LEAN CONSTRUCTION MEANS TO PROMOTE GOOD- AND ERADICATE BAD VARIATION

Iris D. Tommelein

[1] Director, Project Production Systems Laboratory, http://p2sl.berkeley.edu/, and
Professor, Engineering and Project Management Program, Civil and Environmental Engineering Department,
University of California, 215-A McLaughlin Hall, Berkeley, CA 94720-1712, USA,
Phone +1 510/643-8678, FAX +1 510/643-8919, tommelein@ce.berkeley.edu

ABSTRACT: Lean construction researchers and practitioners have established a new paradigm for managing construction projects. This paradigm stems from insights gained by viewing project delivery as one kind of production and, inspired by the success of the Toyota Production System, leveraging Toyota's 'lean thinking' in the context of such one-of production. Premises of lean construction are that (1) production systems are riddled with variation, (2) variation can be good or bad, but most of it is bad, (3) most of this variation—good or bad—is self-inflicted; consequently 'lean' passionately promotes good- and relentlessly eradicates bad variation. This paper surveys a few of many lean construction means to manage variation. Lean thinking encompasses a lot more than thinking about variation, but that is the lens used here through which construction project management is viewed. Pairing these premises with lean variation-management tools may help readers broaden the insights they can gain from reading the lean construction literature.

Keywords: Lean construction; Variation; Production management; Toyota Production System, Transformation-Flow-Value Theory (TFV)

1. INTRODUCTION

In the course of the last ± 20 years, lean construction researchers have established a new paradigm for managing construction projects. Since 1993, the International Group for Lean Construction (IGLC) (http://www.iglc.net/) and since 1997, the Lean Construction Institute (http://www.leanconstruction.org/) have been advancing lean construction theory and promoting its practical application. We established the Project Production Systems Laboratory at UC Berkeley in 2005 to conduct 'action research' with industry, further tailoring lean concepts to suit the AEC industry's needs, and establishing a theory of project-based production (Koskela et al. 2002, Ballard et al. 2002). Concepts and examples presented in this paper sample the products of research being conducted in our Laboratory jointly with industry participants and by others; they do not present a comprehensive overview of all on-going lean construction research.

The lean construction paradigm stems from (1) insights gained by viewing project delivery as one kind of production (on a spectrum of production types that also includes job shops, batch flow, line flow, and continuous flow production) and (2) leveraging the 'lean thinking' that lies at the heart of Toyota's Production System (e.g., Ohno 1988, Womack et al. 1990, Liker 2003) in the context of such one-of production.

Researchers and practitioners of lean construction, inspired by the success of the Toyota Production System, aim to achieve the 'lean' ideal, namely to "do what the customer wants, in no time, and with nothing in stores." In addition, their lean thinking has been inspired by Koskela's (1992, 2000) observation, stemming from extensive review of the literature and discussion with colleagues, that three competing views on production management emerged in the course of the last century: (1) the Transformation view, (2) the Flow view, and (3) the Value-generation view. Koskela argued that these views are complementary to one another and all three must be adopted when managing production. Accordingly, he refers to the theory that combines them as the 'TVF theory of production.'

In the transformation view, "production is conceptualized as a transformation of inputs to outputs."

Koskela et al. (2002) noted that conventional construction is predominantly managed in accordance with the transformation view while ignoring flow and value generation, e.g., management efforts are centered on individual task optimization and resource productivity (Koskela 1992). The transformation view has two deficiencies (Koskela et al. 2002): “It is not especially helpful in figuring out (1) how to avoid wasting resources, and (2) how to ensure that customer requirements are met in the best possible manner.” Therefore, projects managed using such approaches tend to be ineffective and inefficient (Koskela and Vrijhoef 2000). In the flow view, goals include reducing variation, clearly articulating and simplifying handoffs, and decreasing lead times. In the value view, goals include identifying customers at all levels and generate value for all. “The crucial contribution of the TFV theory of production lies in calling attention to modeling, structuring, controlling, and improving production from these three points of view combined” (Koskela et al. 2002).

How then does one pursue the lean ideal and the TFV theory of production? This paper suggests that recognizing variation in existing systems is one place to start (variation may be the result of the manifestation of uncertainty, but for the sake of brevity, only the term variation is used in this paper). To illustrate how lean thinking pertains to managing variation in project settings, a sampling of tools and techniques is presented, selected from a much richer set available to lean construction community.

2. RECOGNIZING VARIATION

So what variation is to be recognized? It is common practice in our AEC industry to use deterministic models, ‘averaging’ data (or using other discretization methods), even when more realistic measurement and representation of that data shows it is stochastically distributed. Deterministic models serve a purpose, but one also needs to be aware of the limitations they impose.

To illustrate, consider for example shortcomings of models based on the Critical Path Method (CPM) with respect to capturing process variation. AEC practitioners plan and schedule work using CPM, and in the process assign each activity in the network a deterministic duration. Do project managers believe these activity durations can and will be adhered to? Durations may be sufficiently padded so they are upper bounds on allowable time to complete the activities. However, while using deterministic durations simplifies CPM network computations, it also introduces undue optimism, e.g., about one’s ability to meet project milestones and completion targets. That is, CPM ignores correlations between factors that may affect multiple activities (e.g., if two activities are positively correlated, then when one is late (early), the others will likely be late (early) as well). Furthermore, it also ignores network effects such as merge bias (where two or more paths in the network come together, i.e., ‘merge,’ it is not necessarily the chain of predecessor activities on the critical path that will set the successor activity’s start time; instead, any other path if delayed could define that successor’s start time). CPM also is based on the assumption that one knows exactly which dependency links will be followed (no conditional or stochastic branching) and that iteration (backtracking) does not occur.

Because the CPM model is based on such assumptions, users of this model are likely to overlook—if not ignore altogether—many kinds of possible process variation. Yet, process variation can have a significant impact on production system performance. For example, process models, such as the Pipe-spool Model (Tommelein 1998, 2006) and the Parade of Trades (Tommelein et al. 1999), have shown that tight coupling of tasks and variation in handoffs yield quite different performance results than a CPM model would be able to show, had such a model been developed for the same situation, because CPM would have required the modeler to abstract out stochastic production details and product variety.

A second example illustrates shortcomings of Building Information Models (BIMs) with respect to capturing product variation. An essential feature of a BIM is that it represents a building geometry in three dimensions (3D). Many BIMs also capture time and cost (4D and 5D) as well as other component and system attributes, yet, few of the models we have seen used explicitly reflect that the values taken on by geometric, temporal, or other variables may not be known exactly, but can vary for reasons such as human indecision or physical reality. Tools must be developed to support BIM users who want to explicitly capture such variation (e.g., Milberg and Tommelein 2005), though people recognize that variation may manifest when the BIM gets used in construction.

People’s reasoning and problem-solving abilities are biased by the conceptualization and representation they choose to adopt. Tommelein (2003) argued for developing and using representations that lend themselves to studying the impact of variation and uncertainty on the integrated product- an process-development process. A world in which no variation is recognized gets modeled naively, producing modeling results that tend to be unrealistically optimistic.

These observations are not new. The Program Evaluation and Review Technique (PERT) (Malcolm et al. 1959), which anti-dated the development of CPM, captured variations in project durations (though ignored the merge bias effect). Many stochastic models emerged after that. Forrester (1961), Crichton (1966), and others also expanded on systems being plagued by variation and uncertainty. This notwithstanding, besides recognizing variation, and building on the knowledge that the occurrence of variation can be detrimental to production system performance (Hopp and Spearman 2000), what 'lean' offers is a different, new mind-set and approaches for how to manage variation.

3. CHARACTERISTICS OF VARIATION IN PRODUCTION SYSTEMS

Characterizing various kinds of variation, gauging how large and dynamic variations can be, and identifying where variation may manifest itself in a system, are steps towards designing a production system that will take the most advantage of desired variation and be the least impeded by undesired variation. Relative to established construction management practices, this is a point of departure for lean construction.

Lean thinking applied to construction (meaning 'construction' in the broadest sense, not referring just to what takes place on site, but rather to all aspects of project delivery systems, e.g., including design and supply phases) starts from several premises:

1. Production systems are riddled with variation. Variation manifests itself in terms of product variation (e.g., alternative configurations, differences in attributes such as geometry, size and tolerances) as well as process variation (e.g., alternative methods and sequences of steps over time), as previously mentioned when pointing out limitations of CPM and BIM.

2. Variation can be good or bad, but most of it is bad. From a project-production system perspective and based on the values one espouses, some variation is deemed good, whereas other variation is deemed bad. For example, a community may not want each building in its neighborhood to look the same; here, variety is good because an individual or group of people values it (corresponding to 'do what the customer wants' in TPS and 'deliver value,' the V in TFV). However, if variation is not explicitly, positively valued, lean thinking treats it as unwanted and therefore strives to root it out.

3. Most of this variation—good or bad—is self-inflicted. The occurrence of variation is a consequence of how we structure and manage the systems we create; there is no inherent necessity for those systems to be subject to variation to the extent they are.

The following two sections categorize lean construction tools and techniques based on whether they promote good variation or eradicate bad variation, starting with the latter one first.

4. RELENTLESSLY ERADICATE BAD VARIATION

Some of the perhaps better-known practices in lean construction help to relentlessly eradicate bad variation. The AEC industry is so riddled with waste that many lean implementers start by tackling that form of variation first.

4.1 LAST PLANNER™ SYSTEM FOR PRODUCTION CONTROL

Fifteen-some years ago, Ballard conceived the Last Planner™ System in order to shield on-site construction from upstream variation (e.g., variation in the timing and quantities of the delivery of materials) (Ballard and Howell 1997, Ballard 2000a). With the shield in place (Figure 1), on the one hand, project participants can work to improve performance behind the shield (Ballard and Howell 1994a) and increase reliability of demand (reduce variation); on the other hand, they can work upstream with suppliers in order to shape the work flow, reduce lead times, standardize products and processes, and apply other supply-chain management practices (Tommelein et al. 2003) in order to likewise increase the reliability of supply (Ballard and Howell 1994b).

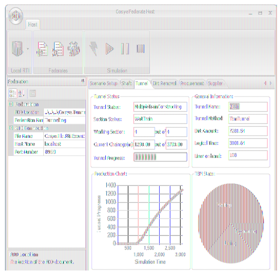

Figure 1: Last Planner™ System (after Ballard and Howell 1994; slide from Lean Construction Institute, http://www.leanconstruction.org/)

4.2 POKA YOKE OR MISTAKE PROOFING

'Poka yoke' in Japanese means 'mistake proofing,' a concept introduced at Toyota by Shingo (1986). Shingo's premise of 'zero quality control' is to 'do it right the first time.' Bodek stressed this idea (ibid p. vii) by stating that we should "drop the idea that defects are a normal part of manufacturing." In the AEC industry (and other industries), their thinking is contrary to the reliance of practitioners on inspection and punch lists as means to work towards an acceptable end product, hopefully one that is satisfactory and of quality! To eliminate the need for quality control, the practice of mistake proofing sets out to prevent errors or defects (unwanted variation) from occurring in the first place.

Dos Santos and Powell (1999) among others recognized the potential of poka-yoke devices to reduce variability in construction. Tommelein (2008) pointed out "that mistake proofing is particularly well suited for the AEC industry with its low-volume and mixed production systems where statistical quality control methods cannot be implemented due to lack of data and un-timeliness of findings that result from after-the-fact data processing. Mistake proofing requires a different way of thinking about production processes and its constituent operations, but once practitioners have learned to recognize mistake proofing devices, their new mind-set will enable them to spot numerous opportunities available to mistake proof their workplace. They will find that many mistake proofing practices can be implemented at a minimal cost, though some do require investment in new product development."

Her examples show "that mistake proofing can be practiced within a specialty (e.g., plumbing, electrical, or mechanical work), it can be practiced by designers, manufacturers, or fabricators to benefit a product as it is being constructed or throughout its lifecycle performance, or it can be practiced by designers to benefit a system (e.g., assembly of multiple components by multiple trade specialists).

AEC industry researchers and practitioners are not taking advantage to the extent they could of opportunities to mistake proof their processes and products."

5. PASSIONATELY PROMOTE GOOD VARIATION

A number of lean construction tools and techniques help to passionately promote good variation. They were developed in response to the recognition that project delivery is a complex socio-technical system in which numerous specialists participate, overcoming hurdles of extreme fragmentation as is the case for the AEC industry. People have to be able to speak openly, clearly, and in a timely fashion, so as to bring their wealth of discipline-specific expertise to the fore while pursuing value generation on a project.

5.1 EAMWORK IN THE BIG ROOM OR 'OBEYA'

Lean project delivery systems foster collaborative environments. Specialists may be co-located in an 'obeya' so that they can easily exchange knowledge and answer each other's questions, in order to design product and processes not necessarily optimal from any one individual's perspective, but more optimal as a whole.

"Obeya in Japanese means simply 'big room.' At Toyota it has become a major project management tool, used especially in product development, to enhance effective and timely communication. Similar in concept to traditional 'war rooms,' an Obeya will contain highly visual charts and graphs depicting program timing, milestones and progress to date and countermeasures to existing timing or technical problems. Project leaders will have desks in the Obeya as will others at appropriate points in the program timing. The purpose is to ensure project success and shorten the plan-do-check-act cycle" (Lean 2007). "The visual tools used in the o(o)beya along with the structure and discipline required to use them effectively have enabled a few companies to dramatically shorten project cycle time and quality (Tanaka 2005).

The practice of co-locating design and construction specialists is still extraordinary in the United States but it is becoming more common on lean projects. For example, on the Camino Medical Project (Mikati et al. 2007), specialty detailers from mechanical, electrical, and plumbing design-build contracting firms were co-located with the design engineers and general-contractor personnel on site. This enabled them to tightly coordinate their detailing work using BIM and readily work out solutions with other specialists (Khanzode et al. 2005, Hurley 2006).

5.2 SHARED UNDERSTANDING

Not only is setting the stage for open communication and collaboration important; also important in terms of managing variation are the removal of ambiguity in language use and the creation of shared understanding.

Macomber (2004) and Howell et al. (2004) state that "management of work in a lean project delivery is understood as 'making and keeping commitments'." They build on

Flores' (1982) work on language-action that articulates the notion of 'reliable promising' (Flores and Ludlow 1980), an effort at reducing variation caused by misunderstanding, now practiced among lean construction practitioners (at least in Northern California)(Macomber and Howell 2003).

Furthermore, lean construction contracts, such as the Integrated Form of Agreement (Lichtig 2006), can require that project participants establish clear communication and well-defined processes, thereby eliminating unwanted variation. By their very nature, such contracts also define the timing of opportunities to develop shared understanding (Lichtig 2008).

On projects, shared understanding develops gradually over time, based on when specialists join the delivery team. Figure 2 represents traditional project delivery. The owner selects the architect first to produce a concept design for the facility. Additional design specialists then get hired to engineer the foundation, structure, mechanical-, electrical- plumbing-, and other systems. When the design has been completed, it is submitted for building permitting and put out to bid. The general contractor and specialty contractors then get hired to create submittals confirming design intent, and to build the facility. Towards the end of the project, participants may reach ± 100% shared understanding if they reach it at all.

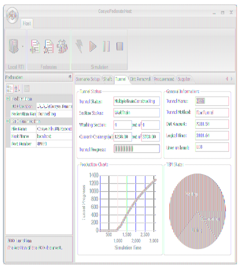

Figure 2: Development of shared understanding in traditional project delivery (after Lichtig 2008)

Contrast figure 2 with figure 3 that represents an opportunity created by using lean project delivery. The owner brings in early not only the architect but also design specialists and contractors, as well as representatives of regulatory agencies. Accordingly, the team can develop shared understanding much earlier and have more time to work toward reaching 100%.

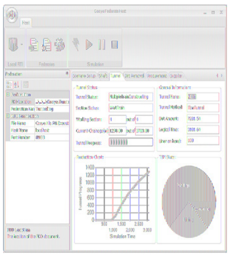

Figure 3: Development of shared understanding in integrated project delivery (after Lichtig 2008)

5.2 SET-BASED DESIGN

Set-based design (Sobek et al. 1999, Ward 2007, Ward et al. 1995, Morgan and Liker 2006, Kennedy 2008) offers a means for a variety of discipline specialists to explore project solutions that are more optimal as a whole, than a solution otherwise would be if everyone tried to optimize their own part. We have explored the use of a set-based approach for reinforced concrete design, bringing together a team of structural engineers, general contractors, placer-fabricators, and software providers (Parrish et al. 2007, Parrish 2009). We also have been documenting set-based approaches used in practice (Parrish et al. 2008).

Using set-based design, specialists keep their design spaces open for as long as possible; in this context, more variation is better because it offers them the opportunity to study value trade-offs. The methodology demands that specialists explore the value of each alternative in their own focus area, but that they also study overall value after integrating their alternatives with alternatives in other focus areas. Specialists weed out subsets only at the last responsible moment, i.e., the moment after which the decision maker no longer has that alternative to choose from, so that the need for backtracking (usually unwanted variation or 'negative' iteration (Ballard 2000b) can be minimized if not totally eliminated.

5.3 TEAM DECISION-MAKING USING THE CHOOSING BY-ADVANTAGES (CBA) SYSTEM

Teams of specialists must have means to make sound decisions when choosing between alternatives. Our P2SL researchers and industry practitioners are therefore using the Choosing by Advantages (CBA) system (Suhr 1999). The CBA system suits lean thinking exceptionally well because it promotes transparency (especially when different specialists in a group want alternatives to meet competing criteria) and decision-making based on facts. Furthermore, it enables teams to defer the most subjective assessment part of their decision making until the very end of the process (Parrish and Tommelein 2009).

5.4 USE OF A3 REPORTS TO SUPPORT CONTINUOUS LEARNING WITHIN AND ACROSS PROJECTS

Last but not least, at the heart of lean thinking is the desire to learn and continuously improve. In that vain, Toyota uses A3 reports (Shook 2008). A3 reports illustrate and explain implementation of the 4-step Plan-Do-Check-Act cycle—also known as the Shewhart (1939) cycle or the Deming (1986) cycle. Sobek II and Smalley (2008) relate PDCA to the scientific method: “Plan is developing a hypothesis and experimental design; Do is conducting the experiment; Check is collecting measurements; and Act is interpreting the results and taking appropriate action.” According to Deming (2000), the 4 steps in the cycle determine causes of variation, and define and test possible remediation of these causes.

6. CONCLUSIONS

This paper shed light on construction project management by viewing it through the lens of ‘variation.’ It introduced lean thinking about project delivery in this context. Accordingly, a simple characterization of lean construction may be: “lean construction offers means to promote good variation and eradicate bad variation.” Lean thinking encompasses a lot more than thinking about variation, nevertheless the view that was presented here may help readers broaden the insights they can gain from reading the lean construction literature.

7.ACKNOWLEDGMENTS

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