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Lean management methods for complex projects

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This paper reviews the principles, history, applications and current research issues associated with lean construction, in order to provide a foundation for future research in this area. Lean is a management approach that emerged in the automobile industry and spread initially to other forms of repetitive manufacturing and ultimately to service industries. Despite its success in practice, the lean philosophy and methods have not been fully evaluated and incorporated into the academic literature. The question remains to what extent lean management methods are unique and beneficial and how they are related to principles and models in management science, production management and related fields. One of the relevant issues is the adequacy of lean methods to the management of complex projects. As project complexity increases, emergent phenomena increase. Consequently, leadership must become more adaptive and less prescriptive in order to be successful. This paper describes some of the key lean management methods that deliver better outcomes on complex projects and also the interdependence of these methods with the structuring of commercial terms and organizational integration. It also describes the relationship between lean project management methods and conventional methods, and the limitations of both, and suggests directions for future research.

Keywords: Lean methods, project complexity, project management.

Introduction

This paper reviews the history, principles, applications and current research issues associated with lean construction.

The term ‘lean’ was coined by John Krafcik, a researcher on the International Motor Vehicle Program at MIT, to describe what had been found from comparison of American, European and Japanese motor vehicle firms. Finding that the Japanese firms as a group performed so much better than their international peers persuaded the research team that they were confronting a new form of production system, not simply better execution of the same system. ‘Lean’ was chosen because the Japanese used less of everything—time, resources and money—and produced vehicles with fewer defects and greater variety than their competitors (Krafcik, 1988; Womack *et al.*, 1990). In their later book, *Lean Thinking*, Womack and Jones (1996) reported that Toyota was the cause for much of the superiority.

The claim that lean is a new or superior form of production system has been contested by some scholars (Schonberger, 1986; Berggren, 1992) and supported by others (Ward *et al.*, 1995; Adler, 1996; Sobek *et al.*, 1999), but it has not been fully evaluated and incorporated into the academic literature. The question remains to what extent lean management methods are unique and beneficial and how they are related to principles and models in management science, production management and related fields. Levitt’s recent paper (Levitt, 2011) is a welcome contribution on these issues.

This paper is a further contribution to the discussion, focusing on the adaptation to complex projects of thinking and practice originating in repetitive manufacturing. It consists of a short history of the origin of lean construction, the adaptation of principles and methods for the project environment, a discussion of the limitations of lean construction methods and recommendations for future research.

Lean production and Toyota

Lean production originated with Toyota. After World War II, General MacArthur was charged with

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redeveloping Japan. To that end, the Japanese were taught management methods. Most famous were the courses given by Joseph Juran, W. Edwards Deming and other experts in quality management. Management training also extended down to direct supervisors. Toyota is said to still use the Training Within Industry courses in Job Instruction, Job Methods and Job Relations (Dinero, 2005).

So the story goes (Ohno, 1988) that Toyota visited the automotive manufacturers in the USA, but found their way of producing vehicles inappropriate for Toyota. At that time, Toyota was restricted to a national market and had quite a low demand, but for a wide variety of vehicles. The expensive, high-volume machines used by Ford and General Motors were not needed and could not be afforded. Engineer Ohno was challenged by Toyota's CEO to overcome within three years the 9:1 productivity disadvantage the company had relative to US producers and to do so in a way appropriate to Toyota's circumstances, that is, producing small numbers of a wide variety of products.

Ohno reports that he was much taken with the method of restocking American grocery store shelves, a method he labelled 'pull' as distinct from the 'push' observed in US motor vehicle fabrication and assembly plants (Ohno, 1988). Customers pulled replacement inventory onto shelves by purchasing and removing them. This seemingly simple idea became the fundamental lean principle: Do work only on customer request.

Ohno also identified seven forms of waste, of which 'overproduction', doing work before it is needed, was said to be the cause of other forms of waste—to be avoided by pulling. Ohno's seven forms of waste are as follows:

(1) Defects in products
(2) Overproduction of goods not needed
(3) Inventories of goods awaiting processing or consumption
(4) Unnecessary processing
(5) Unnecessary movement of people
(6) Unnecessary transport of goods
(7) Waiting by employees for process equipment to finish work or for an upstream activity to complete. (Ohno, 1988)

Expressed in this list are the basic elements of the lean philosophy of management: 'lean' consists of an ideal to be pursued, principles to be followed in that pursuit and methods to be used to apply the principles. The ideal is to deliver exactly what your customer (immediate or ultimate) needs, with no waste.[1] A representative principle is to only do work on customer request. Different methods have been developed for applying this principle in different circumstances. For example, kanban are tags used to communicate requests for specific components from one factory workstation to another. Alternatively, visual signals, such as empty bins, are used to replenish inventories of parts installed at different workstations. In construction, some companies are having vendors manage inventory replenishment based on computer information systems that record withdrawals, much like the grocery stores that Ohno had observed (Ohno, 1988; Elfving *et al.*, 2010). As we will see in the later discussion about the Last Planner System, requests are made directly between the individuals responsible for different, interdependent types of works, for example, between architects and structural engineers or between pipefitters and electricians.

Understanding of Toyota's contribution has changed over time. It was initially understood in terms of manufacturing, how products were made in the Toyota Production System. Harvard's research on product development (Clark and Fujimoto, 1991) expanded this understanding from only making to designing and making. Ward *et al.* (1995) published a provocative article in the Sloan Management Review titled 'The Second Toyota Paradox', which offered a solution to the puzzle how Toyota can spend more time on more prototypes and still develop new products faster and less expensively than anyone else. This introduced another fundamental principle, namely to apply all relevant criteria to the evaluation of design alternatives simultaneously. The authors named this 'set-based engineering' as distinct from the point-based one. The underlying issue is how projects are structured, as sequential or as organizationally integrated processes. Since design criteria are best applied by those expert in various specialities, these specialists must be members of an integrated team in order to realize the principle.

Yet another expansion in understanding Toyota's contribution came in 2003 with the publication of Jeffrey Liker's *The Toyota Way*, in which Toyota's philosophy was presented as a general and fundamental philosophy of management, based on 14 principles (Liker, 2004):

(1) Base management decisions on long-term philosophy even at the expense of short-term financial goals.
(2) Create continuous process flow to bring problems to the surface.
(3) Use 'pull' systems to avoid overproduction.
(4) Level out the workload (heijunka)—work like the tortoise, not the hare.
(5) Build culture of stopping to fix problems to get quality right the first time.
(6) Standardized tasks as the foundation for continuous improvement and employee empowerment.

(7) Use visual control so no problems are hidden.
(8) Use only reliable, thoroughly tested technology that serves people and processes.
(9) Grow leaders who thoroughly understand the work, live the philosophy and teach it to others.
(10) Develop exceptional people and teams who follow your company's philosophy.
(11) Respect your extended network of partners and suppliers by challenging them and helping them improve.
(12) Go and see for yourself to thoroughly understand the situation (genchi genbutsu).
(13) Make decisions slowly by consensus, thoroughly considering all options; implement rapidly.
(14) Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen).

According to the Lean Enterprise Institute, lean methods have now been effectively applied in a wide range of industries to different types of works, including repetitive manufacturing of different product types, health care delivery and services such as the Canadian postal service (http://www.lean.org). In the next section, we discuss application/adaptation of lean principles and methods to project production systems.

From lean production to lean project management

A brief history

To our knowledge, lean was first linked to construction in Lauri Koskela's 'Application of the New Production Philosophy to Construction' (Koskela, 1992). Koskela challenged the construction industry to stop hiding behind the excuse that construction is not manufacturing and to learn from the revolution underway in manufacturing.

During his year at Stanford, Koskela and Glenn Ballard, an adjunct professor at U.C. Berkeley, began working together. In August 1993, they held a small conference at VTT, the national building research institute, in Espoo, Finland, where Koskela was a researcher. That was the first annual meeting of what came to be called the International Group for Lean Construction (http://www.iglc.net), a loose association of like-minded scholars and thoughtful practitioners.

The following 19 years have seen both theoretical and practical development. Koskela has led the theoretical battle, counterposing his transformation, flow and value theory of production against the economics-based conceptualization of production solely as a transformation of inputs into outputs (Koskela, 2000). More recently, he has discovered the historical underpinnings of the 1960s shift in management education and research from a foundation in production to a focus on quantitative methods, economics and the behavioural sciences. This shift, now 50 years running, has been repeatedly criticized for its lack of relevance to management practice (Ackoff, 1979; Barley and Kunda, 2001). Koskela now calls for an end to a failed experiment and a return to management education and research with a foundation in production (Koskela, 2011).

Application of lean to practice has not been neglected. Leadership has been provided by the Lean Construction Institute (http://www.leanconstruction.org), founded in the USA in 1997 by Gregory Howell and Glenn Ballard (http://www.leanconstruction.org).

It has proven impossible to simply imitate many of the methods employed in lean manufacturing, although some are more amenable to imitation than others. Generally, adaptation is required to the peculiarities of different types of production systems. This was understood from the beginning of the lean construction movement, partly as a result of historical accident. When Koskela and Ballard met in 1992, Ballard was developing the Last Planner System, to be described in detail in a later section of this paper. Once they and others started grappling with the question as to how to apply lean principles, it was realized that the sequence of tasks and flows of materials could be fixed in repetitive manufacturing by the location and connection of workstations. Construction is a type of fixed-position manufacturing, in which the constructed objects eventually become too large to move through fixed workstations. The situation is reversed; workstations become mobile and move through the objects. The sequence and timing of these workstation movements are driven by planning rather than by fixed structure. This realization made lean construction proponents sensitive to the need to adapt rather than to imitate Toyota's product development or manufacturing practices.

This adaptation was accomplished in large part through a series of white papers published by the Lean Construction Institute in a 14-month period in 1999–2000 (available at http://www.leanconstruction.org). LCI White Paper #8, 'Lean Project Delivery System' (shown in Figure 1), provided a schematic that proved to be useful in standardizing terminology and in defining the research frontier.

It also expressed some basic features of the lean approach to project management; for example:

(1) all life cycle phases are to be taken into account in designing and making,

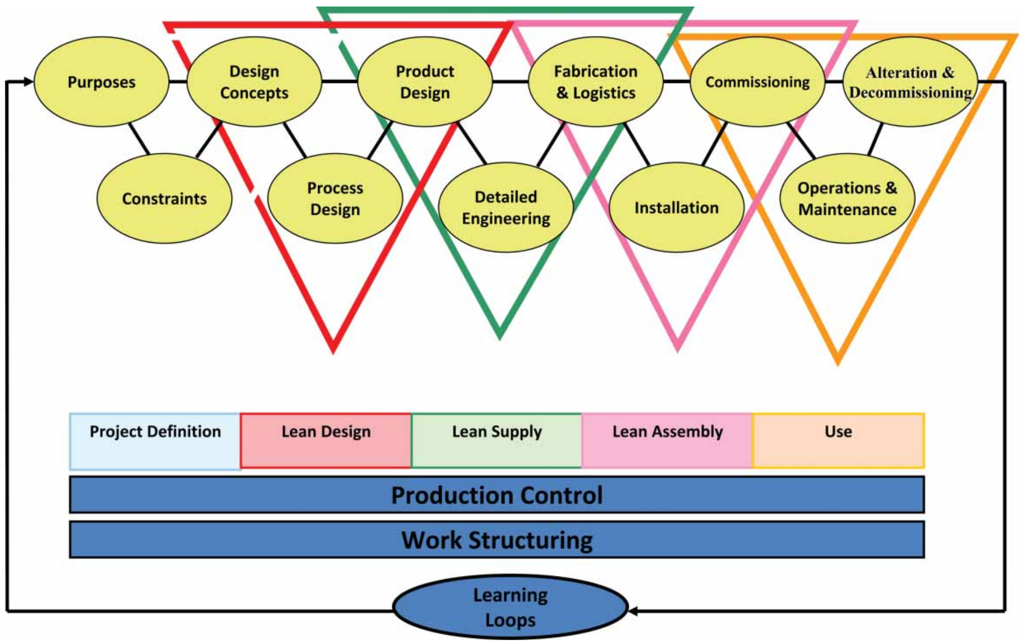

Figure 1 Lean Project Delivery System

(2) project phases are conceptualized as interlinked triads, and development within phases is understood to occur through a kind of 'conversation', consistent with the fundamental lean principle to do work only on request, discussed in the next section,
(3) decisions regarding product and process design are to be made together, and
(4) work structuring (process design at every system level) and production control are the primary management methods for governing project delivery through all its phases.

From repetitive manufacturing to projects

Figure 2 obtained from Schmenner (1993), who adapted it from Hayes and Wheelwright's (1979) typology of production systems, shows the range of systems for making things, from those in which the product flows continuously (liquids and gases) to job shops and projects. Product mix varies from standard products in very high volumes to one of a kind or few. Process pattern varies from rigid, automated flows to very jumbled flows, with process segments loosely linked. Brink and Ballard (2005) noted that lean manufacturing has been successful in converting batch flows into line flows, whether worker paced or machine paced, and explored the limits to applying manufacturing cells, a specific lean method, to job shops and projects, based on the size and temporal duration of product families.[2]

Another limitation in the applicability of lean methods is also apparent as regards automated processes. Process plants may benefit from lean in their design and construction, but there appears to be little place for lean methods in their operation. Perhaps the underlying issue is the human role in operation—or rather the lack of such a role—and the existence of a continuous flow process to start with. If humans need not cooperate in order to produce something, the applicability of lean methods appears to be reduced. When product flows continuously, there is no need for the rule 'Do work only on request'. Conformance to the rule is built into the process flow itself and is governed by automated controls. The lean ideal can still be pursued in the designing of automated production systems, and there is very likely need for lean methods in maintenance, but operations appear to be off-limits. We return to this interesting question of limitations and contextualization of lean in the fifth section.

Although many of Toyota's manufacturing methods are applicable to construction, Toyota's product development system is the true counterpart to construction. Everything that is mass-produced is first produced in a product development system, which stops when repetitive manufacturing begins. Construction projects have the same scope; use of the product begins after construction ends.

The difference between manufacturing's product development and construction projects is that the former develop the means for producing multiple copies of a product, while the latter produce only the prototype and do not produce copies.

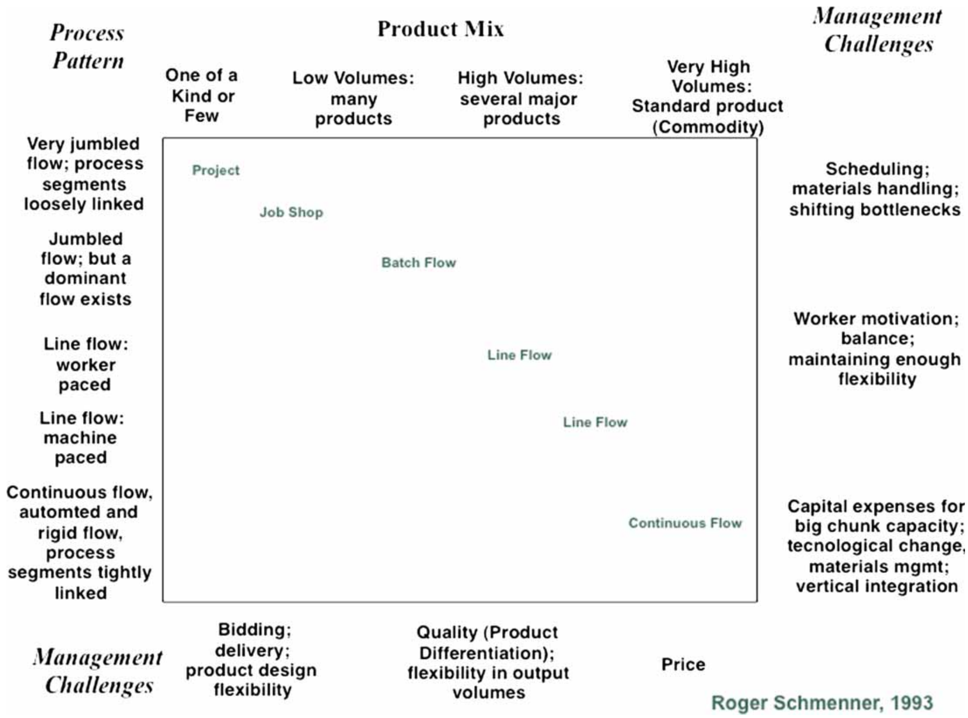

Figure 2 Types of production systems (Schmenner, 1993)

Construction's products are rooted in location and are highly impacted by their physical, social, environmental and aesthetic contexts. Automobiles, refrigerators and wrist watches may be used anywhere on the planet, regardless of where they are made. Buildings, bridges, factories, highways, tunnels and dams must be adapted to their locations. Differences in meteorological and seismic conditions alone demand adaptations of otherwise standard designs. Differences in regulations and codes, in the demand for aesthetic harmony and in the availability and cost of (local and distantly sourced) materials and many more differences further increase the demand for adaptations to context.

Competing approaches to bringing lean into construction

Some attempts to bring lean into the construction industry have proposed to make construction into repetitive manufacturing. Standardization of product design is expected to enable application of repetitive manufacturing methods. This seems to be a particularly strong view in the UK, reflecting the influence of the Egan Report (Egan, 1998).

This has not been the dominant view among lean construction proponents, who are better represented in the following excerpt from 'Construction: One Type of Project Production System' (Ballard, 2005):

> In the U.S., and broadly in the international community, lean construction has been taken up with the idea that the project is a more fundamental form of production system than the factory. For the author, construction is one of many types of projects for which theorists and practitioners are developing theory and tools, alongside air and sea shipbuilding, performing arts productions, software development, product development, fabrication (job) shops, oil field development, health care delivery and work order systems such as plant maintenance.

The argument for the project being the most fundamental form of production system is that all products, mass-produced or custom, are first designed and made in a project, specifically in a type of product development system. Construction is one type of product development system, dedicated to designing and making (producing) engineered-to-order (aka 'custom') products that are rooted in the earth. Some products, traditionally understood as products of construction, such as fabricated housing, may be subject to repetitive manufacturing methods in offsite fabrication shops, as are many of the components that are assembled into custom facilities; consider basic materials such as wallboard, lumber and nails and also more complex components such as motors and pumps. Other components, such as turbines and compressors, are typically engineered-to-order, but can be built in one place and used elsewhere. It is the design of the whole that makes a product engineered-to-order, not the design from scratch of every component.

For those who see construction in terms of engineered-to-order products, the larger challenge of lean construction is to learn how to manage all types of project production systems. What principles and methods apply to all? Which principles and methods require adaptation to differences in the work being performed in each type of project production system?

To take one example, lean has been applied very successfully to oil field production, conceptualizing each well as a project moving through a multi-project processing system. The approach taken was to reduce variation in work flow as wells moved through a series of processes from the design of the well by engineering to putting oil and gas in pipelines where they add to sellable product inventories (Ballard, 2007). The reduction in workflow variation allowed resources to be reduced to match the lower workload peaks, resulting in a saving of 25% in development costs and a reduction of 32% in cycle time (Figure 3), not to mention the additional profits from increased capital turns. Each point in the graphic shown in Figure 3 represents the cycle time of a well from the start of drilling to product flowing into the pipeline. Although there remain a few outliers, the reduction in variation after implementation of lean methods is evident.

Adaptation was needed to the oil field environment, but the lean ideal was held constant, as were many of the lean principles already found in the Toyota Way; for example, principle #3: 'Use "pull" systems to avoid overproduction' and principle #4 'Level out the workload (heijunka) – work like the tortoise, not the hare'. We return to this issue of the limitations on application of the lean philosophy in the fifth section.

Last planner: a lean project management method

This section describes one key lean project management method, the Last Planner System. The development of the Last Planner illustrates the adaptation of lean principles and methods from their origin in repetitive manufacturing to the project domain.

Last Planner originated in 1992, in the discovery that only 54% of tasks on weekly work plans were completed, on average, on numerous projects of seven highly regarded construction companies (Ballard and Howell, 1998). In most cases, labour capacity was diverted to other tasks, making this phenomenon invisible to those focusing only on productivity and on progress. Tasks may have been done out of sequence, but the rework penalty for doing so would be felt later. This was discovery of an underlying determinant of historical norms, so the corresponding unit rates and unit costs did not signal the need or opportunity to improve performance.

The research findings were initially interpreted within the conceptual framework of productivity improvement to explain the low productivity of crews and design squads that had to shift from one task to another. Once introduced to the lean manufacturing literature,

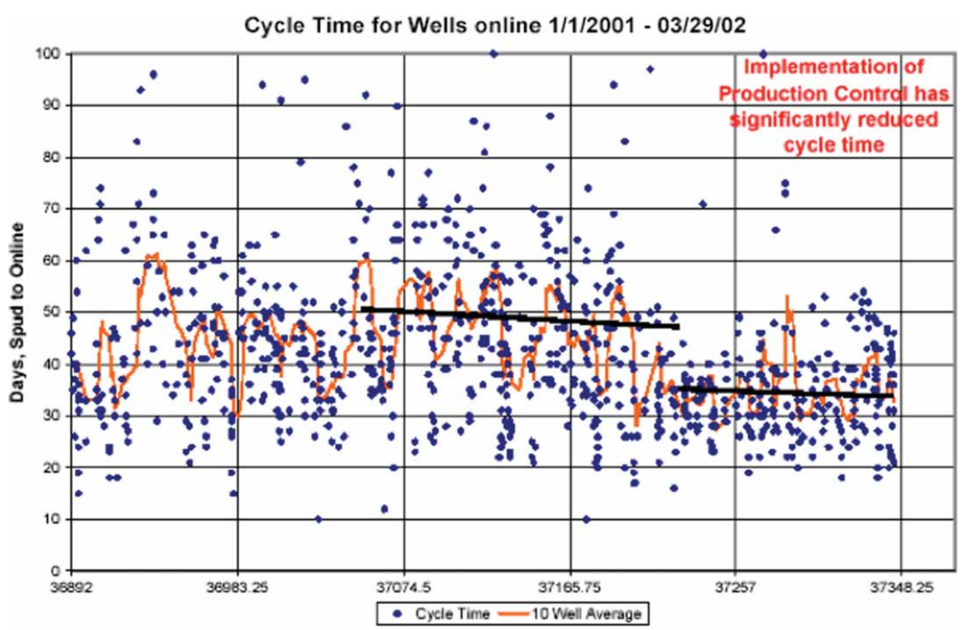

Figure 3 Cycle time per well

it became apparent that the major impact on performance was from poor work flow reliability. Work plans made within one week of execution were very poor predictors of work released to following 'trades' one week later. At 54% percent plan complete (PPC), the chance that the current plan will accurately predict the work available to be done next week was almost that of a coin toss. Given this fact, it would be no surprise if design squad bosses and construction foremen were to give up extensive preparation for performing specific tasks and rather be satisfied to do whatever work happened to be available. It became apparent that the invisibility and low reliability of work flow were major contributors to the poor productivity in construction compared with other industries.

Weekly work plans

The Last Planner System was designed in stages, working from bottom (weekly work plans) to top (project schedules). The first problem was as to how to improve PPC, the percentage of planned tasks completed as planned. Four quality criteria for assignments on weekly work plans were proposed to improve the PPC of these plans: definition, soundness, sequence and size. These were rules for selection and formation of task assignments intended to shield direct production from upstream variation (Ballard and Howell, 1994a).

(1) Definition: An assignment is adequately defined when those who are to perform the assigned task can determine if and how to perform it and what instructions, materials, special tools, special skills, access, equipment, etc. are needed.
(2) Soundness: An assignment is sound if all constraints that can be removed prior to the plan period have been removed, and if those who are to perform the task are confident, the remaining constraints can be removed during the plan period.
(3) Sequence: An assigned task is in the proper sequence when it is critical, in critical path method (CPM) terms, when its immediate customers will be ready to work on its product at release and when performing the task now does not incur a later rework penalty.
(4) Size: Tasks are assigned within the capabilities of those who are to perform the tasks.

Once the importance of work flow reliability was understood, this led naturally to the realization that personal commitments were needed between interdependent front-line supervisors, aka 'last planners', followed quickly by a second realization, namely that you cannot make a promise if you cannot say 'no'. With this insight, the disruptive character of the Last Planner System and lean, in general, began to become apparent. Construction projects had previously been practised largely through command and control, with tasks assigned as orders, reinforced by contractual penalties. Commitments were neither requested nor given (Howell and Ballard, 1994a). Understanding of the extent to which fundamental change is required in industry practice has continued to grow from this original insight.

The lookahead (make-ready) process

Improving PPC was expected to improve productivity by increasing certainty of work available the following week and hence preparation for performing those tasks. However, it was understood that PPC could be 100% and the project could still fail to progress on schedule. Progressing on schedule is rather a function of making the right tasks ready to be performed at the right time. A new and improved lookahead process was proposed to perform this function, principally through meticulous identification and removal of constraints on tasks scheduled to be performed in the next six weeks (Howell and Ballard, 1994b). On reflection, a name different from 'lookahead' might have avoided confusion with traditional lookahead processes in construction, which have not made transparent the status of future work, but rather have functioned as early warnings of mobilization: 'You will be ready to form the interior basement walls two weeks from now, right?'. These are not requests for commitments, but thinly disguised commands to which the expected response is 'Aye aye, sir'.

Typical constraints for tasks were identified and spreadsheets, like the one given in Table 1, were used for status constraint removal and the soundness of scheduled tasks.[3]

In weekly Last Planner meetings, managed usually by the superintendent (construction) or the design manager (design), the supervisors of the various specialists review tasks scheduled to be performed in the next three to six weeks and accept responsibility for removing constraints. The rule is to notify the team immediately if one loses confidence that constraints can be removed in time to start the task when scheduled. Note the difference from waiting until you are sure you cannot remove a constraint to notify the team. A early warning provides more time and resources for removing the constraint or, if this is not possible, for replanning around the constrained task.

As shown in Figure 4, the design of work methods has been considered part of the lookahead planning process since the initial design of the Last Planner System (Ballard and Howell, 1994b). The current thinking is

Table 1 Constraint analysis in the lookahead process

Activity ID	Activity description	Planned start date	Responsible party	Contract/ change orders	Design			Materials	Labour	Equipment	Prerequisite work	Space	Sound?	Comments
					Drawings complete	Submittals	Requests for Information (RFIs)							
11	Rebar erection for first-floor columns 5–8	15 January 2007	Rebar sub	X	X	X	X	Delivery Monday am	X	X	X	X		
12	Electrical inserts/rough-in for first-floor wall w1	15 January 2007	Electrical sub	X	X	X	X	X	X	X	X	X		
13	Formwork for first side for first-floor wall w1	15 January 2007	General contractor (GC)	X	X	X	X	X	X	X	X	X		
14	Mechanical penetrations in first-floor wall w1	15 January 2007	Mechanical	X	Shop drawing approval	Puddle flange (seal)	X	X	X	X	X	X		
15	Strip formwork for columns 1–4	15 January 2007	GC	X	X	X	X	X	X	X	X	X		
16	Electrical inserts/rough-in for columns 5–8	16 January 2007	Electrical sub	X	X	X	X	GI couplers	X	X	X	X		
17	Formwork for first-floor columns 5–8	17 January 2007	GC	X	X	X	X	X	X	X	Inspection	X		
18	Formwork for second side for first-floor wall w1	16 January 2007	GC	X	X	X	X	X	X	X	Inspection	X		
19	Pour concrete for first-floor wall w1	17 January 2007	GC	X	X	X	X	X	X	X	Inspection	X		
20	Pour concrete for first-floor columns 5–8	18 January 2007	GC	X	X	X	X	X	X	X	Inspection	X		
21	Second-floor slab falsework for area 1	16 January 2007	GC	X	X	X	X	X	Carpenters	X	X	X		
22	Second-floor slab deck formwork for area 1	17 January 2007	GC	X	X	X	X	Plywood delivery Tuesday pm	X	X	X	X		
23	Second-floor rebar installation for area 1	18 January 2007	GC	X	X	X	X	X	X	X	Deck	X		
24	Second-floor slab electrical rough-in works	19 January 2007	Electrical sub	X	X	X	RFI # 33	X	X	X	X	X		
25	Second-floor slab mechanical penetrations (service crossings and box outs)	19 January 2007	Mechanical	Yes	Revision awaited	X	X	X	X	X	X	X		
26	Falsework for first-floor staircase 1	19 January 2007	GC	X	X	X	X	Scaffold delivery Wednesday am	X	X	X	X		
27	Preassemble forms for lift wall	19 January 2007	GC	X	X	X	X	X	X	X	X	X		

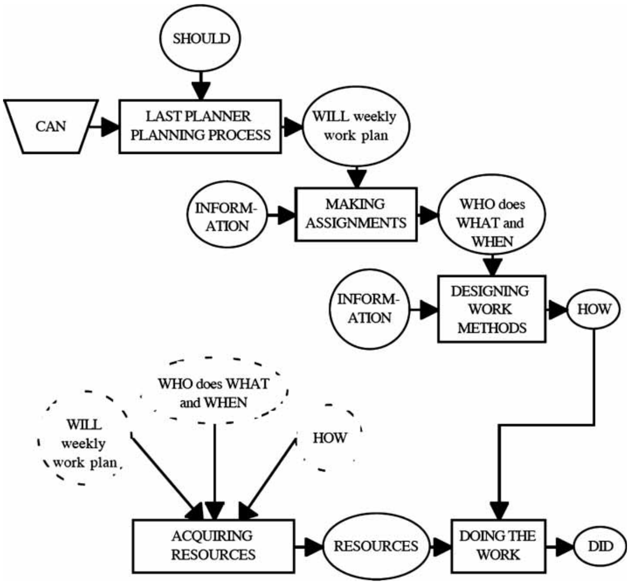

Figure 4 Designing work methods (from Ballard and Howell, 1994b).

to do constraint analysis at the process level of task definition (the level at which phase planning is usually done) in the first three weeks of the six-week lookahead period, then breakdown scheduled tasks into operations,[4] and finally design these operations so that they can be tested in their first runs (Hamzeh *et al.*, 2008).

Master and phase scheduling

Constraint analysis and removal, supported by the solicitation and making of public commitments, proved effective in making tasks that appear in the lookahead window ready, but did not assure that all relevant tasks were included in the schedule or that tasks were in the best sequence. Consequently, scheduling was added as a third component of the Last Planner System.

Outside construction, it is well understood that all plans are forecasts and all forecasts are wrong and that both forecasting further into the future and forecasting at greater levels of detail increase forecast error (Nahmias, 1997). Based on this premise, it was decided to plan in greater detail as we get closer to doing the work, principle #1 of the Last Planner System (Ballard, 2009a).

This principle was first applied to the master project schedule, the schedule covering the entirety of the project, from the start date to the end date, with the recommendation that such schedules be kept at the level of phase milestones, the level of detail often referred to in the construction industry as a proposal schedule. This follows from recognition that scheduling done nearer in time to execution generally benefits from more reliable information. The common industry practice was rather to develop schedules to a high level of detail in order to reduce the discretion of those performing the scheduled work and to facilitate micro-management. 'The schedule says you're to be placing piers 101A, B and C today in Area 5. Why aren't you doing that?'.

If all plans are forecasts, then the forecasting errors mentioned above apply to them. Far from being able to predict the day when specific work will be performed two years later, the only thing certain is that the work will not be done in accordance with that master schedule!

Specification of the second principle, to produce plans collaboratively with those who will do the work, led to collaborative production of phase schedules. Incorporating the experience and knowledge of those responsible for doing the work being planned was expected to yield schedules with higher anticipation of needed tasks and better sequence of tasks. Although there has been, to our knowledge, no rigorous evaluation, industry practitioners report good results and pull scheduling is in widespread use in companies involved with the Lean Construction Institute and its international affiliates.

Learning from plan failures

In the dynamic environment of construction projects, it is unlikely that we will be perfect planners. Indeed, in everyday life, we sometimes break our promises, despite thoughtful consideration of our capability to perform prior to committing. Even so, we can aspire to never making the same mistake twice. This requires learning from our plan failures, our broken promises.

This has been the most challenging component of the Last Planner System to put into practice. On projects, which are obsessively focused on objectives, there never seems to be time to reflect and to analyse. The strong temptation is to clean up the mess and move on, despite the fact that doing so virtually insures a repetition of the same breakdown in the future.

Sidney Dekker, who has devoted his career to exploring the challenges of learning from breakdowns[5] in safety, divides accident investigations into two types. In the first type, investigators are content with identifying a path, which, if taken, would not have resulted in the breakdown. The parties considered responsible are blamed for failing to take that path and the investigation is complete. Dekker says of this type of accident investigation that it does nothing to prevent the same accident from reoccurring.

He further proposes that prevention requires understanding why people acted as they did in the circumstances as they experienced them, that is, putting yourself in their shoes, subject to the same competing objectives, unclear information, delayed feedback, etc. For a number of reasons, the second type of accident investigation is very difficult to do. For one thing, in a short time after events, we begin reconstructing our experience. But perhaps the biggest obstacle is the desire to avoid blame and hence to withhold information that is argued by Dekker to be critical in preventing reoccurrence of the accident. There is a tension between the desire to learn and the desire to hold people accountable for their actions—a tension which is exacerbated by cultures that prize knowing over learning.

A number of different methods of root cause analysis have been proposed, but none have been systematically employed in practice. The problem appears rather to be in behaviour than in methodology. Although it seems quite clear that individuals have benefited enormously from the rigorous testing of their 'hypotheses' about reality, complete implementation of the learning component of the Last Planner System remains elusive.

Conclusion

The Last Planner System of production planning and control is disruptive to current project management practices, if for no other reason, because requests replace commands. It has proven effective in stabilizing work processes, which is a prerequisite for substantial investments in optimization. Its principles include 'Plan in greater detail as the time for action approaches' and 'Produce plans collaboratively with those who will do the work' (Ballard, 2009a). The first conflicts with the traditional practice of highly detailed master schedules. The second conflicts with imposing these schedules unilaterally on those who are to do the work.

As projects become more complex and uncertain, the extent to which pre-programming is effective is reduced, and dependence on proactive and opportunistic steering during project execution increases. Last Planner is a method that facilitates steering in rough seas.

The limits of lean project management

Lean project management is especially critical for successful performance of complex and uncertain projects. Traditional project management assumes a high degree of certainty and levels of complexity sufficiently low that they can be buffered by adding time to schedules and money to budgets and still keep projects economically viable. The fundamental requirement for successful application of traditional, non-lean project management methods is scope stability. If what is wanted can be definitively specified, with no risk of major change, then traditional management methods can be successful. Such methods include sequential processing, fixed-price contracting, reductionist work breakdown structuring and reactive project control.

Sequential processing comes with a rework penalty, in consequence of failing to consider all relevant design criteria when forming, evaluating and selecting from design alternatives. For example, reviewing designs for constructability after they are fully developed often reveals deficiencies in the designs. Rework is needed to correct these deficiencies. The risk of incurring the rework penalty, and the amount of rework to be done, increases directly with the extent of design innovation. If an existing design needs to be adapted only slightly to differences in location or capacity, the probability that the currently accepted 'means and methods' will prove to be inadequate is reduced.

Fixed-price contracting, when based on nominally complete design documents, is at risk for changes in the design, which provokes change orders, providing contractors an opportunity to increase their profitability. When competitive bidding is used as the basis for contract award, bidders may rely on change orders for all their profits or simply make them whole. This puts the parties to the contract in an adversarial, zero sum game. To the extent that the scope is firm and design is complete, the risk of exploitation is reduced. However, note that this does not reduce the risk to the project of the difference in commercial interests of the parties.

Work breakdown structuring is traditionally done to assure that all work scopes are assigned with no overlaps or omissions. Subsequently, the created structure is used as the basis for contract management and managerial control, which acts as if each contract and node in the work breakdown structure was independent and hence could be optimized for duration and cost as a means for optimizing the project. To the extent that the assumption holds, namely that the parts of the whole are independent (i.e. the project is less complex), traditional work structuring and the associated management practice can be successful.

Traditional project control starts with the identification of negative variances between SHOULD and DID. This signals the need for management attention, a scarce resource, which is to be expended on analysis and corrective action. This might be likened to driving a car while looking in the rear view mirror. Maintaining the analogy, a more proactive concept of control is steering the car towards its destination, which implies a management focus on the plan to complete rather than a focus on how well you are performing relative to your original plan. Obviously, traditional project control is the more appropriate choice when both project ends and means are fixed and definitive.

A research challenge

Deciding when to use lean or traditional methods of project management is currently inhibited by inability to adequately evaluate project complexity and uncertainty before project execution. There is little or no empirically based knowledge on the distribution of projects along the continuum between simple and certain, on the one extreme, and complex and uncertain, on the other extreme.[6] Indeed, the relevant variables may not have been accurately identified.

Project management research has focused its efforts on reducing uncertainty (though with less focus on complexity), with much less attention to managing in conditions of uncertainty and complexity. If industry practitioners are correct that projects have been and continue to become more complex and uncertain over time, a shift in research is much needed. Although planning and preparation are critical to project success, the extent to which this is true varies with the nature of the project. Successful management of complex and uncertain projects occurs more during than prior to execution. Furthermore, preparation takes on new content, with changes in team selection, commercial arrangements, organizational structure and management methods. Researchers and practitioners have been developing lean project management to meet the challenges of dynamic projects. It is now time to ground their intellectual products in the broader body of literature and to develop the knowledge needed for deciding when it is best to use lean methods.

Conclusions and recommendations for future research

We have offered a definition of lean as a philosophy of management specified by the ideal pursued, principles followed in that pursuit and methods employed in application of the principles. An explanation has been provided as to how lean was adapted from manufacturing to construction, and a major lean management method has been described, namely the Last Planner. We hope to have shown this and how these methods are helpful in managing complex projects. Finally, we have explored the limitations of lean in construction and explained how the use of traditional, non-lean management methods can be successful when projects are more simple and more certain.

We offer as a conclusion that lean management methods are better suited to complex projects than traditional methods. The greater the complexity, the more the lean methods are needed.

We have also identified a need for future research to develop means for more accurately assessing the complexity of projects before they are started. Examination of current risk management practices is a good starting point, because risk assessment is the current means for determining project challenge. If successful, this research would enable designing project delivery processes tailored to the challenge posed by each project.

Closely related to this research is the quantification of penalties imposed on users of traditional management methods relative to the risks of project failure, where failure is not achieving business objectives within conditions of satisfaction. Once we better understand where a project lies on the continuum between simple and complex, more information will be needed in order to make trade-off decisions.

Notes

1. The lean ideal has been stated slightly differently by different authors; for example, see Ohno (1988) and Womack and Jones (1996). The version provided in this paper is intended to capture the essential elements of the ideal.
2. Nonetheless, they reported successful application to a job shop (precast concrete fabrication) of other lean methods: total quality maintenance, 5S, process mapping, etc.
3. Spreadsheets were used to implement Last Planner in its earliest forms, followed in the late 1990s by software designed for purpose. The earliest, and still most widely used, Last Planner softwares are by Adept Management Limited (http://www.adeptmanagement.com) and Strategic Project Solutions (http://www.strategicprojectsolutions.com).
4. Projects consist of phases, phases of processes, processes of operations, operations of steps and steps of elemental motions. Steps are what are assigned to members of a work team; for example, fit the pipe, grind the pipe and weld the pipe. Designing work methods with the workers who will perform the first run assures the level of detail at which individuals' responsibilities are defined.
5. He has many relevant books. A good starting point is his *The Field Guide to Understanding Human Error* (Dekker, 2006). Dekker's work is focused on accidents in large, complex systems such as the aviation and maritime industries. We generalize from accidents as one type of breakdown, an unintended deviation from target outcomes, to other types of breakdowns relevant for the management of construction projects, namely broken promises (also known as plan failures) and errors that result in defects: planning, safety and quality.
6. Howell *et al.* (1993) are an exception. They reported findings regarding the extent to which there is uncertainty regarding project ends and means as late as the start of construction. They also found that the extent of uncertainty is routinely underestimated.

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