14.4.2 How is the LPDS structured, controlled and improved for achieving the TFV goals?

Management of a production system consists of structuring the system to achieve its goals, controlling the system for goal achievement during execution, and improving both structure and control during execution and between projects (Koskela, 2000). Projects are *structured* to pursue the TFV goals by the application of many principles and techniques. Ballard *et al*. (2001) present a more fully developed hierarchy of ends and means. Techniques include:

- involving downstream players in upstream decisions
- deferring commitments to the last responsible moment
- aligning the interests of participants, e.g., so that it is always in the interest of the producer to maximize value for the customer
- selecting, sizing, and locating buffers to absorb variability and match the value of time versus cost for each customer.

The essence of traditional project control is in monitoring actual performance, comparing it to planned or intended performance, and identifying negative variances on which management should act. In other words, it is like trying to steer a car by looking in the rear view mirror. Lean production *control* is achieved through a systematic process for making assignments ready to be performed, combined with explicit commitment by people at the production level to what work will be released to their 'customer' processes in the next plan period, which is typically 1 week, and ongoing identification and action on root causes for plan failures.

Improvement is accomplished between projects primarily through post-occupancy evaluations, which examine both product and process. To what extent was design and construction based on a correct determination of customer and stakeholder values? To what extent was the facility designed and delivered so as to allow realization of customer and stakeholder purposes?

Within projects, improvement is closely linked to control. For example, the Last Planner system of production control[7] tracks plan reliability through its Percent Plan Complete measurement and also identifies reasons for plan failure so they can be acted upon (Ballard and Howell, 1998).

14.4.3 Linking the LPDS Upstream and Downstream

The starting point for project delivery varies widely. Clients with on-going capital facilities programs typically perform a business analysis and feasibility assessment prior to engaging a delivery team. In other cases, analysis and feasibility may occur only after engaging the team. Generally, it has been found to be preferable for the delivery team to be involved earlier in business analysis and feasibility assessment. When a team is engaged after those functions have been performed, the first task should be to review previous planning, so they can at least thoroughly understand the business case of the client, and may be able to make valuable contributions regarding alternative possibilities, previously unconsidered options, the cost or time of options, and so on.

The Lean Project Delivery System produces a facility for a customer to use. Customer use can be represented by a fifth triad, containing Commissioning, Operations and

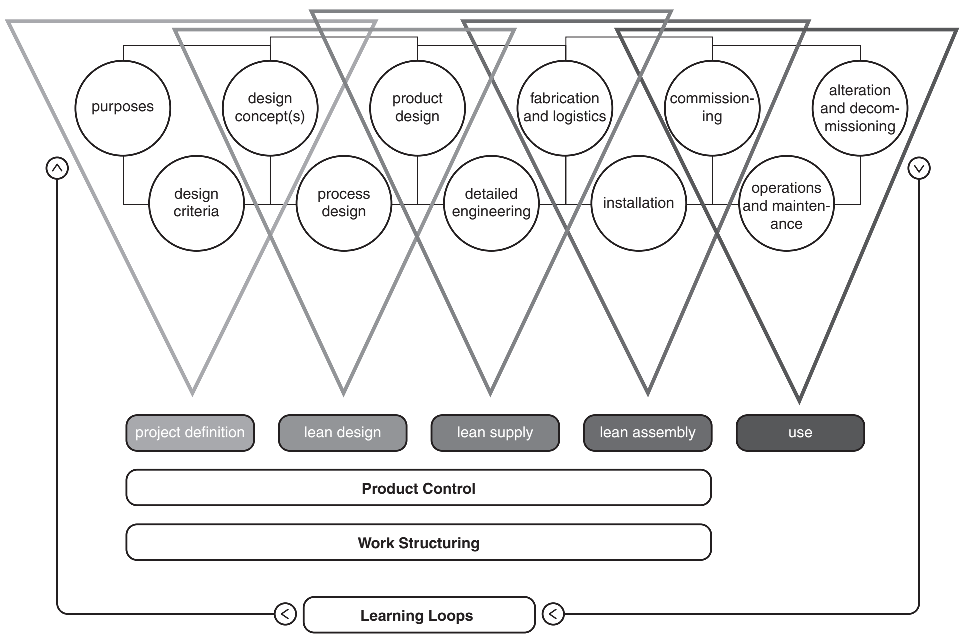

Figure 14.2 Triads of Lean Project Delivery System plus Facility Use.

Maintenance, Alteration and Decommissioning, all of which are anticipated in the previous phases (Figure 14.2).

The hand-off from the delivery team to the operations and maintenance team is typically done during commissioning and start-up of the facility. However, strictly speaking, hand-off occurs once the facility is operating to targeted performance. Consequently, that ramp up time should be included in measurements of project duration, and also be included in efforts to reduce project duration.

14.4.4 Summary of the LPDS

The comparison of LPDS to more traditional systems shows that this new approach is a radical departure from current practice (Table 14.2).

Table 14.2 Comparison of traditional and lean project delivery systems

Lean	Traditional
Focus is on the production system	Focus is on transactions and contracts
TFV goal	T goal
Downstream players are involved in upstream decisions	Decisions are made sequentially by specialists and 'thrown over the wall'
Product and process are designed together	Product design is completed, then process design begins
All product life cycle stages are considered in design	Not all product life cycle stages are considered in design
Activities are performed at the last responsible moment	Activities are performed as soon as possible
Systematic efforts are made to reduce supply chain lead times	Separate organizations link together through the market, and take what the market offers
Learning is incorporated into project, firm, and supply chain management	Learning occurs sporadically
Stakeholder interests are aligned	Stakeholder interests are not aligned
Buffers are sized and located to perform their function of absorbing system variability	Participants build up large inventories to protect their own interests

14.5 Implementation

Implementing this approach in existing organizations or with people schooled in current practice is hardly automatic. Lean-based project management requires changes in individual behaviour and larger organizational development efforts to overcome the ways current practice contradicts the new. Implementing Lean Construction requires the progressive application of a new way to design project-based production systems. The change required is both conceptual and practical. Changing long-held ways of thinking and acting is hard but rewarding work. Changing procedures, techniques and corporate systems is the easy part; changing minds is the real challenge. The lean literature, books like 'Lean Thinking' (Womack and Jones, 1996) are full of stories about companies and people making the transition. Urgency, leadership, focus, structure, discipline, and trajectory themes are apparent in both these stories and in construction and some patterns can now be perceived.

14.5.1 Urgency

Companies that are more likely to implement lean processes will view themselves as being in the business of execution of production (or services). This is in contrast to companies that see themselves as being in the business of brokering projects by contracting work from others, while minimizing their own involvement in the actual execution of the work. Among these companies, declining performance creates the urgency for action. Fear seems a better stimulus than greed for driving change. In any case, the leadership of a company going lean must first explain why this change is needed so that people understand the context for the effort.

14.5.2 Leadership

While a steady purpose must be communicated, transformational leadership requires getting change started and sustaining it. Perhaps the best metaphor is teaching a child to ride a bicycle; lectures and explanations help but the only place to learn is in the saddle, so demonstrating the new behaviour and causing action, getting people involved in doing different things, is vital. Continuing with the bike metaphor, leaders must expect some falls and scraped knees. Leaders often miss the fact that others throughout the organization have been trying for some time to ride the bike and have been criticized for both their effort and mistakes by those holding fast to current practice. Leadership becomes a matter of putting new people in the saddle and finding and encouraging those already trying the ideas on their own. Catching people doing it right, praising them and rewarding them, builds credibility and confidence that this is more than another passing fad.

14.5.3 Focus

Making quality assignments by applying the Last Planner System of Production Control is the place to start. This system brings real change at all levels, produces measurable results, and once in place leads to wider change in the way projects are designed, supplied and controlled. Pilot projects can be established to both prove the ideas in practice and to make apparent the differences between the new and current practices. These projects should not be seen as experiments or tests because people will sense that the commitment to lean is not yet firm. One caution: companies often incorporate some ideas and practices from lean into their current planning and management approach – the result is better performance and a reduced sense of urgency. The company then claims they are 'doing it' even though no real change has occurred.

While there are many differences between the lean approach and current practice, an important implementation milestone occurs when the project organization shifts from only measuring the performance of each activity (the task view) to actively improving the predictable release of work from one specialist to the next (the flow view). Since planning at the assignment level is what finally causes work to be done, the ability of the planning system to predict, indeed cause, a certain time when specific tasks will be completed can be measured[8] This milestone matters because it indicates that the organization, by the controls it employs, is shifting from trying to optimize the performance of each activity to optimizing at the project level.

14.5.4 Structure

Kotter (1996) speaks of developing and expanding the 'guiding coalition' as a key to transformation. In construction companies we see more or less formal steering committees made of executives, key training and coaching staff, and leaders from throughout the company. These groups plan and carry out the implementation activities, develop materials and collect and tell success stories. This forum is also where contradictions between lean and current practice are identified and resolved.

14.5.5 Discipline

Lean is not a programmatic patch or a one-time problem to solve. It is a different way to think and act that must be learned through disciplined practice. Keep at it and keep the effort to perform better against the lean ideal visible. Some companies attempt to manage the transformation on their own or with only modest help. Training is required but it alone is insufficient to assure success. Significant coaching is also required; this means having people work on projects with the management team to assure the system is installed and running. Project managers and superintendents are not the kind of people who ask for help so the coaches need to be proactive and engaged.

14.5.6 Trajectory

Most companies start with pilot implementation of the Last Planner System. This system is designed to assure the reliable release of work from one station to the next. It is not uncommon for those leading this effort to come to the startling realization of the power of this idea, as in 'This reliability stuff is really important'. (This is an interesting moment, much like when a child realizes the tremendous freedom, speed, and range made possible by learning to pedal a bike.) In construction, this realization usually means that the practitioner understands that new levels of performance are really possible and that changes in design, supply, assembly and control will lead to even better results.

Two models of organizational change are now apparent. The first is the more classic, larger organizational change model that includes developing vision and values, aligning interests, re-examining practices, and taking first steps. These efforts involve multiple activities on many fronts. They stress immediate action, getting people on the bike, in parallel with other efforts. Another model for change is emerging and, while it is relatively new, it appears to offer great promise. This approach implements the Last Planner System in conjunction with focus and training on making and keeping reliable promises (Winograd and Flores, 1986). These skills provide an immediate link between the design of the planning system and the human and organizational issues required for its implementation. Just as the focus on reliable work flow creates a line for continuous action linked to improved system performance against the lean ideal, the pressure for making and keeping reliable promises progressively reveals contradictory organizational policies and practices. This is not to suggest that a company cannot successfully implement lean construction without installing the Last Planner System and Reliable Promises, but it does suggest that a more direct route to implementation may be more effective.

14.6 Conclusion

Lean construction is still, to a considerable extent, 'work-in-progress'. However, its development to date supports two major claims: first, lean construction is based on a better theory than conventional construction; second, lean construction is more effective than conventional construction. Thus, lean construction is not just another specific approach to construction, but rather a challenger of the conventional understanding and practice of construction. In consequence, it is in the interest of every player in the construction sector to assess this new thinking and practice.

The future development of lean construction will have two directions: breadth and depth. On one hand, the seminal ideas of lean construction were related to the management of site operations. After that, new methods were developed for supply chain management, design management, cost management, and for total project delivery. This process of increasing breadth will eventually lead to the situation where all issues of construction project delivery have a methodical solution based on the new theoretical framework.

On the other hand, this new theoretical framework is – and should be – constantly moving, leading to increasing depth. Up until now, the main focus of theoretical development has been on the theory of production and its application to the specific characteristics of construction. Next, the theory of management and the theory of communication need to be clarified and integrated into the existing body of theoretical knowledge.

Among managerial sciences, the quest for a theory is not a phenomenon restricted to construction management. Rather, a similar movement is emerging in the wider fields of operations research and management science (Saaty, 1998). The characterization of a shift of focus, from individual problems to a theory of the system where the problems are embedded, presented in this wider context is perfectly adequate also regarding construction management (Saaty, 1998):

> After more than a half century of tinkering with and solving problems, we need to characterize the system underlying our activity, classify, and generalize its problems.

Endnotes

1 ēan Project Delivery System (LPDS) and Last Planner are both Trademarks.
2 This conception is common especially in the UK. The attacks by Green (1999) on lean construction seem to address this 'tool cocktail' conception.
3 Flowdown of requirements refers to the stagewise decomposition and conversion of high level requirements to requirements for part design, fabrication and assembly.
4 In the thermostat model (Hofstede, 1978), there is a standard of performance, and performance is measured at the output of the controlled process. The possible variance between the standard and the measured value is used for correcting the process so that the standard can be reached.
5 The Japanese word 'kanban' means card or sign board. In the Toyota production system, cards are often used for controlling the flow of materials through the factory. The basic concept is that a supplier or the warehouse only delivers components to the production line as and when they are needed eliminating the need for storage in the production area. Supply points along the production line only forward desired components when they receive a card and an empty container, indicating that more parts are needed in the production line (Hopp and Spearman, 1996; Olson, 2001).
6 See Ballard (2000).
7 The Last Planner system is described in detail in Chapter 15.
8 The test question to determine if the organization is serious about managing work flow is: 'Are you measuring the performance of your planning system with PPC (Percent Plan Complete) and acting on reasons?' Even here we occasionally find companies who use the terms but modify the measurement criteria to measure the amount of work completed rather than the ability of the planning system to assure release of work from one crew to the next. The focus should remain on doing it right. Both these methods are presented in more detail in Chapter 15.

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