

# JOURNEY TOWARDS LEAN CONSTRUCTION: PURSUING A PARADIGM SHIFT

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## ABSTRACT

Professor Iris Tommelein was selected as the 2014 recipient of the ASCE Peurifoy Award. She was recognized “For her contributions in developing Lean Project Production theory, methods and tools, and for successfully disseminating these theories, methods and tools into multiple large, complex projects in the U.S. and worldwide.” With this recognition she was asked to present her vision on the field of construction engineering and management to participants in the 2014 Construction Research Congress, held in Atlanta, GA. This paper is the transcription of her presentation to this audience given on May 20, 2014.

## KEY WORDS

Lean construction, lean production, construction engineering and management, project management, sense-making, paradigm shift, design science, action research.

## 1. INTRODUCTION

It is a great honor to be recognized for my research work by being given the ASCE Peurifoy Award this year. I personally know many of the past award recipients and I am humbled seeing my name among theirs. Thank you for selecting me.

A presentation like this offers the opportunity for the speaker to reflect and share some learning. I thought I should share some learning from my ‘Journey to Lean Construction,’ a journey through changing times, and of course, a journey not taken alone, but with others, in particular those involved in the International Group for Lean Construction ([www.iglc.net](http://www.iglc.net)).

I am grateful that I have many people to thank—grateful that I have more people to thank than I possibly can thank in the time allotted for this presentation. This being the case, unfortunately, I

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cannot single out every one to whom I owe thanks: mentors, colleagues, the 1,000-some students I have taught and learned from in the course of 25+ years of teaching, other participants in research, friends, and family. I am also grateful for people in industry and in other organizations who have funded us over the years so we could do our research. I will name a few people in this presentation, but regardless of whether I name you or not: I thank you all.

## **2. WHAT IS LEAN – DEFINITION 1**

This presentation is about the processes we use for designing and making things, things such as capital projects, including buildings, bridges, etc. These processes make up a system, whether we intentionally design it or not. I will talk about designing that system. I will view that system from a lean perspective, so I will give several definitions of lean construction along the way, using illustrations based on the research I have been involved in.

Here is a definition of the more general term ‘lean production.’ First, what lean is not: Lean is not craft production, not mass production, but truly a third type of production system design. Lean refers to the pursuit of an ideal that is to: (1) Do what the customer wants, (2) in no time, and (3) with nothing in stores.

That sounds simple enough but it is really hard to do all three at once because these three are in tension with each other. For example, a supermarket may offer many choices of products on their shelves, so the customer can immediately get what they want, but this comes at the expense of the store carrying a huge inventory. Many paradigms sacrifice one for the benefit of the others. In construction we talk about time, cost, and quality: pick any two. Lean aims to achieve all three at once.

In order to achieve this ideal, lean thinkers follow a set of principles to attain that ideal, and in turn a set of methods and tools to apply those principles. Lean construction adopts the ‘lean thinking’ mindset. Lean is a philosophy. In this brief presentation I can only broach the subject, but if you would like to know more, there are many books to read (e.g., Womack et al. 1990, Womack and Jones 1997, Liker 2003, Liker and Meier 2005) and you can join the International Group for Lean Construction ([www.iglc.net](http://www.iglc.net)); we are open to all.

The desired outcome of this presentation—at least as far as I am concerned—is that I would like you to leave, if not necessarily agreeing with my thesis, than at least considering that lean thinking offers a new paradigm for construction and that it is worth pursuing.

## **3. CONCEPTUAL UNDERPINNING**

Let me start with defining concepts to frame this thinking and methodology, before we go on the journey.

### 3.1 Paradigm Shift

One underpinning is the concept of ‘paradigm shift.’ We owe the term paradigm shift to Thomas Kuhn (1962) who wrote the book “The Structure of Scientific Revolutions.” Let me quote from a practical source, Wikipedia (2014c), to explain what this is about:

“Kuhn made several notable claims concerning the progress of scientific knowledge: that scientific fields undergo periodic ‘paradigm shifts’ rather than solely progressing in a linear and continuous way; that these paradigm shifts open up new approaches to understanding what scientists would never have considered valid before; and that the notion of scientific truth, at any given moment, cannot be established solely by objective criteria but is defined by a consensus of a scientific community.

Competing paradigms are frequently [...] competing accounts of reality which cannot be coherently reconciled. Thus, our comprehension of science can never rely on full ‘objectivity;’ we must account for subjective perspectives as well, all objective conclusions being ultimately founded upon a subjective worldview.”

Paradigm shifts occur when anomalies are being observed, that cannot be explained by current thinking. Anomalies are incongruences within our current thinking. I will give some examples later (also see Koskela and Howell 2002). “As anomalous results build up, science reaches a crisis, at which point a new paradigm, which subsumes the old results along with the anomalous results into one framework, is accepted. This is termed ‘revolutionary science.’” (ibid).

As construction researchers, we have the opportunity to engage in revolutionary science.

### 3.2 Design Science and Action Research

What kind of a science is it? Obviously not physical science (such as physics or biology, i.e., the study of things that exist in and of their own in the world) or a fundamental science (e.g., mathematics), but what Herb Simon (1969) called the ‘sciences of the artificial.’ We know this now as ‘design science’ (e.g., March and Smith 1995), the second conceptual underpinning. Design science concerns itself with designing and making human artifacts to fulfill a purpose, and then testing and validating them.

Within design science, we can practice so-called action research (e.g., Dick and Dalmau 1999, 2000, Jarvinen 2007, Lukka 2003). Action research follows a progression of what W. Edwards Deming—and Walter Shewhart before him—called the PLAN-DO-CHECK-ACT steps for continuous improvement, a means for becoming a learning organization (e.g., Senge 1990). Figure 1 illustrates the process, starting by defining the issue by conducting initial observations and existing data, then planning an intervention, then intervening, and ultimately analyzing and reflecting on that intervention as well as reporting out. This cycle gets repeated over and over.

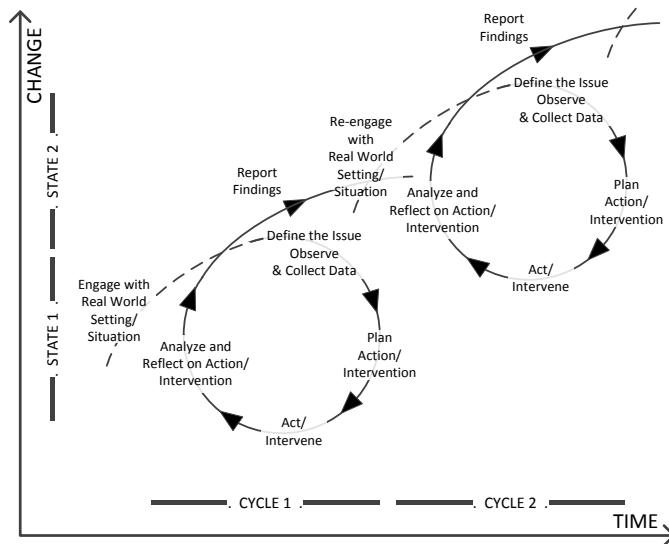


Figure 1: Action Research Cycles (modified from KIT (no date))

In order to do action research, we engage directly with the real world: action research in construction means working with design and construction personnel on live projects to try out new things. Live projects are our laboratory.

### 3.3 Cynefin Framework for Sense-making

The third conceptual underpinning is based on what David Snowden calls the Cynefin (pronounced /'kʌnɪvɪn/) framework for sense-making (Figure 2) (Kurtz and Snowden 2003, Snowden 2010, Snowden and Boone 2007).

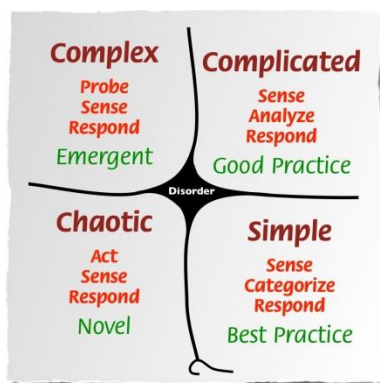


Figure 2: Cynefin Framework for Sense-making with all Five Domains Labeled (Wikipedia 2014a)

Snowden (2010) describes “Cynefin is a Welsh word that signifies the multiple factors in our environment and our experience that influence us in ways we can never understand. It stands for

habitat or place, a place of multiple belongings. You are rooted in many different parts which profoundly influence who you are, but of which you can only be partially aware. That is a complex system.”

This applies to projects too: projects are complex systems. In order for project managers in any situation to know how to manage, they must understand the domain they are in.

The Cynefin framework recognizes causal differences between different systems, so that given the situation you are in you can choose to use appropriate methods to respond, suitable to the domain. The framework includes three basic systems (Figure 2): at the right, the ordered domain (including the simple domain and the complicated domain) and at the left, the complex domain and the chaotic domain.

At the center of the framework is ‘disorder:’ the state we are in most of the time, not yet having recognized the domain we are really in. People interpret this then in terms of their personal preference for action, which is not necessarily the best one.

For the sake of time, let me explain just two of these (using quotes from Snowden 2010), but not all.

“In the simple domain, cause-effect relationships (1) exist, (2) they are predictable, and (3) they can be determined in advance. In simple systems, that relationship is self-evident to any reasonable person, as a result a manager can Sense-Categorize-Respond: we see what is coming in, we make it fit predetermined categories and we decide what to do, that is, we apply best practice.”

“In the complicated domain, cause-effect relationships (1) exist, (2) there is a right answer, but it is not so self-evident and therefore requires expertise. You will have to use an analytical model or call in experts who built expertise in that domain, who can make the right decision. In the complicated domain, we apply good practice (not best practice). There are several ways of doing things, all of which legitimate, if you have the right expertise. You’ll tick people off, by forcing them to adopt one practice, if they want to use another practice.”

Also notice that the boundary between simple and chaotic, marked by a wave at the bottom, is a cliff, not a transition as the other boundaries are. As Snowden (2010) says: “If you start to believe that things are simple, if you start to believe that they are ordered, you start to believe in your own myths. You start to believe that past success makes you invulnerable to future failure, you move to the complacency zone (the boundary cliff) and you fall over the edge into a crisis.”

So with these in mind, I can describe history better than I could have at the time, so let’s start the journey going back 30 years.

## 4. FORMATIVE YEARS 1984-1989

### 4.1 Commoditization of Computing

1984 was an exciting year, not in the least because the Apple Macintosh got launched. It is hard to appreciate today, but we were thrilled to have a computer you could carry with you in a bag, with a keyboard, a mouse, and 128K of memory. It was the start of the commoditization of computing technology.

### 4.2 Colleagues at Stanford

It was also the year I arrived for graduate school at Stanford where I spent five formative years, from 1984 through 1989. My advisors were Professor Ray Levitt and Dr. Barbara Hayes Roth, a cognitive psychologist. Others in and around the Construction Engineering and Management Program in the time period I was there included Clark Oglesby (retired), John Fondahl, Boyd Paulson, Bob Tatum, Hank Parker (retired), Greg Howell, Paul Teicholz, and John Kunz.

### 4.3 Construction Site Layout using Expert Systems

I was incredibly fortunate to have Ray as my adviser and he suggested I study expert systems to lay out temporary facilities on construction sites. Why that topic? First, if you think of space as a resource and how we manage it, you will notice the paradox: space is omnipresent but often overlooked in construction management; or at least, it was at that time—this has changed with Building Information Modeling (BIM). Second, few textbooks, if any, said anything at all about it. Spatial problems are inherently non-scalar. In contrast, problems dealing with other resources such as labor, materials, equipment, time and money are scalar: you can simply add up units. When you model space, you'll want two dimensions or even three. Third, it was a problem where expertise appeared to be needed. So in Snowden's framework, it was complicated, and therefore possibly suitable for expert system development, which Ray asked me to do.

With little written on the subject, in order to really grasp the subject, I had to 'go to the gemba:' as we say in lean: go and see for yourself. We selected to study the Intermountain Power Project in Delta, Utah, a large power plant under construction at the time, and off I went down Highway 50.

On site I found that space was abundant, so in that sense the problem was not hard. Of course, layout impacts travel time, so it does matter. The layout methodology used was trial-and-error. The rules of thumb to determine space needs were vague. Why? They had to be vague!

Think about it. On the one hand, the construction schedule was vague: you could not tell exactly what would be needed and when. On the other hand, the delivery schedule for materials to site was vague: you could not tell exactly what was going to arrive and when. So the layout masked (or 'buffered' as we say in lean) huge amounts of uncertainty.

#### **4.4 SightPlan and the BB1 Blackboard System**

In any case, under Ray's and Barbara's guidance, I used the BB1 blackboard expert system to develop SightPlan (Tommelein 1989, Tommelein et al. 1991, 1992a, b, c). I captured site layout domain knowledge as abstract strategies that could then be applied to any one specific project. You could call it an adaptive simulation system.

I worked hard on my technology 'solution' so to speak. When the model was running, we asked Reed Nielson from Bechtel, to come in and 'validate' it. Reed patiently watched SightPlan create a site layout. When the program finally had its solution, Reed said: "and how if I move this here and that there?" So I had a program, but not really a solution to the problem. People use computer programs to sharpen their own intuition and judgments.

It would have been nice to have had a different outcome, but isn't the process we went through what really mattered? Why? Because the process you can influence, whereas the outcome you cannot. As a PhD student, you start with one or a few questions that in the course of your research you try to answer. Little do you know however, that by the so-called 'end' of your work, you are going to have many more questions than you had when you started. To many this is unsettling but in lean thinking this is expected: in any current state, there always is a next improved future state to work towards.

Moving right along, the research served its purpose: I earned my degree. I got a job.

### **5. EARLY CAREER - FACULTY AT THE UNIVERSITY OF MICHIGAN 1989-1995**

#### **5.1 Colleagues at Michigan**

In 1989 I joined the faculty at the University of Michigan: My colleagues in the Construction Engineering and Management Program at the time were Bob Harris (retired), Photios Ioannou, Bob Carr, Bill Maloney, and later John Everett. Of note is that I was hired on with a 1989 cohort of assistant professors in the College of Engineering, including Bill Birmingham, Al Ward, and Jeff Liker. You may or may not know these names, but Al and Jeff became leaders in the development of lean production.

#### **5.2 Conceptualization of Construction Management**

Upon arrival, I found an incongruence: I had to ask that 'space' be added to the front-page image on our Program brochure. Even to date, many textbooks on project management say there are five resources to be managed in construction: (1) labor, (2) materials, (3) equipment, (4) time, and (5) money. Space is missing. If you don't even mention it, how can you manage it?

### 5.3 Technology for Site Layout Management

For some time longer, I followed the technology route. Especially for engineers, it is easier to get funding for that kind of research. We must be aware however, that our research agendas get skewed that way.

I obtained a laser-based positioning system and barcoding equipment, and went to the gemba to collect data on space use (Tommelein 1994a, b). However, the more I did of this, the more I realized the futility of the exercise. I really needed to understand what the space needs were driven by. This led me to take a broader systems view and study materials management, and later supply chain management.

### 5.4 Broader Systems View: Materials Management and Supply Chain Management

While studying these, what did I find? Embedded in the processes advocated as exemplary, e.g., for materials management (Figure 3), was waste, waste, waste. In lean, we categorize waste, so we can understand what causes it, and we can then systematically drive it out. Waste is anything the customer is not happy to pay for.

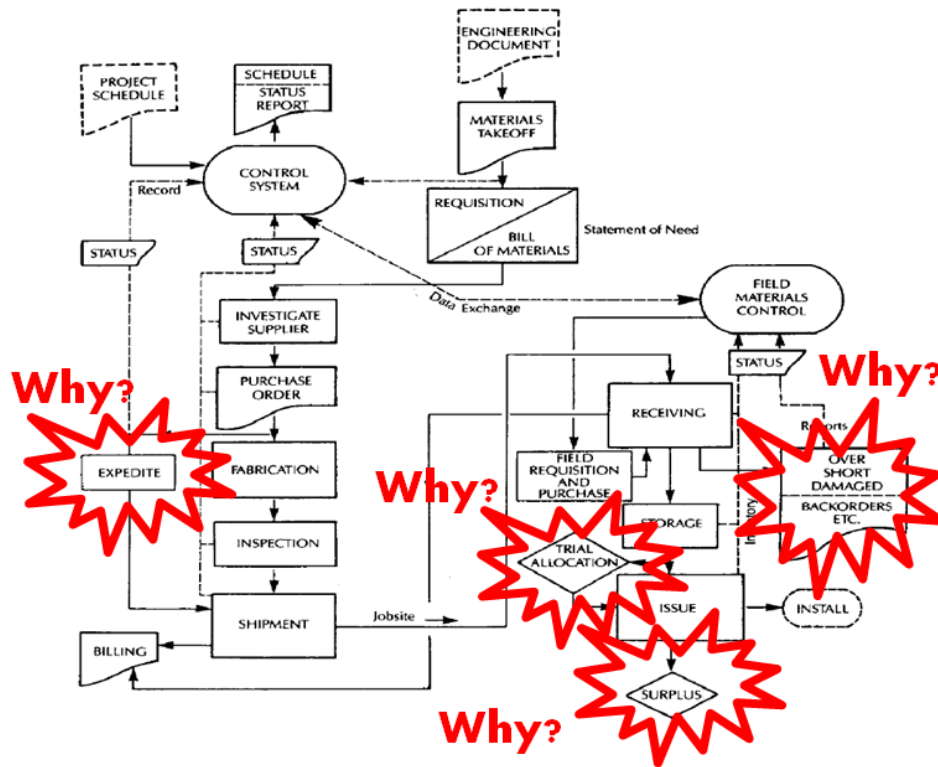


Figure 3: Construction Materials Management (adapted from Figure 1 in CII 1988a)

Figure 3 refers to ‘expediting.’ Per Wikipedia (2014b), expediting is “a concept in purchasing and project management for securing the quality and timely delivery of goods and components. The procurement department or an external expeditor controls the progress of manufacturing at



the supplier concerning quality, packing, conformity with standards and set timelines. Thus the expeditor makes sure that the required goods arrive at the appointed date in the agreed quality at the agreed location.” But expediting is a waste: it is because the supplier did not make a reliable promise or did not fulfill the promise made, that now someone else has to go check on them and expend additional resources to get what they had been promised to start with.

Let’s look at another one: ‘trial allocation.’ What does Wikipedia (2014d) say about that? “The page ‘Trial allocation’ does not exist.” Shall we add it? No I suggest we do not. Trial allocation is what you do when you prepare a work package for assignment to the crafts: you see what combinations of materials are indeed available to do the work, so you can issue a complete kit. The reason you need to do this is because you don’t really know up until then what materials you truly have available. Trial allocation is a waste. You have to do it because you don’t know what is in your pipeline. How about if we better managed that pipeline, so that we can avoid trial allocation altogether? We must strive to get rid of it.

Figure 3 shows several other examples of wasteful practices: surplus, overages and shortages, backorders, and arguably others. Interestingly enough, at the time, very little was written in the construction management literature on materials management, barring reports by CII (1986, 1988a, b) and one book by George Stukhart (1995). Why? I speculate that it is because materials management is a task related to procurement, often performed by people other than designers, engineers, and contractors.

So here is another incongruence in our thinking: procurement and materials management form a link in our systems: they connect design with construction. If we want to manage the delivery system as a whole, should we then not make them an integral part of it?

## **6. LEARNING TO SEE - SABBATICAL 1995-1996**

In lean we talk about ‘learning to see.’ we must do descriptive research to ‘see’ what really takes place in offices, trailers, and on site. This necessarily includes going to the gembu: go see for yourself. I took a 1-year leave from academia so I could go learn from the best. I am still grateful that Jim Goodwin, at the time Manager of Materials Management at HB Zachry, allowed me to share his construction site office at a refinery project in Pasadena, Texas.

While this project was being delivered using an Engineer-Procure-Construct (EPC) contract, this contract was not working. E and P mean that the engineering firm will handle procurement at least of the engineered and other large components. However Jim had been seconded to the site to come procure all the stuff that had been missed.

I spent a lot of time chasing pipe spools. They are difficult to identify because the drawings are dimensioned but not drawn to scale. Do you think this is making it more complicated than it should be?

This also was in the early days of bar coding, so it was not surprising the system was not working. The bar codes supplied were beautiful: color coded and laminated, yet utterly unsuitable for the task at hand. Bar code readers rely on contrast, so we usually print the bars black on white. Different colors may not offer enough contrast. Furthermore, when materials are sunning in laydown yards for weeks if not months, especially in Houston, the humidity will get under the lamination blurring the code. Why did this happen? Clearly, the bar coding had been supplied to meet contractual obligations, but they failed to do ‘what the customer wants.’

## **7. ON THE LEAN PATH - UC BERKELEY 1996 - PRESENT**

### **7.1 Colleagues at Berkeley**

In 1996 after my stint in Texas, I joined the faculty at UC Berkeley. My new colleagues were Keith Crandall (retired), Ben Gerwick (retired), David Ashley, Bill Ibbs, Laura Demsetz, Bob Bea, and last but not least Glenn Ballard. Also in 1996 I joined the International Group for Lean Construction and started to collaborate with Lauri Koskela and Greg Howell. Lauri, Glenn, and Greg have been enormously instrumental in shaping our lean thinking.

### **7.2 TFV View of Lean - Definition 2**

So here then is a second definition of Lean, one we owe to Lauri. Lauri had studied the project management as well as the production management literature, a body of knowledge spanning more than 100 years (Koskela 1992, 2000). He found that there were three competing schools of thought. (1) The Transformation (T) school of thought, where the whole gets broken into pieces, each with its inputs and outputs. Transformation is the dominant view in construction management. (2) The Flow (F) view, where one is concerned not only with transformation but also with resources and queues in-between. This is the view adopted, e.g., by those involved in time-based simulation. (3) The Value (V) view, where one aims to understand and deliver what the customer wants. Lauri argued that in order to manage systems effectively, we must adopt all three of these perspectives on production at the same time. He called it the TFV view of production.

### **7.3 Glenn Ballard and the Last Planner® System**

I also owe a lot to Glenn for his insights based on years of experience he gained as a productivity improvement consultant. Glenn had developed the Last Planner® System (Ballard 1994, 2000). Learning about the Last Planner® brought home to me that our planning systems should not be all the same one-size-fits-all, but rather adapted to the situation they are used in. Glenn also introduced a process metric called Percent Planned Complete (PPC) to gauge plan reliability, that is, it focuses on means-, not results of planning. The Last Planner® System offers a principled approach to planning, and it is fundamental in the lean construction toolbox.

## 7.4 Feedback Control Systems

Understanding the need for planning systems to be able to adapt to the circumstances as they arise, I started to study systems dynamics and feedback control systems (Tommelein 1998). Our traditional planning systems are push based: “I do what I need to do and then leave the output assuming someone is going to want it.” In contrast, lean advocates for pull planning systems, as they are responsive to customer needs and therefore superior in performance (e.g., Hopp and Spearman 1996).

Simulation is a good tool to design and experiment with pull systems. Figure 4 shows a model of pipe spool design (at the upper left), fabrication (at the lower left) and on-site construction work (at the right) subject to uncertainty in sequencing of work and uncertainty in time. In the center is a feedback link (pull) that helps to synchronize the onsite- with the offsite work, thereby improving system performance.

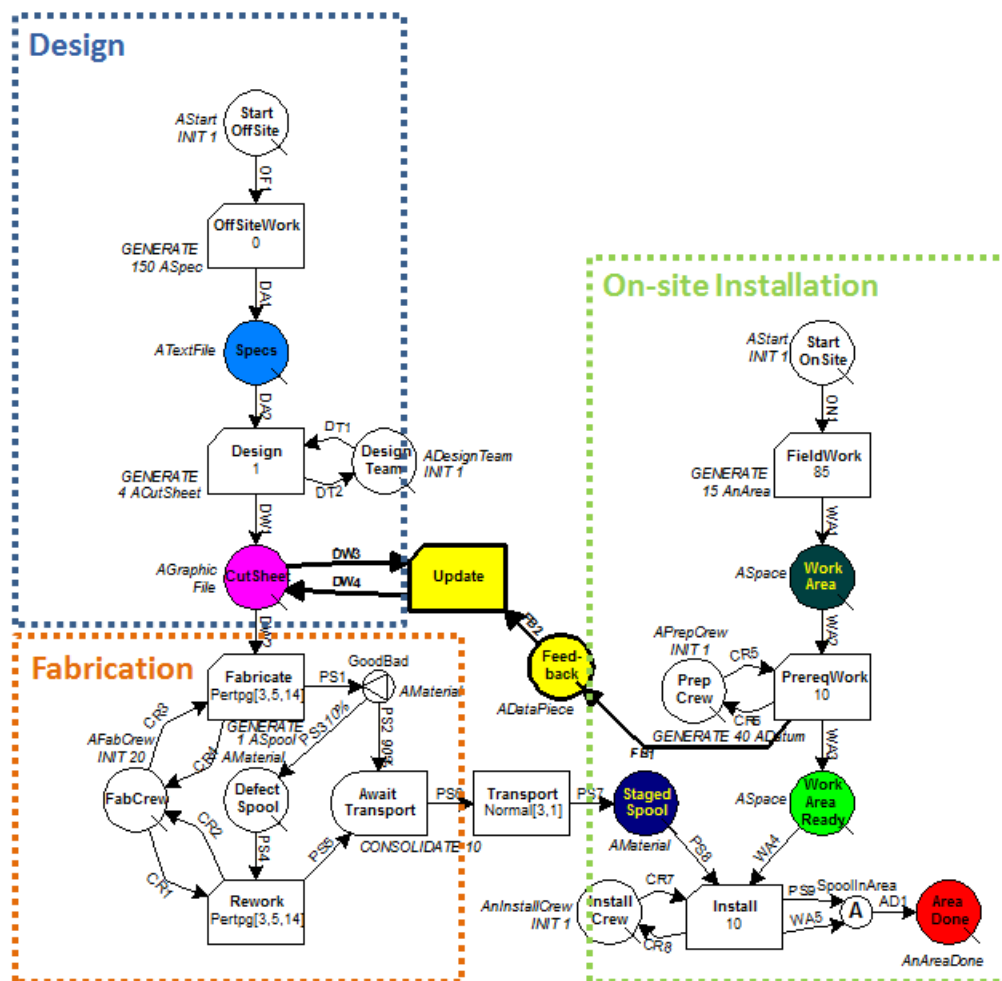


Figure 4: Pipe-spool Model with Feedback

We can plan all we want, but if work gets out of sequence, either onsite or offsite, we must give feedback to others, so the schedule can be adjusted. We need real-time feedback in our systems, especially in systems where parts are unique, as was the case for all those pipe spools.

## 8. WHAT IS LEAN - DEFINITION 3

This brings us to yet another definition of lean. Lean recognizes that the world is subject to all kinds of variation; it distinguishes good variation from bad variation. Good variation is variation that is intentionally wanted (e.g., we want buildings to not all look the same); all other variation is bad. To improve performance, lean starts by relentlessly driving out bad variation and then buffering where needed.

Look for example at the floor of this airport waiting area (Figure 5). Is its unevenness good or bad variation? One can argue it either way; it is a matter of personal value. I actually like the reflection of the light as if it were a ripple on water.

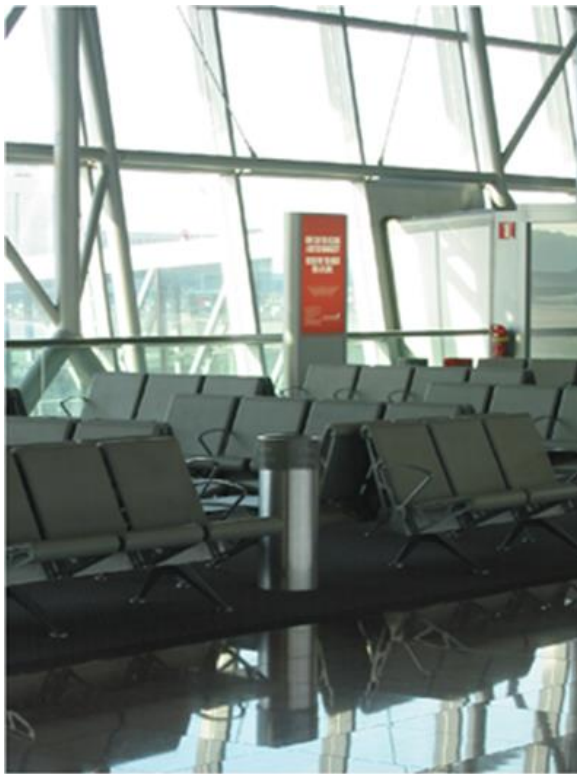


Figure 5: Waiting Area in Airport (© 2007 Iris D. Tommelein. All rights reserved)

How about the variation shown in Figure 6? Is it good variation or bad variation? And how about the variation shown in Figure 7? Is this good or bad variation?



Figure 6: Pipe Going through Floor (© 2007 Iris D. Tommelein. All rights reserved)

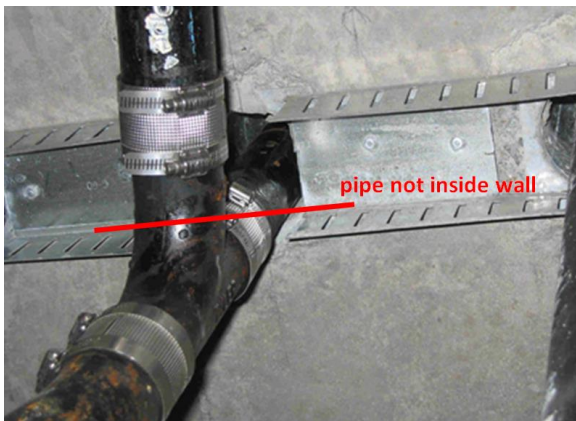


Figure 7: Pipe Going through Ceiling (© 2007 Iris D. Tommelein. All rights reserved)

These were examples of variation in space; of course there other kinds of variation, such as variation in time. You may be familiar with the ‘who waits for whom’ problem: e.g., Does the doctor wait for the patient, or does the patient wait for the doctor? This is the kind of question we must address in production system design.

## 8.1 Concept of Merge Bias

We need conceptual tools to recognize variation, so we can then eradicate all bad variation. So what concepts can we build on? Are you familiar with the term ‘merge bias?’ It is not a new concept, but it is a fundamental concept in production system design. In my opinion, it should be taught in every construction curriculum if it is not already.

Figures 8 and 9 offer an illustration. Assume that two activities A and B need to be completed by a certain time, say time 5, so C can start at time 5. If 5 is the mean value for the completion time of A, there is a 50% chance that A will be done by time 5. Likewise, if 5 is the mean value for the completion time of B, there is a 50% chance that B will be done by time 5. Therefore, C has only a 25% chance of starting at time 5. This is called merge bias.

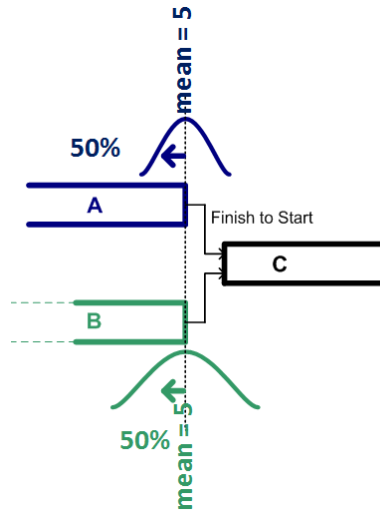


Figure 8: Example Schedule to Illustrate the Merge Bias Effect (© 2007 Iris D. Tommelein. All rights reserved)

	$A \leq 5$	$A > 5$
$B \leq 5$	C can start at 5	C delayed
$B > 5$	C delayed	C delayed

Figure 9: Computation of the Merge Bias Effect (© 2007 Iris D. Tommelein. All rights reserved)

Is merge bias a useful concept? When do we have to worry about merge bias? All the time! It matters in scheduling, or as shown in the pipe-spool model (Figure 4), where the offsite supply chain feeds the on-site construction work, and so on.

Figure 10 combines the merge bias concept with lean thinking. On the left as well as on the right, the merge bias effect occurs, but on the right, we have driven out variation so the distribution is more narrow for both A and B. How does that affect the likelihood that C will start, at time 5? It doesn't. But how does that affect the likelihood that C will start, say at time 6? In the case shown at the right, it will be much more likely. Elimination of variation makes the system more predictable. Lean strives for predictability: that is why we need to drive out bad variation.

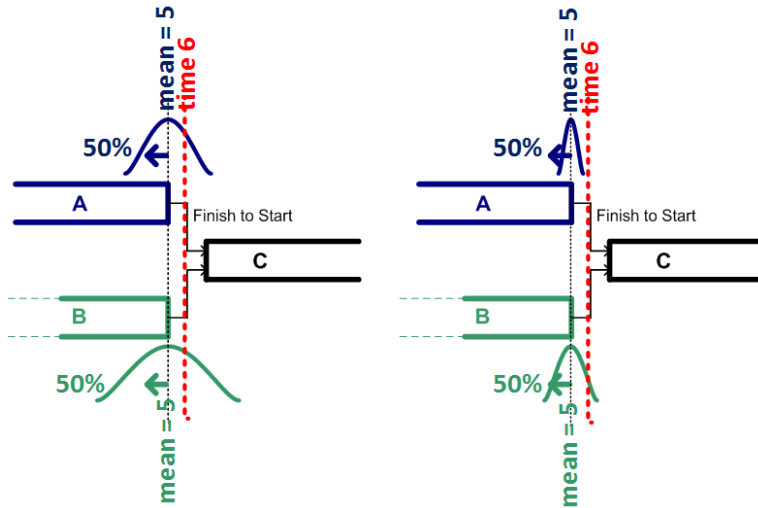
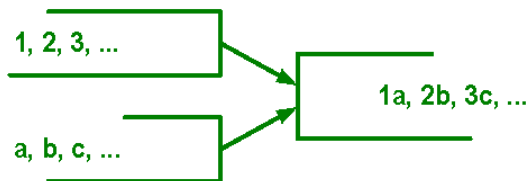


Figure 10: Lean and the Merge Bias Effect (© 2007 Iris D. Tommelein. All rights reserved)

## 8.2 Concept of Matching Problems

What I call the ‘matching’ problem occurs when you have unique parts that must be combined. As Figure 11 (top) shows, parts 1, 2, 3 and so on, must be matched up with parts a, b, c, and so on, to result in 1a, 2b, 3c, and so on. Of course the slightest out-of-sequence supply will throw off the system (bottom of Figure 11).

### EXPECTATION:



### REALITY:

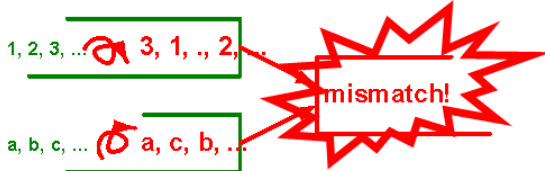


Figure 11: Illustration of a Matching Problem (© 2007 Iris D. Tommelein. All rights reserved)

This recognition should help encourage people to reduce variation, e.g., by standardizing parts. But do we? How many different kinds of doors might you expect in a prison facility with 1,000-some doors? Look at Figure 12: Why are there that many? Is this good variation or bad variation? Why?

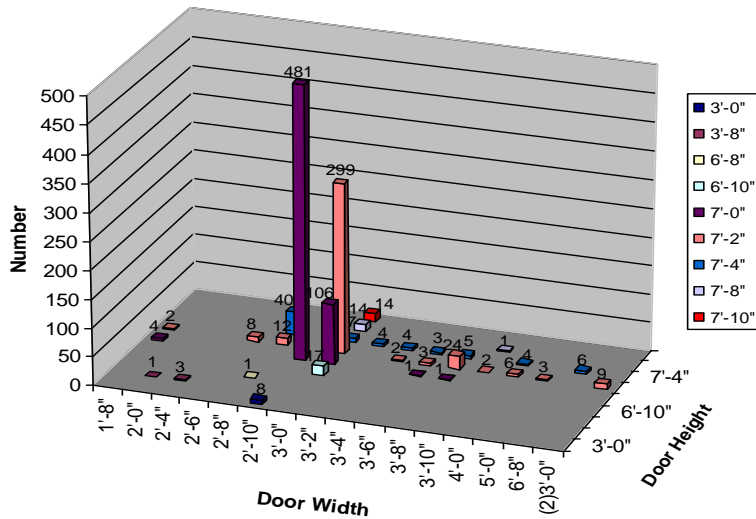


Figure 12: Variation of Hollow Metal Door Frames in a 750-bed Correctional Facility (n=1,095) (Tsao 2005, 2007, used with permission)

Why do we do this to ourselves? Let’s look at a metal stud wall in a healthcare facility. How many gauges of metal can we expect? Too many! Why? This is because designers design and then use cost models that are informed by estimating books that show different costs for different gauges (Figure 13). To stay within budget, they use lighter gauges where possible. But if more than 1 gauge is needed, we need to put more effort into procurement, we can suffer from matching problems, we lose out on substitutability, etc. Contractors who understand such process costs and risks, will ask to change the design.

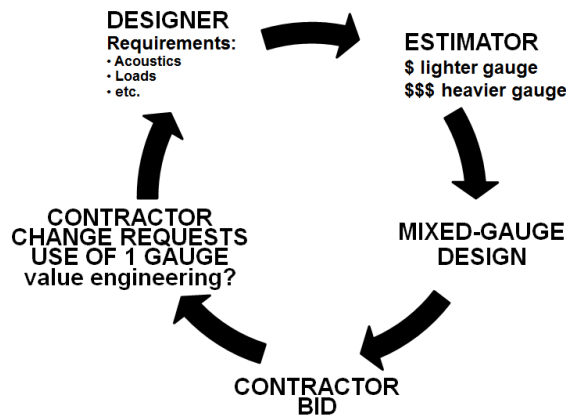


Figure 13: Design-Estimate-Redesign Loop (© 2013 Iris D. Tommelein. All rights reserved)

Is this change value added? No: it should not be a change! The designers should have considered such process implications of their product choices from the get-go. Regrettably even today our cost and estimating models are lacking in this regard.



Furthermore, many things happen at construction sites; people are creative. But is being creative a good thing? Creativity may lead to what Lauri calls the ‘make-do’ category of waste (Koskela 2004). Look at Figure 14 showing different means of capping rebar for safety, all observed on one project site. Is this good or bad variation?



Figure 14: Different Means for Capping Rebar for Safety (© 2014 Iris D. Tommelein. All Rights Reserved.)

The safety hazard has been addressed. If we inspect this work—when we ‘manage by results,’ that is, look at outcomes—all rebar is covered, all is well! But is it?

If instead we ‘manage by means’ (e.g., Johnson and Broms 2000, Rother 2009) as we do in lean, we must wonder what process led to so much variation. Is it good variation or bad variation? Is one method better than the other? And if so, why not adopt the best one as the current standard?

## 9. BREAKING AWAY FROM THE RESOURCE UTILIZATION PARADIGM

Let me give you one more example. I was on an infrastructure project, just last week, that is being delivered using a design-build-operate-maintain contract. I asked the contractor in the Joint Venture what this agreement enabled them to do in regards to constructability, that they would not have been able to do in a design-bid-build situation.

My host commented on the input they had had in the design process, especially in regards to standardization of the piers for the elevated rail system. With the designer, they had spent significant effort on limiting the number of different ones. But he felt they had not done enough: “I feel we have been too concerned with minimizing the use of concrete. We could have standardized more.”

Now I should ask you for the gut-feel sense you have: How many standard piers do you think they had? Three. This surprised me too! Three seems low already; how low can we go? We must study this case so we can really understand “we have been too concerned with minimizing the use of concrete.” It makes clear that we need to better understand how the resource utilization paradigm, in this case, minimization of materials, limited the systems design thinking and prevented them from standardizing even more. Again, I’d like to claim that we do not appreciate (enough) the process implications of product choices.

In the new paradigm, we can rethink what we do. Ongoing research in our Project Production Systems Laboratory ([p2sl.berkeley.edu](http://p2sl.berkeley.edu)) includes work on built-in quality and takt time planning (Frandsen and Tommelein 2014), among other topics. The superintendent on the project where we are engaged in action research to study takt time planning noted: “We have never sat down with the trades and asked them how they wanted to do their work before giving them the schedule.” Imagine the possibilities we have for designing our systems, if we could start with a blank sheet of paper!

## **10. LEAN TO SHAPE CONSILIENCE BETWEEN DESIGN AND CONSTRUCTION**

We have a huge opportunity, here and now. As mentioned, we do not (yet) know how to quantify the process implications of product choices. This is an old challenge, of course, so why is it a good time to get to the heart of it?

The reason is that after years of, first, specialization and fragmentation of the industry, and then, vertical and horizontal integration, we are now seeing consilience between design and construction (Isaacs 2012). “While design and construction functions are becoming increasingly complex and require ever-more specialization, the disciplines’ segregated silos are crumbling, creating space for integrated, cross-disciplinary thinking; new risk management strategies; and comprehensive business structures. ... What we have is the emergence of the polymath or Master Builder, reintegrated—within companies or between industry players” (Hoover 2013). While the age of the Master Builder is long gone, we have the opportunity to shape the capabilities of a Virtual Master Builder. Lean thinking can drive that shaping.

With the complex world we live in, in mind, let us revisit David Snowden’s Cynefin framework for sense-making. Remember, “the Cynefin framework is an analytical decision-making framework that recognizes the causal differences that exist between system types and proposes

new approaches to decision-making in complex social environments.” I think it can serve us to understand the nature of the project delivery systems we are trying to manage.

My hunch is that at least some of what makes our systems complicated, some of what makes them complex—is self-inflicted. It is the result of inadvertent or bad production system design choices. So here is a working hypothesis: I think that Lean thinking can help us take out a lot of self-inflicted, unwanted complexity as well as self-inflicted, unwanted complication, so we can do more with simpler systems. Application of lean practices helps us move in the direction of the arrows as shown in Figure 15.

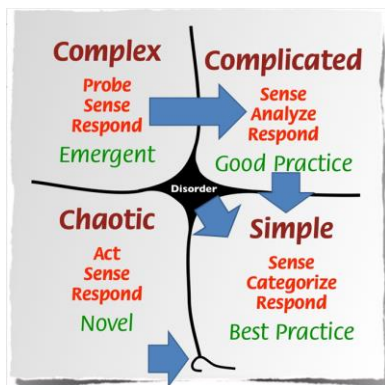


Figure 15: Change in Context by Applying Lean Thinking (arrows added to image from Wikipedia 2014a)

## 11. CONCLUSIONS

I hope that the Lean Thinking I have explained, of going to the gemba, finding incongruences, repeatedly asking why, and then through action research addressing these questions to improve the system, will serve you in your research. A lean expression is “What I can do today, I can do better tomorrow.” We must relentlessly pursue continuous improvement in our industry.

Thank you for giving me the opportunity to speak. Let’s hear your questions.

## 12. REFERENCES

- Ballard, G. (1994). “The Last Planner.” Northern California Construction Institute, Monterey, CA, April 22-24, available at <http://www.leanconstruction.org>
- Ballard, G. (2000). *The Last Planner System of Production Control*. PhD Diss., Faculty of Engrg., Univ. of Birmingham, UK, 192 pp.
- CII (1986). *Cost and Benefits of Materials Management Systems*. Publication 7-1, Construction Industry Institute, Austin, TX, November.

- CII (1988a). *Project Materials Management Primer*. Publication 7-2, Materials Management Task Force, Construction Industry Institute, Austin, TX, 20 p.
- CII (1988b). *Project Materials Management Handbook*. SP-4, Construction Industry Institute, UT Austin, TX. (Superseded by IR7-3, Procurement and Materials Management: A Guide to Effective Project Execution, and related documents IR257-2, Global Procurement & Materials Management: An eGuide to Effective Project Execution, and IR257-3, Materials Management Planning Guide).
- Dick, B. and Dalmau, T. (1999). *Values in Action - Applying the Ideas of Argyris and Schön*. 2<sup>nd</sup> ed., Chapel Hill, Qld:Interchange.
- Dick, B. and Dalmau, T. (2000). "Argyris and Schön: Some Elements of their Models." online at <http://www.aral.com.au/resources/argyris2.html> visited 14 May 2014.
- Frandsen, A. and Tommelein, I.D. (2014). "Development of a Takt-Time Plan: A Case Study." ASCE, *Proc. Construction Research Congress 2014*, Atlanta, GA.
- Hoover, S. (2013). *Beyond Vertical Integration: The Re-engineering of the Design and Construction Industry*. FMI Corp., Raleigh, NC, 12 pp., online at <http://www.fminet.com/media/pdf/article/BeyondVerticalIntegration.pdf> visited 14 April 2013.
- Hopp, W.J. and Spearman, M.L. (1996). *Factory Physics: Foundations for Manufacturing Management*. 1<sup>st</sup> ed., Irwin McGraw Hill.
- Isaacs, S. (2012). *The Consilience of Design and Construction*. FMI Corp., Raleigh, NC, 12 pp., online at [http://www.fminet.com/media/pdf/article/ConvergenceofDesign\\_Trends2012.pdf](http://www.fminet.com/media/pdf/article/ConvergenceofDesign_Trends2012.pdf) visited 14 April 2013.
- Jarvinen, P. (2007). "Action Research is Similar to Design Science." *Quality & Quantity*, 41:37-54.
- Johnson, H.T. and Broms, A. (2000). *Profit beyond Measure: Extraordinary Results through Attention to Work and People*. Productivity Press, 272 p.
- KIT (no date). *KIT Dossier Monitoring & Evaluation for Learning in Rural Innovation Systems*. Royal Tropical Institute, Amsterdam, The Netherlands, <http://www.kit.nl/kit/Dossiers/Dossiers-Dossier.html?dossier=62595> visited 10 May 2014.
- Koskela, L. (1992). "Application of the New Production Philosophy to Construction." *Technical Report 72*, CIFE, Dept. of Civil Engrg., Stanford Univ., Stanford, CA, September, 75 p.
- Koskela, L. (2000). *An exploration towards a production theory and its application to construction*. VTT Pubs., Technical Research Centre of Finland, Espoo, Finland, 296 p.
- Koskela, L. (2004). "Making Do - The Eighth Category of Waste." *Proc. 12<sup>th</sup> Ann. Conf. of the Int'l. Group for Lean Constr.*, Elsinore, Denmark.
- Koskela, L. and Howell, G.A. (2002). "The Underlying Theory of Project Management is Obsolete." PMI, *Proc. PMI Research Conf. 2002: Frontiers of Project Management Research and Application*, pp. 293-302.
- Kuhn, T.S. (1962). *The Structure of Scientific Revolutions*. 1<sup>st</sup> ed., Univ. of Chicago Press, 172 p.
- Kurtz, C.F. and Snowden, D.J. (2003). "The New Dynamics of Strategy: Sense-making in a Complex and Complicated World." *IBM Systems Journal*, 42 (3) 462-483.

- Liker, J. (2003). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill, 330 p.
- Liker, J. and Meier, D. (2005). *The Toyota Way Fieldbook*. McGraw-Hill, 476 p.
- Lukka, K. (2003). "The Constructive Research Approach." In Ojala, L. and Hilmola, O-P. (eds.) *Case Study Research in Logistics*. Pubs. of the Turku School of Econ. and Business Admin., Series B1, pp. 83-101.
- March, S.T. and Smith, G.F. (1995). "Design and Natural Science Research on Information Technology." *Decision Support Systems*, 15:251-266.
- Rother, M. (2009). *Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results*. McGraw-Hill, 306 p.
- Senge, P.M. (1990). *The Fifth Discipline: the Art and Practice of the Learning Organization*. Doubleday/Currency, 432 p.
- Simon, H.A. (1969). *The Sciences of the Artificial*. 1<sup>st</sup> ed., MIT Press, Cambridge, MA.
- Snowden, D.J. (2010). "The Cynefin Framework." <http://www.youtube.com/watch?v=N7oz366X0-8> uploaded on 11 Jul 2010, visited 10 May 2014.
- Snowden, D.J. and Boone, M.E. (2007). "A Leader's Framework for Decision Making." *Harvard Business Review*, Nov.
- Stukhart, G. (1995). *Construction Materials Management*. CRC Press, 344 p.
- Tommelein, I.D. (1989). *SightPlan: An Expert System that Models and Augments Human Decision-Making for Designing Construction Site Layouts*. PhD Diss., Dept. of Civil Engrg., Stanford Univ., Stanford, CA, August, 203 pp.
- Tommelein, I.D. (1994a). "MoveCapPlan: An Integrated System for Planning and Controlling Construction Material Laydown and Handling." *Proc. 1<sup>st</sup> Computing Congress*, ASCE, New York, NY, 1172-1179.
- Tommelein, I.D. (1994b). "Materials Handling and Site Layout Control." *Proc. 11<sup>th</sup> ISARC*, 24-26 May, Brighton, U.K., in Chamberlain, D.A. (1994). *Automation and Robotics in Construction XI*, Elsevier Sci. Pubs., pp. 297-304.
- Tommelein, I.D. (1998). "Pull-driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique." ASCE, *J. of Constr. Engrg. and Mgmt.*, 124 (4) 279-288.
- Tommelein, I.D., Hayes-Roth, B., and Levitt, R.E. (1992a). "Altering the SightPlan Knowledge-based Systems." *J. of Artificial Intell. in Engrg., Design, and Mfg.*, AI EDAM, 6 (1) 19-37.
- Tommelein, I.D., Levitt, R.E., and Hayes-Roth, B. (1992b). "SightPlan Model for Site Layout." ASCE, *J. Constr. Eng. Manage.*, 118 (4) 749-766.
- Tommelein, I.D., Levitt, R.E., and Hayes-Roth, B. (1992c). "Site Layout Modeling: How Can Artificial Intelligence Help?" ASCE, *J. Constr. Eng. Manage.*, 118 (3) 594-611.
- Tommelein, I.D., Levitt, R.E., Hayes-Roth, B., and Confrey, T. (1991). "SightPlan Experiments: Alternate Strategies for Site Layout Design." ASCE, *J. Computing in Civil Engrg.*, 5 (1) 42-63.

- Tsao, C.C.Y. (2005). *Use of Work Structuring to Increase Performance of Project-based Production Systems*. PhD Diss., Dept. of Civil & Envir. Engrg., Univ. of California, Berkeley, Fall, 298 pp.
- Tsao, C.C.Y (2007). “Improving Sustainability through Lean Project Delivery.” Lecture on 24 April, Women in Sustainable Design Lecture Series, Depts. of Arch. and Mech. Engrg., Green Design Research Collab. and Ctr. for Bldg. Energy Research (CBER), Iowa State Univ., Ames, IA.
- Wikipedia (2014a). [http://en.wikipedia.org/wiki/File:Cynefin\\_framework\\_Feb\\_2011.jpeg](http://en.wikipedia.org/wiki/File:Cynefin_framework_Feb_2011.jpeg) visited 10 May 2014.
- Wikipedia (2014b). <https://en.wikipedia.org/wiki/Expediting> visited 19 May 2014.
- Wikipedia (2014c). [http://en.wikipedia.org/wiki/The\\_Structure\\_of\\_Scientific\\_Revolutions](http://en.wikipedia.org/wiki/The_Structure_of_Scientific_Revolutions) visited 19 May 2014.
- Wikipedia (2014d). <https://en.wikipedia.org/wiki/Special:Search?search=trial+allocation&go=Go> searched 19 May 2014.
- Womack, J.P. and Jones, D.T. (1997). *The Machine That Changed the World: The Story of Lean Production—Toyota’s Secret Weapon in the Global Car Wars That Is Now Revolutionizing World Industry*. Free Press, 352 p.
- Womack, J.P., Jones, D.T., and Roos, D. (1990). *The Machine That Changed the World: Based on the Massachusetts Institute of Technology 5-Million-Dollar 5-Year Study on the Future of the Automobile*. Scribner, 336 p.