

PRACTITIONERS' GUIDE TO ESSENTIAL LEAN RESEARCH



LCI RESEARCH COMMITTEE

Introduction

Welcome to the first installment in a series of Lean Construction Institute (LCI) research maps. The LCI Research Committee, composed of seven academic researchers with decades of research experience in the design-and-construction industry, produced these maps to meet the needs of practitioners interested in the most current and most reliable research relevant in advancing their Lean journeys.

The focus of this first research map is essential research, not necessarily the most recent, but the most groundbreaking or foundational in the field. This set of fourteen was chosen through a rigorous process of peer reviews by the LCI Research Committee; commentary on why the articles were selected is included in the descriptions. The summaries of the papers are taken from the original publication (edited for length). We adopted the organizational categories developed and used by the International Group for Lean Construction (IGLC), a long-standing academic clearinghouse for international research on the topic of Lean.

Essential research papers are self-contained in this map with internal links; suggestions for further readings are provided as citations with web-based links whenever possible. Some links may require additional sign-in, others are open source.

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Categories



CONTRACT AND COST MANAGEMENT

Connecting contract terms with project success, readings cover organizational integration...risk-reward, Lean management, and Target Value Design (TVD) benchmarking. The TVD article covers the history of its evolution and basics. Many of the subtopic areas in Contracts relate to People Culture since many contractual terms in collaborative delivery cover cultural aspects of team.



LEAN THEORY

Applying tools without a grounding in the basic theories of Lean will likely be ineffective. Fortunately, Foundation of Lean Construction is an excellent and accessible resource. In particular, the article "Underlying theory...is Obsolete" has been a highly influential text in Lean research but requires a relatively advanced level of understanding of conventional project management. Overall, this topic relates to Lean teaching.



PEOPLE CULTURE

Research in this topic focuses on project teams and aspects of collaboration. The "Building a Lean Culture..." article is an ideal starting point for understanding the basic topic area of human behavior and organizational culture. Two other articles, which are slightly more advanced, should be read after the teamwork article. This topic area has some connection to the contract topic since legal terms are often used to manage obstacles to collaboration.



PRODUCTION PLANNING AND CONTROL

Last Planner® System (LPS) is the primary means for production planning and control. Different scales are addressed: "Current Process Benchmark..." addresses LPS broadly and "Pull Driven Schedule..." uses a case study example. More advanced readings include nuanced understanding of fine grained controls, including "Workflow Stabilization..."



PRODUCTION SYSTEMS DESIGN

The Production Systems topic is closely tied with production planning and control. Articles in this topic cover specific aspects of Production Systems, such as supply-chain design, location-based planning, and Takt planning.



SAFETY QUALITY GREEN LEAN

Linking safety, quality and green goals with Lean processes is a key aspect to increasing value. Research in these areas show the interconnection of goals and effective ways to manage them together. People Culture since many of the contractual terms in collaborative delivery focus on cultural aspects of team.



TEACHING LEAN

This topic is related to Lean Theory category but focuses on how Lean is taught in a variety of settings. The effectiveness of simulations, games, and other teaching is covered in the selection of articles.



ENABLE LEAN WITH IT

The use of technology to support and enable Lean has evolved over time from modest beginnings to a sophisticated integration of Lean tools with technologies, particularly Building Information Modeling (BIM). One of the earlier articles "Interaction of Lean and BIM..." is a good starting point; more recent articles address current use of BIM.



SUPPLY CHAIN MANAGEMENT

This topic is related to process-systems design and production planning and controls. Supply-chain-management research was well established as a research area with in "Lean Supply..." and further expanded with the "In Search of Lean Suppliers..." article.



Motivation and Means: How and Why IPD and Lean Lead to Success

Cheng, Renée, and Andrea Johnson. *Motivation and Means: How and Why IPD and Lean Lead to Success IPDA*, 2016.

WHY THIS IS USEFUL

A comprehensive report linking project success to Lean and IPD. This report documents ten case studies, showing data on cost and schedule with graphics that allow readers to compare across project types. Emphasis is placed on decision-making processes and developing team-first culture.

SUMMARY

The case studies discussed in the report demonstrate how new and innovative practices, techniques, and strategies make a significant difference in project outcomes. The report explores ten projects from around the United States and Canada: four healthcare projects, two medical office buildings, and four office buildings, including both new and renovation, with scopes ranging from \$9.6M to \$119M. All projects utilized an integrated form of agreement and employed Lean design and construction techniques. Each project case study provides a detailed deep dive in 24 areas across five major categories: Context, Legal/Commercial, Leadership and

Management, Processes and Lean, Alignment and Goals, and Building Outcomes. **The major finding of this report is a striking uniformity of success for all the teams in this study, regardless of project type, scope, geographic location, or previous experience with IPD and Lean. The second finding was that the powerful complementary strength of IPD and Lean supports success.**



Target Value Design: Using Collaboration and a Lean Approach to Reduce Construction Cost

Zimina, Daria, Glenn Ballard, and Christine Pasquire. "[Target Value Design: Using Collaboration and a Lean Approach to Reduce Construction Cost.](#)" *Construction Management and Economics* 30 (2012): 383–98. doi: 10.1080/01446193.2012.676658.

WHY THIS IS USEFUL

One of the first comparative study that generates data on project performance, specifically focused on the introduction of target costing to construction industry.

SUMMARY

Target costing is an effective management technique that has been used in manufacturing for decades to achieve cost predictability during new product development. Adoption of this technique promises benefits for the construction industry as it struggles to raise the number of successful outcomes and certainty of project delivery in terms of cost, quality, and time. Target value design is a management approach that takes the best features of target costing and adapts them to construction. The concept of target value design is introduced based on the results of action research carried out on 12 construction projects in the US.

It has been shown that systemic application of target value design leads to significant improvement of project performance—the final cost of projects was, on average, 15% less than market cost. The construction industry already has approaches that share similarities with the target value design process or use the same terminology, e.g., partnering, target cost contracts, cost planning, etc. Target value design is positioned as a form of target costing for construction that offers a more reliable route to successful project outcomes.



The Foundations of Lean Construction

Lauri Koskela, Greg Howell, Glenn Ballard, and Iris D. Tommelein. Chapter 14 “The Foundations of Lean Construction,” and Chapter 15 “Lean Construction Tools and Techniques.” In *Design and Construction: Building in Value*, edited by Rick Best and Gerard Valence, 211–54. Oxford: Butterworth Heinemann, 2002.

WHY THIS IS USEFUL

The book chapters 14 and 15 give a solid introduction and overview into the development of Lean in the construction industry by early developers. A broad range of topics related to the processes of Lean design and construction is addressed to give the reader a good grasp and rounding in the topic of Lean construction. Although this was first published in 2002, the information remains essential and highly relevant today.

SUMMARY

Chapter 14 provides an overview of Lean construction as a theory-based approach to project management, which is compared to conventional non-Lean project management, and outlines the Lean-based project delivery system and its implementation. Chapter 15 describes several tools and techniques that support this new approach.

The overall aim is to look at ways that clients can improve the value-for-money outcomes of their decisions to construct buildings.

These chapters do not give detailed instructions for implementing Lean construction but provide a comprehensive overview of the philosophy and practice of Lean as it applies to construction.



Building a Lean Culture

Hackler, Cory, Erika Byse, Dean Reed, and Thais Alves. "Building a Lean Culture." *Proceedings of 25th Annual Conference of the International Group for Lean Construction, IGLC 2017*, 309–16. Heraklion, Greece, 2017.

WHY THIS IS USEFUL

This paper, written by practitioners, describes what one large general contracting company did to embed Lean principles into its leadership at every level in the company. Couched in the language of everyday practice, the article discusses how Lean leadership is at the heart of creating and sustaining Lean culture.

SUMMARY

To accelerate the understanding and implementation of Lean throughout a large general contracting company, the Lean leadership group, with the support of management at all levels, shifted from training employees on tools and solutions to educating them about Lean principles as an overarching way to run projects. This industry paper describes the work that the company has done and is currently doing to train professionals in all of its business units. It explains why and how the effort started,

the feedback received from participants who have attended a new course in Lean leadership, and the plans to expand this program to increase and sustain Lean implementation. **The paper provides a contribution to the literature on Lean implementation and change management and underscores the importance of creating a culture based on solid understanding of the Lean vocabulary, principles, and goals to reach critical mass across projects.**



Current Process Benchmark for the Last Planner® System

Ballard, Glenn, and Iris D. Tommelein. "[Current Process Benchmark for the Last Planner® System.](#)" *Lean Construction Journal* (2016): 57–89.

WHY THIS IS USEFUL

This article explains in detail the Last Planner System (LPS)—its origin and history, its functions, its underlying presuppositions, its principles, and its methods. Also included is a glossary of terms, frequently asked questions, and recommendations for future research to further improve and extend the Last Planner System.

SUMMARY

This article first provides a brief history of the LPS, explaining why it was invented and why it is needed. The subsequent sections describe the functions the LPS is designed to perform and its presuppositions (what is held to be true about the world in which the functions are to be implemented). From these, principles (behavioral guidelines for executing functions given the presuppositions) are inferred. Next, processes are described to explain how the functions are linked

together to make a system, and finally, the methods used to perform the functions within processes consistently with presuppositions and principles are described. **In sufficiently describing the Last Planner System for users to understand its fundamentals—namely, functions, presuppositions, principles, and processes—they can better specify methods and tools to accomplish the functions consistently with these fundamentals.**



Pull-Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique

Tommelein, Iris D. "Pull-Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique," *ASCE Journal of Construction Engineering and Management* 124, no. 4 (July/August 1998): 279–88.

WHY THIS IS USEFUL

One of the first mathematical demonstrations of the benefits of pull planning. The article describes the demonstrated effectiveness of simulation (rehearsal of construction) for improving processes and operations.

SUMMARY

Many construction processes include the installation of unique materials in specific locations in the built facility: materials and locations must be matched before installation can take place. Mismatches due to delays and uncertainties in supplying materials to or completing prerequisite work at the locations hamper field productivity. This is illustrated in this paper with a matching problem in a materials-management process, which is typical of fast-track process-plant projects. The uniqueness of materials and locations combined with the unpredictability

in duration and variation in execution quality of the steps in the supply chain allow for different ways to sequence material delivery and work-area completion. The impact of several alternatives on process execution is illustrated by probabilistic process models. **A third probabilistic model illustrates the use of the Lean construction technique called pull-driven scheduling, which yields smaller buffers and earlier project completion and, when properly accounted for, increases productivity.**



Case Study for Work Structuring: Installation of Metal Doorframes

Tsao, Cynthia C., Iris D. Tommelein, Eric Swanlund, and Gregory Howell. "Case Study for Work Structuring: Installation of Metal Door Frames" *Proceedings of the 8th Annual Conference of the International Group for Lean Construction, IGLC 2000*. Brighton, UK, 2000.
<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.17.1048&rep=rep1&type=pdf>

WHY THIS IS USEFUL

This paper addresses applied Lean practices at the supply-chain management level and is the result of an accidental discovery made when looking closely at a randomly assigned activity: the installation of doors at a prison. The working method for door installation was heavily influenced by how the doors were procured. Tracking back through the supply chain revealed many opportunities for improvement.

SUMMARY

Work structuring means developing a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts. The goal of work structuring is to make workflow faster and more reliable while delivering value to the customer. Current work structuring practices are driven by contracts, the history of trades, and the traditions of craft. As a result, they rarely consider alternatives for making the construction process more efficient. To illustrate current practice and the opportunities provided by work structuring, this case study discusses the installation of metal doorframes at a prison. Because the project is a correctional facility, the

doorframe-installation process involves a special grouting procedure, which complicates the installation process. Those involved recognized the added challenge of the situation, but better solutions were impeded by normal practice. **This case study thus illustrates how one can come up with alternative ways to perform the work without being constrained by contractual agreements and trade boundaries. In doing so, we define what work structuring means.**



Lean Processes for Sustainable Project Delivery

Lapinski, Anthony R., Michael J. Horman, and David Riley. "Lean Processes for Sustainable Project Delivery." *Journal of Construction Engineering and Management* 132, no. 10 (2006). doi: 10.1061/(ASCE)0733-9364(2006)132:10(1083).

WHY THIS IS USEFUL

This is groundbreaking research applies Lean in pursuit of sustainability goals. Until this paper, sustainable design was assumed to be limited to environmental concerns. Partly due to this work, sustainable design is now framed as tripartite: people, planet, profit. This article is the first to show Lean as an economic contributor to sustainable design. More work is needed to continue this rich vein of research.

SUMMARY

This paper reports on a study that identified the presence of value and waste in a sustainable building project. Through an empirical investigation mapping Toyota's capital facility delivery process, the steps in project delivery critical for success (value) and those that are wasteful were identified. The investigation focused on the South Campus Facility of the Real Estate and Facilities Division of Toyota Motor Sales, which received U.S. Green Building Council's Leadership in Energy and Environmental Design Gold certi-

fication at a project cost equivalent to a conventional facility. **Post hoc process-based analysis was used to obtain insight about what added value and waste at Toyota. The results identified additional improvement opportunities in Toyota's delivery process. For corporate facility owners and the architecture engineering construction industry, the results illuminated on how to successfully and economically deliver sustainable facilities.**



Working Near the Edge: A New Approach to Construction Safety

Howell, Gregory A., Glenn Ballard, Tariq S. Abdelhamid, and Panagiotis Mitropoulos. "Working Near the Edge: A New Approach to Construction Safety." *Proceedings of the 10th Annual Conference of the International Group for Lean Construction, IGLC 2002*. Gramado, Brazil, 2002. <https://iglcstorage.blob.core.windows.net/papers/attachment-a0ca79d4-545b-4872-a5c1-fc3a0cb370f6.pdf>

WHY THIS IS USEFUL

This paper introduced a new paradigm for thinking about safety in construction, a field assumed to inevitably expose workers to hazards. Before this paper, focus was on avoiding hazards; after this, the industry broadened to find ways to prepare for hazard exposure, shifting thinking about safety programs and prevention. This paper ushered in a new thought process and introduced a new stream of research.

SUMMARY

Construction safety has substantially improved over time but has plateaued. Further improvement will come from spreading best practice throughout the industry or from breakthrough that transcends best practice. We are working on breakthrough and propose that what is needed is a new theory of accidents.

Current best practice is described in tandem with its underlying theoretical assumptions. A research program, based on the work of Jens Rasmussen,

a leading thinker on risk management in dynamic environments, tests that theory to develop a new approach to safety management.



Parade Game: Impact of Workflow Variability on Trade Performance

Tommelein, Iris D., David R. Riley, and Greg A. Howell. "Parade Game: Impact of Workflow Variability on Trade Performance." *Journal of Construction Engineering and Management* 125, no. 5 (1999).

WHY THIS IS USEFUL

This is one of the earliest articles to show the impact of variation on the release of work and presents a simulation that teaches the fundamental concepts of Lean.

SUMMARY

The Parade Game illustrates the impact that workflow variability has on the performance of construction trade participants and those trades that follow. The game simulates a construction process in which resources produced by one trade are prerequisite for work performed by the next trade. Production-level detail, describing resources being passed from one trade to the next, reveals that throughput will be reduced, project completion delayed, and waste increased by variations in flow. The game shows

that it is possible to reduce waste and shorten project duration by reducing the variability in workflow between trades. Basic production-management concepts are thus applied to construction management. **They highlight two shortcomings of using the critical-path method for field-level planning: The critical-path method makes modeling the dependence of ongoing activities between trades or with operations unwieldy, and it does not explicitly represent variability.**



Interaction of Lean and Building Information Modeling (BIM) in Construction

Sacks, Rafael, Lauri Koskela, Bhargav A. Dave, and Robert Owen. "[Interaction of Lean and Building Information Modeling in Construction.](#)" *Journal of Construction Engineering and Management* 136, no. 9 (September 2010): 968–80.

WHY THIS IS USEFUL

This article was one of the first to address sociotechnical issues that had not been yet well explored by the Lean community. Currently, it remains an underexplored issue. Paper provides a useful matrix showing connections between BIM and Lean.

SUMMARY

Lean construction and building information modeling (BIM) are quite different initiatives, but both profound impact the construction industry. A rigorous analysis of the myriad of specific interactions between them indicates that a synergy exists that, if properly understood in theoretical terms, can be exploited to improve construction processes beyond the degree to which it might be improved by either of these paradigms alone.

Using a matrix that juxtaposes BIM functionalities with prescriptive Lean construction principles, 56 interactions

have been identified—all but four of which represent constructive interactions. Although evidence for the majority of these has been found, the matrix is not considered complete but rather a framework to explore the validity of the interactions. Construction executives, managers, designers, and developers of information technology systems for construction can also benefit from the framework as an aid to recognizing the potential synergies when planning their Lean and BIM adoption strategies.



A Method for Planning of Workflow by Combined Use of Location-Based Scheduling and 4D CAD

Jongeling, Rogier, and Thomas Olofsson. "A Method for Planning of Workflow by Combined Use of Location-Based Scheduling and 4D CAD." *Automation in Construction* 16, no. 2 (March 2007): 189–98. doi: 10.1016/j.autcon.2006.04.001.

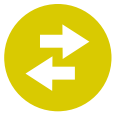
WHY THIS IS USEFUL

This paper looks at the combination of 4D computer aided design (CAD) with location-based planning, resulting in a visually based paper with many screenshots. It relates to production planning and control, but its primary focus is on technology.

SUMMARY

There is great potential to improve the flow of resources on construction sites, termed workflow. Current activity-based scheduling techniques do not provide adequate support for the planning of workflow due to practical and methodological reasons. Location-based scheduling techniques provide a promising alternative to activity-based scheduling techniques. However, neither location-based nor activity-based scheduling techniques provide users with insight about the spatial configuration of scheduled construction operations.

A technique that can provide this insight is 4D CAD in which 3D-CAD models are combined with data from construction schedules. **This article presents a process method for the planning of workflow by the combined use of location-based scheduling and 4D CAD. We suggest that a location-based approach to 4D CAD can improve the usability of the 4D-CAD models for workflow analyses.** In addition, the article suggests that 4D CAD can enhance the value of location-based schedules.



Lean Supply Systems in Construction

Arbulu, Roberto and Glenn Ballard. "Lean Supply Systems in Construction." *Proceedings of the 12th Annual Conference for International Group for Lean Construction, Helsingør, Denmark, January 2004.*

WHY THIS IS USEFUL

This is a basic article outlining fundamental issues when looking at supply chain, pinpointing key areas of waste and proposing web-based tools to improve reliability, predictability and efficiency.

SUMMARY

This paper proposes a strategy to improve the management of supply systems in construction using Lean principles and techniques. The objective is to assure on-time delivery of information and materials to project sites at the least cost and maximum value to the final customer. The primary means to achieve this objective is to accomplish supply management functions with the least waste; e.g., low supply and demand reliability, large inventories not needed to absorb variability, and minimal physical waste. The paper explores supply complexity in construction to better understand where certain types of waste originate. **The strategy proposes the use of a web-based tool**

based on the Last Planner® System to improve planning reliability to minimize demand variability, the use of regional logistics centers for distribution of materials to sites, the use of kanban techniques to pull selected materials on a just-in-time basis, and the link between production control and material management processes on-site. It also highlights the importance of minimizing material lead times, with emphasis on standardization and preassembly practices to make supply systems more effective. It concludes by highlighting the most important challenges for the implementation of this strategy.



In Search of Lean Suppliers Reporting on First Steps in Supplier Development

Elfving, Jan A., and Glenn Ballard. "In Search of Lean Suppliers—Reporting on First Steps in Supplier Development." *Proceedings from 21st Annual Conference of the International Group for Lean Construction, IGLC 2013*, 746–54. Fortaleza, Brazil, July 2013.

WHY THIS IS USEFUL

This is one of the only papers addressing supplier development, which is a key part of supply-stream management outside of construction. It is a key area without much research. This paper outlines basic steps, often not followed, recommended for suppliers to ensure consistent quality and reliability.

SUMMARY

This paper reports on some early findings related to supplier development: the result of prequalification, performance evaluation, and supplier development from five pilot regions in three countries. It is a follow-up to an IGLC paper presented in 2011. Supplier development can be seen as a third option when make or buy options do not lead to desired results. It appears to be a little-used option in the construction industry. **This paper reveals that, at least in the pilot regions, supplier development needs to start from very basic needs, such as helping to fulfill legal and company requirements and setting standards for measuring quality and delivery**

reliability. More than half of the supplier base do not fulfill the basic requirements. When suppliers do measure quality and delivery, the measurements often do not capture the issues important to their customers, the projects. The findings have resulted in the redefining of supplier segments, which are presented in this paper along with the next steps in supplier development.

Further Readings

CONTRACT AND COST MANAGEMENT

Esmaeili, Behzad, Bryan Franz, Keith Molenaar, Robert Leicht, and John Messner. "A Review of Critical Success Factors and Performance Metrics on Construction Projects." *Proceedings of Annual Conference of Canadian Society for Civil Engineering 2013*. Montreal, Canada. May, 2013.

Matthews, Owen, Gregory Howell, and Panagiotis Mitropoulos. "Aligning the Lean Organization: A Contractual Approach." *Proceedings of 11th Annual Conference of the International Group for Lean Construction*. Virginia, 2018. <https://iglcstorage.blob.core.windows.net/papers/attachment-987f1542-3d55-4b02-b823-3854ce820819.pdf>

Lichtig, William. "Sutter Health: Developing a Contracting Model to Support Lean Project Delivery." *Lean Construction Journal 2* (2005). https://www.leanconstruction.org/media/docs/lcj/LCJ_05_008_a.pdf

Darrington, Joel. "Using a Design-build Contract for Lean Integrated Project Delivery." *Lean Construction Journal*, (2011): 85–91. https://www.leanconstruction.org/media/docs/lcj/2011/LCJ_11_002.pdf

LEAN THEORY

Koskela, Lauri. 2000. "An Exploration Towards a Production Theory and its Application to Construction." PhD diss., University of Huddersfield, Finland. <https://www.vtt.fi/inf/pdf/publications/2000/P408.pdf>

Koskela, Lauri, and Greg Howell. "The Underlying Theory of Project Management is Obsolete." *Proceedings of PMI Research Conference*. Seattle, WA, 2002. <https://www.pmi.org/learning/library/underlying-theory-project-management-obsolete-8971>

PEOPLE CULTURE

Ballard, Glenn, Kim, Yong-Woo, Azari, Rahman, and Kyuncho, Seong. 2011. *Starting from Scratch: A New Project Delivery Paradigm, Research Team 271 Report*. Chicago: Construction Industry Institute, 2011. https://www.researchgate.net/profile/Glenn_Ballard/publication/232322531_Starting_from_Scratch_A_New_Project_Delivery_Paradigm/links/5665ad3f08ae192bbf925a81/Starting-from-Scratch-A-New-Project-Delivery-Paradigm

Bayfield, Richard, and Paul Roberts. "Contract or Co-Operation? Insights from beyond Construction: Collaboration—The Honda Experience." *Lean Construction Journal 2* (2005): 22–50. https://www.leanconstruction.org/media/docs/ktll-add-read/Contract_Or_Co-Operation_Insights_From_Beyond_Construction_Collaboration_-_The_Honda_Experience.pdf

PRODUCTION PLANNING AND CONTROL

Tang, Pingbo, David Grau, Ram Ganapath, Jose Diosdado, Amin Abbaszadegan. 2014. "Workflow Stabilization with Fine-grained Work Packaging and Near Real-time Progress Monitoring." *Proceedings of 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production*, IGLC 2014, 739–50. Oslo, Norway, 2014.

Sacks, Rafael. "What Constitutes Good Production Flow in Construction?" *Construction Management and Economics* 34, no. 9 (2016): 641–56

Shingo, Shigeo, and Andrew P. Dillon. *A Study of the Toyota Production System: From an Industrial Engineering Viewpoint*. New York: Taylor & Francis, 1989.

PRODUCTION SYSTEMS DESIGN

Yu, Haitao, Tarry Tweed, Mohamed Al-Hussein, and Reza Nasser. "Development of Lean Model for House Construction Using Value Stream Mapping." *Journal of Construction Engineering and Management*, August 2009. doi: 10.1061/(ASCE)0733-9364(2009)135:8(782).

Yassine, Tarek, Mohammad Bassel Saleh Bacha, Farah Fayek, and Farook Hamzeh. "Implementing Takt-Time Planning in Construction to Improve Work Flow." *Proceedings of 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production*, IGLC 2014. Oslo, Norway, 2014. doi: 10.13140/RG.2.1.4721.8726.

Emdanat, Samir, Meeli Linnick, and Digby Christian. "A Framework for Integrating Takt Planning, Last Planner® System and Labor Tracking." *Proceedings of 24th Annual Conference of the International Group for Lean Construction, IGLC 2016*, 53–62. Boston, MA, 2016. <https://iglcstorage.blob.core.windows.net/papers/attachment-1ba15100-39c5-4f9b-9ca1-4259521ac151.pdf>

SAFETY QUALITY GREEN LEAN

Antillón, Eric Israel. 2010 "A Research Synthesis on the Interface between Lean Construction and Safety Management." Master's Final Thesis, University of Colorado at Boulder.

Howell, Gregory, Glenn Ballard, and Sevilay Demirkesen. "Why Lean Projects Are Safer." *Proceedings of 25th Annual Conference of the International Group for Lean Construction, IGLC 2017*, 9–12. Heraklion, Greece, 2017. <https://iglcstorage.blob.core.windows.net/papers/iglc-03243d9d-22be-4363-982e-ffdf5f36aea8.pdf>

Schafer, D., Tariq S. Abdelhamid, Panagiotis Mitropoulos, and Gregory A. Howell. 2008. "Resilience Engineering: A New Paradigm for Safety in Lean Construction Systems." *Proceedings of the 16th Annual Conference of the International Group for Lean Construction, IGLC 2008*, 723–34. Manchester, UK, 2008. <https://iglcstorage.blob.core.windows.net/papers/attachment-1cba72f2-2513-4101-9c18-d188b7f955ff.pdf>

Schafer, D., Tariq S., Abdelhamid, and Panagiotis Mitropoulos. "Resilience Engineering: A New Approach for Safety Management." *Proceedings of the 2009 Construction Research Congress*. Seattle, WA, 2009. <https://ascelibrary.org/doi/abs/10.1061/41020%283339%2978>

TEACHING LEAN

Nofera, Wenda, Tariq Abdelhamid, and Ali Lahouti. "Teaching Lean Construction for University Student(s)." *Lean Construction Journal* (2015): 34–44. https://www.leanconstruction.org/media/docs/lcj/2015/LCJ_15_004.pdf

Warcup, Robert, and Edward Reeve. "Using the Villego® Simulation to Teach the Last Planner System." *Lean Construction Journal* (August 2014): 1–15. https://www.leanconstruction.org/media/docs/lcj/2014/LCJ_13_008.pdf

ENABLE IT WITH LEAN

Mandujano, Maria, Claudio Mourgues, Luis Alarcon, and John Kunz. "Modeling Virtual Design and Construction Implementation Strategies Considering Lean Management Impacts." *Computer-Aided Civil and Infrastructure Engineering*, March 2017. doi: 10.1111/mice.12253.

Guerriero, Annie, Sylvain Kubicki, Fabruce Berroir, Clement Lemaire. "BIM-enhanced Collaborative Smart Technologies for Lean Construction Processes." *Proceedings of the 2017 International Conference on Engineering, Technology and Innovation*. Funchal, Portugal, 2017. doi: 10.1109/ICE.2017.8279994.

SUPPLY CHAIN MANAGEMENT

Koçtaş Çotur, Özlem, and Ömer Baybars Tek. "Understanding Construction Supply Chains: A Multiple Theoretical Approach to Inter-Organizational Relationships in Construction." *Proceedings of International Logistics and Supply Chain Congress 2013*, Cappadocia and Kayseri, Turkey, November 2013. https://www.researchgate.net/publication/265008938_UNDERSTANDING_CONSTRUCTION_SUPPLY_CHAINS_A_MULTIPLE_THEORETICAL_APPROACH_TO_INTER-ORGANIZATIONAL_RELATIONSHIPS_IN_CONSTRUCTION

Essential Lean Research Articles and Excerpts

Click to Enter

MOTIVATION AND MEANS: How and Why IPD and Lean Lead to Success

Research Report
November, 2016

University of Minnesota in collaboration with University of Washington, University of British Columbia, Scan Consulting
Sponsored by Integrated Project Delivery Alliance (IPDA) & Lean Construction Institute (LCI)



Executive Summary
Research Methodology
Literature Review
Glossary/Definitions

Context				Legal Commercial				Leadership & Management				Processes & Lean				Alignment & Goals			Building Outcomes				
At A Glance	Project Description	Project Timeline	Owner Identity & Interface	Choosing IPD & Lean	Team Selection	Developing Contract	Developing Parties	Champions	Decision Structure	On Board & Off Board	Clarity of Goals	Resources & Facilitation	Tools & Processes	Lean Effectiveness	BIM	Workplace	Team Alignment	Collaboration	Team Culture	Profit & Payout	Budget & Schedule	Building Outcomes	Project Credits

COMPARATIVE ANALYSIS
Comparisons & Best Practices
AKRON CHILDREN'S HOSPITAL, KAY JEWELERS PAVILION
AUTODESK BUILDING INNOVATION LEARNING AND DESIGN SPACE
MOSAIC CENTRE FOR CONSCIOUS COMMUNITY AND COMMERCE
QUAIL RUN BEHAVIORAL HEALTH HOSPITAL
ROCKY MOUNTAIN INSTITUTE INNOVATION CENTER
ST. ANTHONY HOSPITAL
SUTTER MEDICAL OFFICE BUILDINGS (LOS GATOS & SUNNYVALE)
T. ROWE PRICE OWINGS MILLS CAMPUS BUILDING 1
WEKIVA SPRINGS CENTER EXPANSION

Executive Summary (1 of 4)

The report *Motivation and Means: How and Why IPD and Lean Lead to Success* presents a study of ten recent successful building projects in the United States and Canada using an integrated form of agreement. The yearlong, in-depth study focused on the questions of how and why are integrated project delivery (IPD) and Lean effective. Our conclusion is that IPD sets the terms and provides the motivation for collaboration; Lean provides the means for teams to optimize their performance and achieve project goals.

The overall findings are consistent with the larger body of research showing that teams using IPD and Lean are more reliable in terms of the schedule and cost and in meeting the owner's goals. This research adds to the evidence of the effectiveness of IPD and Lean, and by documenting positive examples in a systematic and rigorous manner, begins to identify the motivations and mechanisms for collaboration that are key to project success.

FINDINGS AND OBSERVATIONS

Our major finding was a striking uniformity of success for all the teams in this study, regardless of project type, scope, geographic location, or previous experience with IPD and Lean. The second finding was that the powerful complementary strength of IPD and Lean supports success. While there was a great deal of variation in how success was achieved, these teams reinforced current research conclusions that IPD and Lean teams are reliably able to meet schedule and cost and in meeting the owner's goals for quality. It should be noted that because the subjects of the study were volunteers who gave researchers access to their documents and their time, they were more likely to be teams that sought to highlight their positive experiences and may

not be representative of all IPD projects. At the same time, the teams were very candid about the significant challenges they faced, mistakes made, and lessons learned. Based on these stories and the overall successes, these teams demonstrated a remarkably consistent attitude of team first or project first that gave them the enhanced ability to anticipate complexity and a great resiliency to recover from unexpected setbacks. With our limited sample size of uniformly successful projects, we cannot confirm a causal path that IPD and/or Lean led to resilience, but we have many positive stories of team members attributing their ability to overcome challenges to mechanisms within IPD or ways of thinking elicited by Lean.

For many of the owners and teams, the choice to use Lean tools and processes was seen as an integral decision in choosing to pursue IPD. Most owners, regardless of their previous project delivery experience, believed that IPD facilitated (or in some cases, contractually obligated) the use of Lean practices. In our interviews, many owners and teams conflated the two terms and used them interchangeably. Since Lean and IPD are often considered together, it may not be useful to draw a black-and-white distinction between the two. However, for the purposes of this study, we define IPD as the contractual project delivery method used by these project teams that created shared risk/reward structures, fiscal transparency, and release of liability. We define Lean tools and processes as the specific tools and processes outlined by Lean Construction Institute as well as the variations developed by the teams that share the intent and spirit of those tools. The way IPD and Lean worked for these teams is that IPD provided a contractual environment and motivation for collaboration through sharing of risk and reward, early involvement and equality of stakeholders, project-first thinking, limitation of liability, and some of the

mechanisms for trust (development of the contract, open-book transparent finances, shared understanding of each other's goals, values, and business objectives). Lean provided the means by which to focus the team's energy to collaborate effectively for cost (particularly target value design), schedule (Last Planner System, which includes pull planning, reliable promising, and plan percent complete), and other goals that could be developed and aligned using Lean tools (such as A3, Plus/Delta, or plan-do-check-act). Lean tools and processes provided the most consistent metrics for team productivity and progress toward project goals, but we also saw examples of teams developing customized worksheets, dashboards, or matrices that provided additional and tailored mechanisms for measurement.

TEAMS MATTER: IDENTIFYING, BUILDING, AND SUPPORTING A SUCCESSFUL TEAM

There is a common industry perception that collaborative behavior occurs spontaneously within a group of high-performing team members and that it cannot be dictated by contracts or mandated by decision-making structures. Our findings offer a different reading of how collaboration occurs: we believe it can be *fostered* by IPD contracts and Lean processes and tools. One architect in our study said IPD and Lean are "always a carrot, never a stick." As "carrots," they enhance team members' willingness and ability to collaborate. We found examples of team formation that place emphasis on motivating, aligning, and mentoring the team, as well as using active and intentional on-boarding and off-boarding processes. Together, these practices *cultivated* high-performing team behaviors because members were supported, encouraged, and rewarded for collaborative approaches to project challenges.

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In our previous research (see literature review for past case studies and surveys), we closely examined team culture and how it can be measured as an outcome as well as a contributor to overall project success. Based on a study of projects with a range of outcomes, we were able to establish a causal relationship between positive building outcomes, positive team outcomes, and the key ingredients that contributed to both, namely, mutual trust and respect, accountability, and effective communication. For this study, we chose to build upon that work and focused more specifically on how the team interacted with the owner and translated the owner’s goals into action. All the projects in this study had very positive team cultures, ranking as high as any of the top-performing projects we have studied—this makes it harder to establish causal relationships since the results are so uniformly positive. However, the findings in this study align with prior research, which validates these findings. This study provides the industry with a guide to why these teams were successful.

The owners in this study considered or committed to IPD before starting to form the collaborative teams. Through interviews, surveys, and document review, we observed that all of the teams functioned as high-performing collaborative partners who were able to meet project challenges and successfully deliver projects that met the owners’ goals. There were some common strategies and processes. All projects had effective processes to:

- identify potential team members;
- select team members and award the contract;
- build, coach, support, and strengthen the team throughout the project duration.

With these teams, the process of identifying team members and awarding the contract typically included some discussion of who would be included in the agreement and who would be included in the risk/reward pool.

We studied how the teams demonstrated their mutual trust and respect (sometimes called psychological safety) and how champions came from all levels and areas of expertise. Lastly, we traced how the teams used mechanisms for team building, such as learning and self-assessment, to cultivate the team-first or project-first spirit so evident in interactions across the projects. The high camaraderie and empathy within the teams and the described hard-won understanding of each other’s business practices allowed partners to candidly call out problems and work together to find solutions. The teams were resilient and worked together without blame (or learned to do so) and were able to accommodate new ways of working, even when they were not comfortable.

The most significant finding in the area of team culture was that these teams were effective in making sense of the owners’ goals and translating this understanding into action, even in cases when the goals were not completely clear or there were changes that occurred over time. In these case studies, 100% of the owners believed projects met or exceeded expectations for budget and schedule, even if not all the projects met the initially identified targets.

There are several future research opportunities to better understand IPD and Lean project teams: First, there is a need to develop rules of thumb on the number and diversity of the incentive-pool members, which could be related to the overall size of team, project scope, complexity of the project, level of experience with collaborative delivery, or all of these. Second, the industry needs to better define and validate on-

boarding techniques and team-building efforts, particularly to see how self-assessment tools that evaluate core strengths, personalities, and communication styles work for teams in the building industry. Third, there is a need for further research into the motivational effects of financial stake, particularly for architects and engineers who are different from the constructor team members in the timing of their input to optimize their affect on project costs.

MEANS AND METHODS OF COLLABORATING: WHAT IS ESSENTIAL AND WHAT IS OPTIONAL

While we documented several common tools, metrics, methods, and approaches among several teams, for every team that found a particular approach essential, another team found it too cumbersome. This set of cases suggests that building information modeling (BIM), co-location, and pull planning fall into the “could be essential if done well” category; while validation and metrics are “essential and need to be done well.” To do IPD well requires a strong team-oriented project culture with a sustained investment in team building throughout the project.

IPD also requires an investment in early planning as well as team building. We consistently heard from teams that managing the time required for early planning, coordination, and fiscal reporting is challenging. At the same time, teams noted time saved in the later parts of the project because of the early planning. Additionally, teams described that their time and energy was more positively directed to advance project goals since time was not wasted on resolving conflicts and documenting changes to avoid dispute. Based on these cases, more research is needed to quantify the shifts in the amount of time, level of personnel, and

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intensity of engagement on IPD projects as these are not yet well understood. These teams often started from scratch and developed planning and project-administration time requirements over the course of the project.

In these projects, there was a relationship between teams with a high degree of Lean practices and the most positive collaboration outcomes. The project teams with the most positive perception of their team's culture and effectiveness also tended to have invested the most in planning and communication, particularly in Lean processes and tools. While we saw a correlation, more research would be needed to fully understand this relationship. For example, correlation may be due to the increased awareness and intentional goal setting around team effectiveness, or it may be that the activities around Lean planning provided a base for stronger team culture.

MARKERS AND METRICS

Traditional markers of project success are budget and schedule. However, we found that these measures are highly dependent on the ability of the team and owner to accurately judge market costs and to establish feasible targets at the beginning of the project. Furthermore, outside market variables impact these metrics and do not necessarily reflect the quality of the team and their attention to the project goals.

From the onset of this research effort, we hoped to find more consistent development and use of alternatives to cost and schedule metrics. While there were excellent examples of effective metrics, the industry is far from establishing commonly accepted industry standards that could drive improvement. Project teams, even with high-performance

building goals, often defaulted to cost and schedule metrics to measure the project's success. We were able to track profit and payout for the projects in this study and gather feedback from individual companies on their performance with IPD in general and on these specific projects.

We observed that the team-culture behaviors that the teams engaged in most consistently were marked by a number of traits, including clear communication between all members of the project team, fluid trading of scope during construction, team experiences reported as fun, reported excitement about the project, and generally less conflict. When compared with their experiences in traditional delivery, the owner and team of these projects spent more energy on advancing the project and less on blame and defense. These are areas that show promise in the development of metrics for team culture and engagement that would allow project managers to better assess the health of the team as the project is underway.

CONCLUSION

Research into understanding IPD and Lean is complex. By documenting positive examples in a systematic and rigorous manner, this research adds to the evidence of effectiveness for IPD and Lean and also begins to identify the motivations and mechanisms for collaboration that are keys to their success.

NAVIGATING THIS REPORT

The presentation of each case follows the framework described in the Methodology section. An interactive matrix format allows review of topics found within one project or the review of one topic across multiple projects.

Case studies can be navigated with the left side menu; comparative analysis allows viewers to see summaries of the findings related to topic tabs arrayed on the top navigation bar.

The top navigation bar contains tabs within six primary categories: Context, Legal/Commercial, Leadership Management, Processes & Lean, Alignment & Goals, and Building Outcomes.

Context				Legal Commercial			Leadership & Management			Processes & Lean				Alignment & Goals			Building Outcomes						
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CASE STUDY COMPARISON TRUTH TABLE

We supplemented the descriptive analysis and in-depth cross-case analysis with a truth table that shows how each of the cases leveraged Lean Construction tools and processes. Using interview data and document review, we determined the shared practices across the projects and the degree to which the teams were able to effectively implement the tools and processes. This truth table analysis allows us to display the variables in a way that lets a reader quickly understand the complexity of the cases. By creating a graphic visualization of the data on building projects we show the variety amongst the cases as they implemented Lean Construction tools and processes.

TRUTH TABLE - LEAN CONSTRUCTION TOOLS & PROCESSES

The table shows how each team leveraged tools and processes. **Validation:** a document produced by team, allowing the team to collectively say with confidence, "We can build this building with this cost and time," and showing a commitment to the target cost. Documentation of building can be in the form of a narrative, drawing, etc. and provides the team and owner with critical information to judge if the project should proceed. **Co-Location:** defined as a work space shared by all stakeholders. Actual implementation of co-location ranged from a permanent dedicated space used by all of the members of the risk/reward pool to an ad-hoc space or space shared only by the contractor and trade partners. **Team Formation:** includes the selection process for identifying team members and on-boarding. **Team Development:** describes team building through such means as facilitated training, team assessments, individual assessments, and continuous reflection. **Goals:** include establishment of goals and how they were documented and progress tracked with metrics. **Workplace and Meeting:** includes how both physical and virtual workspace were utilized, including daily huddles and agendas. **Cost and Decision:** defined as the way the team set up decision-making with Choose by Advantages, set based design, and how they managed costs with continuous conception estimating, target value design. **Project Management:** includes Last Planner System and its sub elements, such as reliable promising. **BIM:** includes the effectiveness and degree of collaboration around BIM.

	Validation	Co-Location	Lean Tools and Processes						BIM
			Lean Team Formation		Goals	Workplace and Meeting	Cost and Decision	Project Management	
			Team Formation	Team Development					
Akron	●	●	●	●	●	●	●	●	●
Autodesk		●	○	○	○	●	●	○	●
Mosaic	●	●	●	●	●	●	●	●	●
Quail Run		○	●	●	●	●	●	●	●
Rocky Mountain	●	●	●	●	●	●	●	●	●
St. Anthony	●	●	●	●	●	●	●	●	○
Sutter Los Gatos		●	●	●	●	●	●	●	●
Sutter Sunnyvale	●	○	●	○	●	●	●	●	●
T. Rowe Price		●	●	●	●	●	●	●	○
Wekiva Springs	●	●	●	●	●	●	●	●	●

- Done well, used often, helpful to the team
- Done, but only somewhat helpful or mixed comments about its effectiveness
- Did it, but it was not seen as particularly effective by most of the team
- Did not have it

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The projects in this study were selected based on the following criteria:

1. Provided incentives (such as reward pool) involving more than three stakeholder groups.
2. Used some form of integrated agreements, such as multiparty (three signatories), poly-party (four or more), charters, riders, etc.
3. Used some form of Lean design and construction practices, tools, and methodologies.
4. Was completed by Dec 31, 2015.

Secondary criteria were used to ensure geographic distribution, variety of project types, owner types, and experience levels. Using an Integrated Form of Agreement (IFOA) was not originally a criterion, but all projects selected happened to use some form of integrated agreement.

Given the complexity of project delivery, there are a large number of potential variables that affect not only team culture and performance but also the reliability of project outcomes. For these integrated project delivery (IPD) case studies, information was collected through 1) interviews with the owner representatives, architects, engineers, and builders, 2) project documents, and 3) a project team survey. In general, we sought to collect documents, interview stakeholders, and then conduct a team survey. However, due to the team's availability, we did not follow this sequence strictly and often followed up the interviews with further document requests. Through the analysis of these three types of case-study data, we were able to internally validate the project findings. Each data source was, for the most part, complemented the other sources. However, the slight differences in perspectives

provided the research team with a nuanced and layered understanding of the projects.

Based on our past research on collaborative delivery and informed by our research goals for this project, we created six categories common to all projects in this report: **Context, Legal/Commercial, Leadership/Management, Processes/Lean, Alignment/Goals, and Building Outcomes**. **Context** includes the specific risks and parameters that the project team worked with, such as budget and schedule. Our research team created diagrams describing the teams' interface with the owner and the key decision-makers within the owner group. **Legal/Commercial** includes the contract type and the range of processes used to select the team, develop the contract, and identify the members of the risk/reward pool. **Leadership/Management** describes the internal champions of IPD and Lean and the structure of decision-making developed by the team. This category also includes the processes used for bringing team members on board and for their removal, and the ways that the teams defined, understood, and eventually implemented measures to achieve the project goals. The **Processes/Lean** category describes how facilitators supported the teams, the team's implementation of Lean tools, and the effectiveness of Lean practices. It also includes the ways that building information modeling (BIM) was used and how the teams used co-location. **Alignment/Goals** is the category that relates to team culture, such as their alignment around goals and the team's ability to collaborate. **Building Outcomes** provides information on profit and the payout of the risk/reward pool and describes how the teams achieved budget, schedule, and other project goals.

NARRATIVES AND INFOGRAPHICS

The narrative text and information graphics were produced by the research team based on analysis of the interviews, document review, and survey results. The project teams were given drafts narratives for fact checking and to verify that quotes were employed in the correct context. The research team reported data consistently for the infographics,; in some cases this information was directly from the project teams, in others the research team worked with the project teams to parse their data in ways that worked for the report. In some cases, teams were still finalizing their numbers; in others, information was confidential. The table on Lean tools and BIM reflects the research team's evaluation on the effectiveness and extent of use of those tools. Peer reviewers—unbiased industry or academic experts – were invited to review an interim and the penultimate version of the report.

CASE STUDY COMPARISON TRUTH TABLE

Using techniques from qualitative comparative-analysis methods, we developed a summative tool called a Truth Table. This allows the team to map out key aspects of each case in a comparative-table format. Each case is shown represented by a row, while each variable is shown as a column. In the body of the table, we indicated if the variables were strongly represented in a case or partially represented in a case. If the variable was not present in a case, we left the cell blank. This allows the reader to quickly assess the variables as they related to the cases. We found that most projects have some types of Lean tools, and other tools were used less often. The results of the Truth Table analysis are shown in the Executive Summary.

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DOCUMENTS

In order to understand the specific interactions within the team, we asked for a variety of documents that defined the processes and policies of the project. We reviewed documents pertaining to the general management of the project, including contracts, project directories, and artifacts that showed how decision-making, and meetings were organized. To understand the workplace environment, we looked at office floor plans for co-located teams, photographs of BIM rooms, and photographs or screenshots of interactive tools. For tools and processes, we sought documents that contained protocols and planning information, such as the BIM-execution plan, A3 protocols, or Last Planner System framework. We requested that the teams share samples of Lean tools used, request for information (RFI) logs, or other project metrics they used to measure progress, communicate, and coordinate work across the disciplines. The teams were extraordinarily open and transparent in sharing their documents to help the research team gain a full understanding of the projects.

INTERVIEWS

We conducted interviews with key project participants in stakeholder groups, based on their role on the project: owners and owner representatives in one group, architects in another group, general contractors in a third. At times, we had a chance to interview design consultants and subcontractors in separate groups as well.

For these interviews, we developed two closely related but tailored and structured interview questionnaires. One questionnaire was created to address the owner point of view (given to the owners, and owner’s representatives) and a

Documents	
<p>All teams provided documentation in each of these categories, though the specific artifacts varied:</p> <p>Commercial and legal</p> <ul style="list-style-type: none"> Request for proposal (RFP) Request for qualifications (RFQ) and criteria for selection IPD agreement and contract exhibits, such as risk/reward distribution, milestone payouts Budget and other financial documents <p>Decision-making</p> <ul style="list-style-type: none"> Protocols for decisions Sample documents related to major decisions by the core team Sample communication of decisions to the larger team Documentation of goals Protocols for meetings Meeting schedules and agendas Sample meeting minutes 	<p>Lean, other tools and metrics</p> <ul style="list-style-type: none"> Samples of A3s and, pull plans Samples of customized tools, screen shots Protocols on how tools were used, including dashboards Metrics, including key- performance indicators and other metrics tracked RFI logs Risk registries <p>BIM</p> <ul style="list-style-type: none"> Execution plan Sample snap shots of models <p>Workspace environment</p> <ul style="list-style-type: none"> Plans and photographs of shared workspaces <p>Project personnel</p> <ul style="list-style-type: none"> Project directories Personnel lists Organizational charts

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second one for project stakeholders such as architects, general contractors, consultants, and subcontractors.

Interview topic areas:

1. Profile/experience/demographics
2. Metrics
3. Commercial/legal terms
4. Team culture
5. Processes, tools, and workplace environment

In the first category, we captured the team member’s past experience with IPD and Lean and had discussions on the perceptions/reflections on the owner’s market sector, experience with construction, and general familiarity with IPD and Lean. For metrics, we asked the team how they measured success on the project. In commercial terms, we investigated the aspirations for using IPD, the development of the contract, and how the contracting terms and processes impacted team culture and performance. Under team culture, we asked the team members to describe team member selection and the joint decision-making processes. In the process and tools category, we focused on Lean processes and BIM tools as well as notable general workplace organizational strategies. In the analysis we further refined these topics, and this refinement is presented in the structure of this report, with the final categories shown in the heading above.

NUMBER OF INTERVIEWS (PEOPLE INTERVIEWED)	ARCHITECTS	ENGINEERS, CONSULTANTS	BUILDERS	OWNER, OWNER CONSULTANTS	TOTAL
AKRON	2 (5)	2 (3)	2 (7)	1 (5)	7 (20)
*^ AUTODESK	1 (2)		2 (2)	3 (4)	6 (8)
SUTTER LOS GATOS	1 (2)	1 (1)	1 (1)	2 (2)	5 (6)
^ MOSAIC	1 (2)	2 (3)	5(8)	1 (1)	9 (14)
QUAIL RUN	1 (2)	1 (3)	(3)	1 (2)	3 (10)
*ROCKY MOUNTAIN	1 (3)	1 (2)	1 (3)	2 (3)	5 (11)
ST. ANTHONY	1 (1)		1 (1)	3 (4)	5 (6)
SUTTER SUNNYVALE	1 (2)	1 (1)	1 (1)	2 (2)	5 (6)
*^ T. ROWE PRICE	1 (2)	2 (3)	3(5)	2 (3)	8 (13)
WEKIVA SPRINGS	1 (1)	1 (1)	1 (1)	1 (1)	4 (4)
TOTAL	12 (23)	11 (17)	18(36)	4 (6)	60 (104)

* for this project, owner category includes owner and owner consultants

^ for this project, the builders category includes general contractors and trade partners

NUMBER OF INTERVIEWS OF PROJECT PARTICIPANTS BY ROLE

Key: number of interviews (number of participants)

For example, 2 (5) represents two interviews with a total of five interviewees.

Note: The categories of architect, engineers, and owner were fairly consistent and easy to define. The owner-consultant category included owner’s representatives as well as other consultants, such as furniture providers or other specialties. The builder category included general contractors and trade partners. Our research team defined trade partners as trade contractors, such as electricians, who were included in the risk/reward pool. There were a few companies that served dual roles, such as mechanical engineer and mechanical contractor. In those cases, we categorized the interviewee according to their primary role on the project.

- Executive Summary
- Research Methodology 1 2 3 4
- Literature Review
- Glossary/Definitions

Context				Legal Commercial			Leadership & Management				Processes & Lean				Alignment & Goals			Building Outcomes					
At A Glance	Project Description	Project Timeline	Owner Identity & Interface	Choosing IPD & Lean	Team Selection	Developing Contract	Developing Parties	Champions	Decision Structure	On Board & Off Board	Clarity of Goals	Resources & Facilitation	Tools & Processes	Lean Effectiveness	BIM	Workplace	Team Alignment	Collaboration	Team Culture	Profit & Payout	Budget & Schedule	Building Outcomes	Project Credits

COMPARATIVE ANALYSIS

Comparisons & Best Practices

- AKRON CHILDREN'S HOSPITAL, KAY JEWELERS PAVILION
- AUTODESK BUILDING INNOVATION LEARNING AND DESIGN SPACE
- MOSAIC CENTRE FOR CONSCIOUS COMMUNITY AND COMMERCE
- QUAIL RUN BEHAVIORAL HEALTH HOSPITAL
- ROCKY MOUNTAIN INSTITUTE INNOVATION CENTER
- ST. ANTHONY HOSPITAL
- SUTTER MEDICAL OFFICE BUILDINGS (LOS GATOS & SUNNYVALE)
- T. ROWE PRICE OWINGS MILLS CAMPUS BUILDING 1
- WEKIVA SPRINGS CENTER EXPANSION

Research Methodology (4 of 4)

SURVEY

To supplement the detailed interview data, we cast a broader net across the project participants with a survey. Following a series of project- and respondent-demographic questions, a project-profile section asked questions measuring successes across project team activities, owner engagement, and the managerial effects of the multisignatory agreement. A section on team culture examined the characteristics of collaboration, decision-making, and goal alignment that probed the details of project management structures and the impact of daily activities on project collaboration. The process and tools section looked at the level of Lean- and BIM-tool use in the project and asked respondents to compare use to previous experience. The metrics section asked respondents to identify the measurements used to manage project work flows and achievements and how those metrics impacted the work of the project team. These categories included professional skills, like communication, accountability, transparency, and trust, as well as outcomes, like effective decision-making, commitment and improvement, and goal alignment with the owner and across the team. Questions were also asked about significant project outcomes, like cost, schedule, energy performance, and sustainability, that offered motivation and challenge to the project team. The last section compared respondent's experiences with IPD on past projects to how this project team performed in terms of budget, schedule, building quality, and overall value in the projects of this study and whether they would choose to use IPD in the future or recommend it to others.

NUMBER OF SURVEY RESPONSES	ARCHITECTS	ENGINEERS, CONSULTANTS	^ BUILDERS	OWNER, OWNER CONSULTANTS	TOTAL
AKRON	3	1	13	2	19
AUTODESK	3	4	12	2	21
SUTTER LOS GATOS	1	1	2	1	5
MOSAIC	2	3	6	1	12
QUAIL RUN	2		5	3	10
*ROCKY MOUNTAIN	4	5	8	7	24
*ST. ANTHONY	8	6	6	2	22
SUTTER SUNNYVALE		3	3	1	7
*T. ROWE PRICE	2	4	4	3	13
WEKIVA SPRINGS	1	4	6	1	12
TOTAL	26	31	65	23	145

* for this project, owner category includes owner and owner consultants

^ for all projects, the builders category includes general contractors and trade partners

NUMBER OF COMPLETED SURVEYS BY PROJECT PARTICIPANTS BY ROLE

Questionnaire participants self-identified with the categories of architect, engineer/consultant, builders, subs, owners, owner consultants. In the project narratives, our research team used the term trade partner for those contractors who were included in the risk/reward pool and subcontractor for those trades who were contracted with the general contractor and not included in the risk/reward pool.

Glenn Ballard & Iris Tommelein (2016). *Current Process Benchmark for the Last Planner System*. Available at p2sl.berkeley.edu

Current Process Benchmark for the Last Planner System

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Outline of the Current Process Benchmark for the Last Planner System

- A. P2SL Current Process Benchmarks
- B. Why Last Planner? - a Brief History
- C. Functions
- D. Presuppositions and Conventions
- E. Principles
- F. Processes
- G. Methods
- H. Implementation
 - a. Design
 - b. Deployment
- I. Future Research
- J. Frequently Asked Questions
- K. Acknowledgements
- L. Glossary
- M. Last Planner Publications

A. P2SL Current Process Benchmarks

The University of California Berkeley's Project Production Systems Laboratory (P2SL) periodically publishes a description of the current benchmark in each project management process that is a subject of research. This reports on the current benchmark for the Last Planner System (LPS) for project production planning and control.

Current process benchmarks are developed with industry practitioners to best incorporate the latest advances in both theory and practice. Consistent with the lean philosophy of continuous improvement, each publication of a process benchmark includes a description of the research needed to surpass it.

We understand LPS, at the level of functions, presuppositions, principles and processes, to be a specification for project production planning and control--not a specific way to plan and control production on projects, but the requirements any specific 'way' must meet in order to be valid. That said, this benchmark can be understood as a "Current Benchmark for Project Production Planning and Control Systems".

We do not want to be overly prescriptive in our description of any management process, including LPS, both because we do not want to discourage experimentation and because it is impossible to specify exactly what needs to be done in every possible context. Our goal is to be sufficiently descriptive of the System so that users can understand its fundamentals; namely, functions, presuppositions, principles and processes, and so be better able to specify methods and tools to accomplish the functions consistent with these fundamentals.

To that end, in the following we first provide a brief history of the development of the LPS, explaining why it was invented and why it is needed. The subsequent sections describe the functions LPS is designed to perform and its presuppositions (what's held to be true about the world in which functions are to be performed), From these, principles (behavioral guidelines for executing functions given the presuppositions) are inferred. Next processes are described to explain how the functions are linked together to make a system, and finally we describe the methods used to perform the functions within processes consistently with presuppositions and principles.

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Recognizing that a standard practice must extend to the level of tools, and that each organization needs to have standards for project production planning and control, we list the elements to be specified in developing a standard. (See the section below on Implementation).

Readers of this document may come at from different angles. The structure was established for readers who want to have a sufficient understanding regarding the WHAT and WHY of the Last Planner System to be able to make reasoned decisions whether to embrace it, or to evaluate their own implementations of the System. Those looking more for HOW to do it may want to first read Sections F, G, H and K (Processes, Methods, Design and Deployment, and Frequently Asked Questions), then return to the remaining sections.

We understand that the Last Planner System can and is being used in a variety of applications, but in this work, we assume that it is applied in a construction project, both in designing and constructing. Methods used only in designing or constructing are tagged as such.

A glossary of terms is located at the end of this document. Terms in the glossary are italicized on first use.

B. Why Last Planner?

A distinction is commonly made between ‘planning’, in the sense of designing ways to achieve objectives, and ‘control’, putting plans into action to cause objectives to be achieved. The Last Planner System (LPS) was created, in the early 1990s, as a system for project production control. *Production control* was thought to be a missing piece in an otherwise complete project management toolkit, which was dominated by *project controls*. The job of project controls is to set cost and schedule targets in alignment with project scope, and to monitor progress toward those targets. The job of production control is to steer toward targets; to do what can be done to move along the planned path, and when that becomes impossible, to figure out an alternative way to achieve targets.

Both are needed. They are two sides of a coin. Project controls without production control is like driving while looking in the rear view mirror. Production control without project controls is like driving with no destination and no awareness of remaining distance or fuel.

The initial equation of LPS with production control has changed over time. Growing awareness of traditional scheduling’s failures in setting detailed time and cost

targets provoked partial addition of that function to LPS in the late 1990s; “partial” because *pull planning* may be used to detail plans at every level of *task breakdown*,

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but project cost and schedule targets (budgets and completion dates) are set outside the Last Planner system.

The inspiration for LPS was the discovery of chronically low *workflow reliability* in construction projects. Consequently, the first step in its development was to improve workflow reliability, to increase the match between DID and WILL; i.e., to learn how to do what we say we're going to do. Beginning in the early 1990s, that was done through meetings with front line supervisors to produce coordinated weekly work plans, following the rule to include on weekly work plans only tasks that are well defined, sound, sequenced, and sized to performer capabilities³.

That was successful. *Percent Plan Complete* (PPC) improved as did labor productivity. But it also became apparent that PPC could be 100%, productivity excellent, and a project still be falling behind schedule. Recognizing that project progress toward scheduled completion dates rises and falls with PPC only when tasks are made ready in the right sequence and rate⁴, a *lookahead planning* process was added to LPS so what SHOULD be done CAN be done when needed⁵.

Once lookahead planning was in place, both project cost and schedule performance improved, but it became apparent that scheduling could be done better. Too often, what SHOULD be done according to the project schedule either could not or should not be done to best accomplish project objectives. This took LPS beyond its original production control functions. Once effective lookahead planning revealed the inadequacy of scheduling, *pull planning* was added to LPS, initially to detail the milestone-level master schedule, phase by phase (*reverse phase scheduling*). Soon collaborative pull planning came to be used to at every level of *task breakdown*: project (master schedules), phase, process, operation and step.

³ See e.g. Ballard & Howell, 1998.

⁴ Whether or not the rate of progress is adequate is a function of the amount of capacity relative to demand. See Presuppositions below.

⁵ Lookahead planning was done in construction well before Last Planner, but has tended to be a dropout from a higher level schedule, assuming that all tasks will be fully sound and capacity to perform them will be sufficient. As such, traditional lookahead planning served as an early warning of mobilization—'You're going to start the walls in the basement three weeks from now, right?'. This is not a question to which "no" is an acceptable answer! The lookahead planning process in the Last Planner System has the job of identifying and removing any remaining constraints on scheduled tasks in the lookahead period. If constraints cannot be removed, the task is rescheduled for a later date when constraints will have been removed.

Last Planner System Insights

Through the years, reflection on implementation experiences has produced important insights. Here are a few; some of which, like the first below, were greatly influenced by the thinking of others:

- To prevent reoccurrence of breakdowns requires understanding what happened. That includes understanding why people did what they did in the circumstances as they experienced them. If people fear punishment, they will not participate in the search for causes and countermeasures. (See Deming, 1986; Dekker, 2006)⁶
- There is always a trade-off between time and cost, but the level at which the trade-off is made changes with work flow reliability, and LPS, properly implemented, improves work flow reliability.⁷
- The principles of LPS apply to all types of work that require coordination between humans.
- From the perspective of continuous improvement, LPS's job is to stabilize operations so they can be further improved, both individually and in the processes which they comprise, but it also improves productivity. Many, perhaps most, people are satisfied with that and don't exploit the opportunity for more fundamental improvement in performance.
- The industry unknowingly plans for productivity at approximately 50% PPC. (Liu, et al., 2010⁸)
- 5 Whys Analysis is practical and brings unexpected benefits, especially when data is stored and mined.
- Work structuring precedes production control and culminates in schedules. Location-based work structures have been successfully combined with Last Planner system production control, which does not presuppose any specific work structure⁹.

⁶ Deming, W. E. (1986). Dekker, S., 2006.

⁷ Queuing theory underlies this phenomenon, which is well illustrated in the Production Flow Graph, Figure 3-17 in *Factory Physics for Managers* by Pound et al. Simply stated, as capacity utilization approaches 100%, wait time accelerates without end. Application to LPS was made in Howell et al., 2001.

⁸ A correlation analysis between labor productivity and PPC is reported in Liu et al. (2010). When the equation for the line of best fit for that data set is determined, substitution of a PPC value of 50% in that equation yields a performance factor (the ratio of actual to budgeted productivity) equal to 0.98 (from unpublished lectures by Glenn Ballard).

⁹ Location based work structures (including takt time planning) have been successfully used with LPS. To the extent that reliable release of locations (takt zones) is achieved, that simplifies

- Currently, the three least implemented components of LPS are design of operations, measurement of lookahead planning performance, and learning from breakdowns. Many only do weekly work planning. Some only do collaborative phase planning. LPS is a system of interconnected parts. Omission of a part destroys the system's ability to accomplish its functions.

C. What are the functions of the Last Planner system?

Functions are the proper work of the system; its jobs.

- 1) Specifying what tasks should be done when and by whom, from milestones to phases between milestones, to processes within phases, to operations within processes, to steps within operations.
- 2) Making scheduled tasks ready to be performed
- 3) Replanning/planning to complete, to achieve project objectives
- 4) Selecting tasks for daily and weekly work plans—deciding what work to do next
- 5) Making release of work between specialists reliable
- 6) Making visible the current and future state of the project
- 7) Measuring planning system performance
- 8) Learning from plan failures¹⁰

Many, perhaps all of these functions, have been recommended by others in some form or fashion, but never, to our knowledge, all together in a single system. Further, a few are perhaps (almost) unprecedented; e.g., the explicit focus on making work ready, on work flow reliability, specification of selection criteria for tasks to be placed on near-term work plans, system transparency, and measurement of system performance.

management of flows and shifts the focus from coordinating work between specialists (design squads or construction crews) to coordinating work within those squads or crews. See Seppanen, et al. (2015) and Frandsen & Tommelein (2016).

¹⁰ NB: Planning system performance and plan failures (failures to successfully execute planned tasks) may result from causes outside the immediate control of those planning and executing design and construction tasks. The whole management and execution system influences performance. Analyzing plan failures is one way to reveal needs and opportunities for improvement in the larger system.

D. Presuppositions and Conventions

Presuppositions are what is assumed to be true about the world in which the production planning and control functions are to be performed. Since production systems are both social and technical, the relevant presuppositions concern the social, the technical, or their combination.

- A. Production systems are both social and technical.
- B. All plans are forecasts and all forecasts are wrong. Forecast error varies with forecast length and level of detail.
- C. Planning is dynamic and does not end until the project is completed.
- D. Involving those who will directly supervise or perform the work being planned results in better plans and greater ability to adapt plans when needed.
- E. Operational performance (safety, quality, time and cost) varies with the degree of planning and preparation.
- F. Willingness to invest in planning and preparation varies with the reliability of workflow, the predictable release of work from one 'specialist' to another. Workflow reliability is measured by PPC (percent plan complete). To illustrate the point, suppose PPC is 40%. That discourages front line supervisors (last planners) from investing time and energy in planning and preparing to perform tasks that are less than a coin flip likely to turn up heads. By contrast, when PPC is 70-80%, front line supervisors have a better chance of their planning and preparation paying off.
- G. Making commitments publically promotes care in making commitments and increases efforts to deliver on commitments that are made. It also increases collaboration between trades, willingness to share assumptions, best path forward, coordination and general quality of the work.
- H. The probability that commitments can and should be kept is increased when both parties, customer and supplier, practice *reliable promising*—they take their promises seriously and engage in a conversation to align the interests and capabilities of both parties.
- I. An essential prerequisite for reliable promising is that suppliers can say “no” to a request by appeal to task appropriateness (*sequence*), or readiness to be performed (*task definition, soundness, or size relative to capacity of performers*).
- J. Actors within a project production system can make choices that help or hinder achieving project objectives; i.e., actors have discretion.
- K.

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- L. Understanding project objectives and the current and future state of the project helps actors make better choices.
- M. Perfect planning may not be possible, but it is possible to never make the same mistake twice.
- N. *Variation* in production systems can be reduced but never eliminated, so *buffers* are required to absorb that variation and protect targets.¹¹
- O. Workflow reliability, as measured by PPC, rises when commitments are made only to tasks that are sound, sequenced, and properly defined and sized (See Principle 6 below).
- P. Productivity rises and falls with PPC. The level of productivity increase or decrease is limited by the extent to which capacity exceeds demand, resulting in labor hours not expended on production.
- Q. Progress rises and falls with PPC to the extent that tasks are made ready in the right sequence and rate. The rate of increase or decrease is a function of the extent to which capacity falls short of demand. If there are fewer labor hours available than needed to perform scheduled tasks, that will reduce the rate of progress from what it could have been.

Conventions are neither true nor false. The following convention is useful when talking about work on construction projects.

- Tasks can be broken down into many different levels of detail. Lacking a generally recognized taxonomy for task breakdown, the following is proposed: Projects consist of phases, phases consist of processes, processes consist of operations, operations consist of steps, and steps consist of elemental motions¹².

¹¹ Strictly speaking, variation of the type mentioned here is one of two types. Buffers are appropriate for variation that can be described by statistical distributions; what might be called the 'predictably unpredictable'. An example is processing durations. Another type of variation consists in low probability/high impact events that disrupt production systems—'emergencies', 'black swans'. They must be handled by building flexibility into plans and enabling team responsiveness and flexibility. *Note thanks to Hajnalka Vaagen, NTNU.*

¹² Motion analysis, the method of analyzing worker movements in terms of elemental motions (therbligs) was developed by Frank Gilbreth in the early 1900's. Therbligs is a jumble of the letters in his last name. Elemental motions are what robots are programmed to do; e.g., grasp, lift, rotate. Motion analysis is not yet visible in construction, but may first appear as robotics are introduced in fabrication shops.

E. Principles and Rules

Principles (also called rules) are guides to acting in the world to perform production planning and control functions consistent with the presuppositions about the world.

1. Keep all plans, at every level of detail, in public view at all times.
2. Keep *master schedules* at *milestone level of detail*.
3. Plan in greater detail as the start date for planned tasks approaches.
4. Produce plans collaboratively with those who are to do the work being planned.
5. Re-plan as necessary to adjust plan to the realities of the unfolding future.
6. Reveal and remove *constraints* on planned tasks as a team.
7. Improve workflow reliability in order to improve operational performance.
8. Don't start tasks that you should not or cannot complete. Commit to perform only those tasks that are properly defined, sound, sequenced and sized.
9. Make and secure reliable promises, and speak up immediately should you lose confidence that you can keep your promises (as opposed to waiting as long as possible and hoping someone else speaks up first).
10. Learn from *breakdowns* (unintended consequences of actions taken).
11. Underload *resources* to increase reliability of work release.
12. Maintain workable backlog; a *backlog of ready work* (tasks ready to be executed) to buffer against capacity and time loss.

F. Processes

In this section, we use two diagrams to show the relationship between levels of planning and the various functions performed at each level.

The structure of the diagram in Figure 1 is based on Should-Can-Will-Did. Master and phase schedules specify what **SHOULD** be done when and by whom. The job of lookahead planning is to make scheduled tasks ready so they **CAN** be performed when scheduled. Commitment plans are formed by selecting from ready work, expressing what **WILL** be done in the plan period. Plan failures (aka broken promises) are identified by comparing **DID** to **WILL**, then analyzed in search of countermeasures to prevent reoccurrence. The methods and metrics used to perform these functions are listed on the right hand side of the diagram. See the glossary for definitions of Percent Plan Complete (PPC), *Tasks Made Ready* (TMR) and *Tasks Anticipated* (TA).

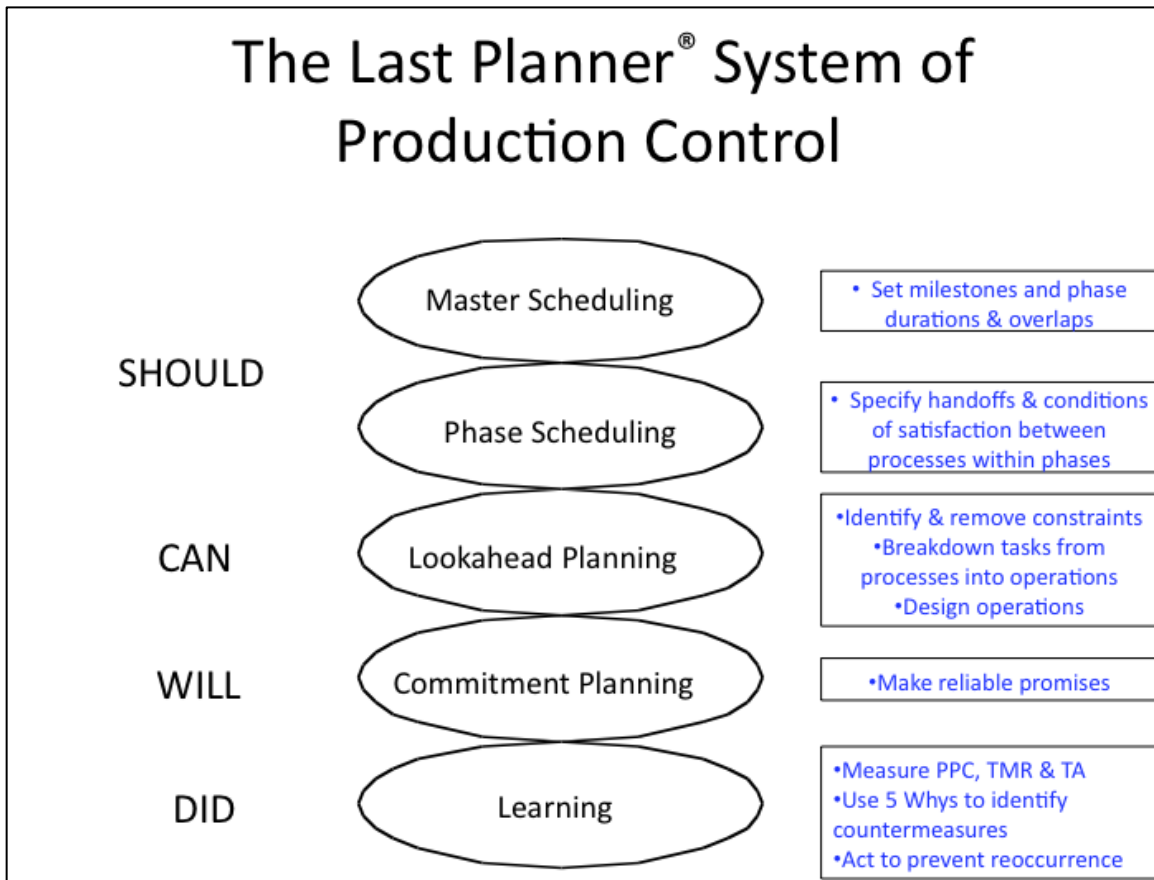


Figure 1: SHOULD-CAN-WILL-DID

Figure 2 shows how one level of planning feeds the next. Function #1 occurs at these task breakdown levels: project, phase, process, and operation. The master schedule is expressed in phases. The phase schedule is expressed in processes. The lookahead schedule is initially expressed in processes, but after task breakdown, the lookahead schedule consists of operations. Operations designs (how they are to be performed) are expressed in steps to be carried out by individuals or teams. Note: the work plan that immediately drives production is the product of selection from eligible tasks in *workable backlog*. The tasks in commitment plans are operations. Execution of operations in accordance with their design is controlled by the front line supervisor (last planner) and those executing the work.

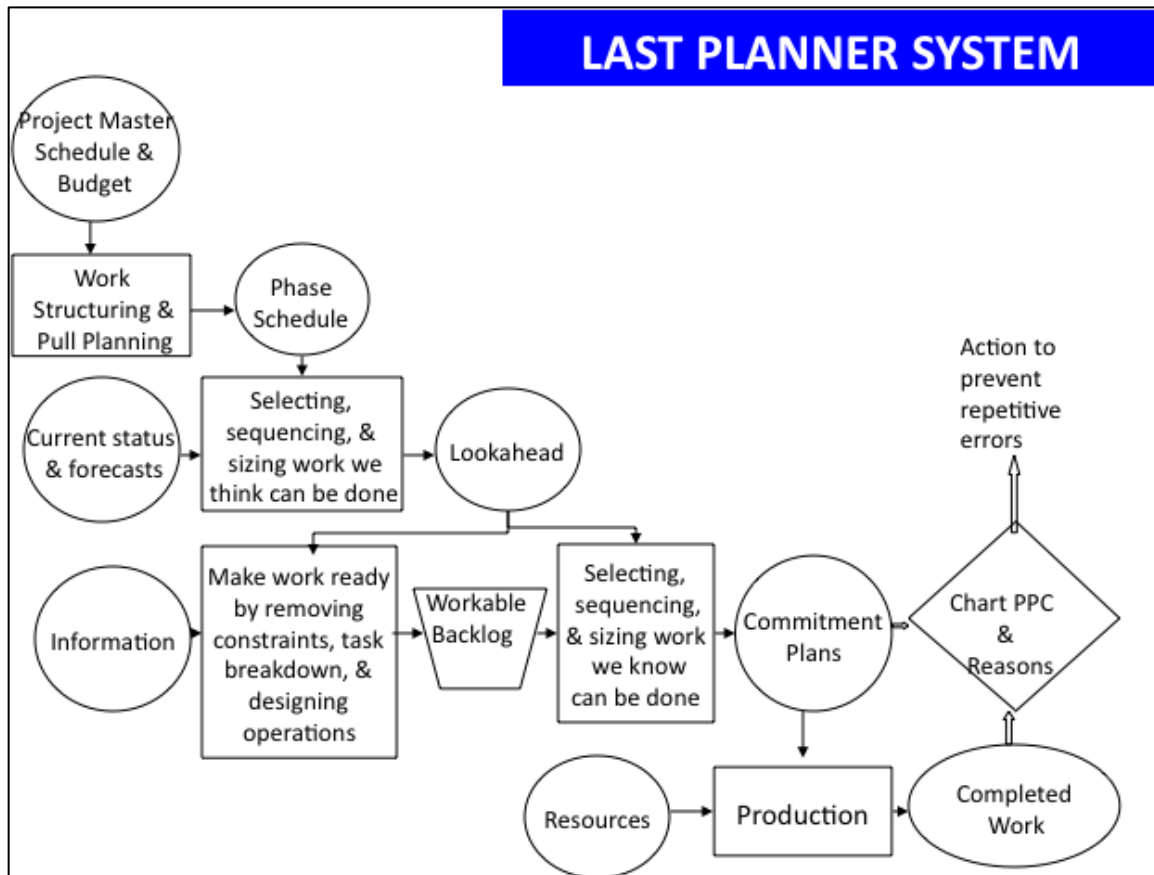


Figure 2: Relationships between planning levels in the Last Planner system

G. What methods are used to accomplish functions?

Methods and tools are products of invention and are judged by their consistency with principles and utility in performing functions within specific circumstances. Walter Shewhart invented Plan-Do-Check-Act in the 1930s¹³. More recently, pull

¹³ Steve Ward contests this explanation: "He did not. Shewhart's original version was "specification, production, inspection" This was adapted into PDSA and taught by Deming to the Japanese in the 1950's. JUSE formed a translation of the concept into PDCA. Deming later (1980's) declared that PDCA was a "corruption" of the original concept and said the "Shewhart Cycle" should be Plan Do STUDY Act."

planning was adapted from earlier collaborative planning approaches. The taxonomy offered here for task breakdown was invented to provide a standard language to distinguish between levels of detail. It is reasonable to expect that inventions will continue to emerge, and when that happens, this Current Process Benchmark for LPS will be modified accordingly. What follows are the best, proven methods of which we are currently aware. We first list the methods, then describe each method.

- a) For specifying Should
 - a. *Pull planning*
- b) For lookahead planning/make ready
 - a. Constraints analysis and removal
 - b. Task breakdown: Commitments are made to execute operations to the conditions of satisfaction of immediate and ultimate customers. Scheduled tasks are broken down, as needed, into operations.
 - c. Collaborative design of operations--what steps in what sequence performed by whom using what:
 - i. *Virtual prototyping*
 - ii. *Physical prototyping (construction operations)*
 - iii. *First Run Studies*
- c) For increasing workflow reliability
 - a. *Reliable promising* – Disciplined approach to commitment making in which both requester and performer interact in conversation to ensure it is clear to both what is being requested--what is to be done to what conditions of satisfaction (e.g., time of completion).
 - b. *Visual controls*
 - c. *Underloading resources*
 - d. *Daily huddles*
- d) For Learning from Plan Failures
 - a. *Analysis of breakdowns* to understand why they occurred and to identify the level of cause at which countermeasures can be effective in preventing reoccurrence.
 - b. *PDCA: Plan-Do-Check-Act*
 - c. *DCAP: Detect-Correct-Analyze-Prevent*
- e) Metrics
 - a. Percent Plan Complete (PPC)
 - b. Tasks Made Ready (TMR)
 - c. Tasks Anticipated (TA)
 - d. *Frequency of Plan Failures*

Pull Planning

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Pull Planning is a technique that is used as part of LPS to develop a plan for doing work at any level of task breakdown, one of which is a Phase Schedule (The levels are Project, Phase, Process, Operation and Step). Pull Planning can be used to plan work in any time horizon, or to sequence activities as part of a production plan.

Use of pull planning to produce phase schedules should occur at least one lookahead period ahead of scheduled start so tasks can be made ready. Lookahead periods typically range from 3 to 12 weeks, depending on the lead time needed to remove constraints (see item D in Frequently Asked Questions).

Pull planning sessions should involve all who are responsible for delivering the work and with authority to make decisions, plus others who can provide needed information; e.g., safety, quality, logistics, auditory engineering specialists. One of the keys to a successful pull plan is to have those experts collaboratively working together to develop the sequence of activities that produces an acceptable work flow.

Pull planning involves the identification and definition of the milestone, or key event that the team will be pulling to; e.g., releasing subsequent work activities. Identifying the conditions of satisfaction of the milestone is critical to a successful pull plan. To assure that shared understanding, the first step in pull planning is to co-create with the team a description of the milestone from which to pull—what's included and excluded, what work it releases, etc. The completion of one milestone sets the stage for the beginning of another one.

After the milestone or key event is clearly defined and the conditions of satisfaction are agreed, the team begins to work backwards from it. Sticky notes (physical or virtual) are posted by performers and requests are made of other performers for prerequisite tasks. Performers negotiate the conditions of satisfaction for the hand-offs between the tasks posted. Participants must deeply understand their own work, and alternative ways of carrying it out, in order to be able to develop the best plan for all parties involved in the work being planned. As noted by Steve Ward, this is an area of weakness when specialty contractors are engaged late in the project and do not have sufficient understanding of the work to contribute effectively to planning.

What someone really needs may not be stated, and have to be drawn out by others asking questions. Too often, we ask for everything when we only need one part of it in order to accomplish our task. Completing the work of one discipline or trade creates the conditions for other work to begin. Participants also have to understand what conditions they have to meet in order for them to start their own work so they can make requests of others.

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While a higher level pull plan may be developed for an entire project phase, unless they are relatively simple and short, there may be multiple detailed pull plans developed for different areas, systems, or time periods.

Pull planning, like all planning, is subject to differences between assumptions about how the future will turn out and what actually happens. One advantage of pull planning is it creates a team able to respond flexibly to such differences.

Constraints Analysis & Removal

In order to ensure most effective and efficient use of capacity, the work that SHOULD be performed by a certain date must be available to be performed (CAN) without any blockage or interruption, i.e., constraint.

Constraints can be either physical (availability of plotter before printing, rebar installation prior to concrete placement) or informational (soils report before foundation design, engineering details before fabrication, permit before hazardous work). These can be identified as part of the process/operations design or as they manifest throughout the execution of a project. *Activity Definition Model* provides a robust framework in which to think through this process.

Responsibility for removing constraints is spread throughout the team. Typically design squad bosses and foremen of construction crews are responsible for having labor appropriately skilled and in the quantities required. Construction engineers may be responsible for removing design information constraints; materials managers for material constraints, etc. It is important to identify the departments and individuals who will be the go-to guys for each type of constraint.

However, it is important to note that the timing rules for identifying a constraint may be very different from resolving it, especially those related to dynamic capacity. Resolving the constraint too far in advance (such as advance delivery of material, equipment, or release of design) may end up generating work-in-process and inventory that prevents effective execution of work and creates potential rework (the very thing that LPS is geared to improve).

Task Breakdown

The task breakdown convention used in LPS understands projects as composed of phases, phases of processes, processes of operations, and operations of steps. (See Glossary for an example). Processes are connected work performed; e.g., detail-fabricate-preassemble-deliver-install. Suppose the lookahead window on a project

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is six weeks, at which time identification and removal of constraints begins. Some constraints may apply to all operations within a process; e.g., materials and information, while others are specific to individual operations. The transition from processes to operations should occur no later than 3 weeks ahead of the scheduled start date for a task to allow time for operations design and identification and removal of constraints that are revealed by that design; e.g., specific skills and permits needed, location and type of equipment, etc.

Collaborative Design of Operations

One fundamental element of LPS is the involvement of the last planners, so-called because their plans directly drive execution, as opposed to serving as inputs to other planning processes. These front line supervisors are most knowledgeable about how to optimally execute the work within the given environment. Design of operations is another application for pull planning, and involves not only the last planners, but also the craftworkers who are to execute the first instance of the operation (first run study), higher level supervisors in the chain of command, and specialists for material sourcing, design buildability, quality, safety, logistics, equipment, etc.

Reliable Promising

All work gets done through language and in the way people speak, listen and collaborate with each other. Reliable promises are the result of the commitments we make to each other out of respect for each other's concerns.

Projects are a network of commitments. Projects extend well beyond the site, even when they have reached the construction phase. Consequently, commitments are made between individuals in the various organizations on and off site.

Before making the promise, the performer makes a reasoned assessment of their capability and capacity to act on the request within the requested timeframe. A fundamental tenet of reliable promising is the acceptance of “No” as an appropriate response to a request. For example, last planners make reliable commitments to following disciplines or trades to complete specific work tasks by a specific time during the next work cycle. Prior to making the commitment, the last planner confirms that the task is well defined, is sound – has no unresolved constraint, is in proper sequence, and is appropriately sized¹⁴. These commitments are documented

¹⁴ See *task sequence*, *task soundness* and *task size* in the Glossary.

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on the commitment plan. Last planners and others make commitments to attend LPS meetings and to come prepared.

People in the extended project network also respond to the requests of others. In order for someone to say yes to a request they must have the ability to say no. If they cannot say no to a request, then they cannot make a promise. This is a huge cultural change from traditional practice and requires persistent and persuasive coaching to both make the change and to sustain it.

In LPS, promises are documented in a variety of ways; for example, in the pull plan, constraint log, the weekly work plan, in supplier's commitments to deliver at a certain time, in fabricator's commitments to manufacture to agreed specifications, etc.

Visual Controls

The purpose of a visual control for a production system is to provide clear visual indicators depicting the status of the system at an appropriate level for the audience to achieve shared understanding so that necessary actions can be taken. Therefore a visual control for a production system must convey in simple visual cues (1) appropriate measurements (not project controls), (2) up-to-date information (not print-out of last week's information), or (3) what's really possible (not a schedule printed on the wall). Simple graphs and charts posted in public places can be very effective.

Modern production systems utilize sensors to provide real-time information and often times provide direct access to mechanisms to address any variations in the production.

Daily Huddles

Brief, typically stand-up, meetings each day by groups of interdependent players, at which each, in turn, shares what commitments they have completed, what commitments they need help with or cannot deliver. This can be done within a design squad or construction crew, and between front line supervisors of design squads or construction crews.

Countermeasures

Analysis of breakdowns is done to find countermeasures expected to completely or partially prevent reoccurrence of the breakdown. Often, the initial reason provided for an incomplete task does not provide sufficient insight into why the task was not done. It may require several interviews to get to effective countermeasures using the 5 Whys technique.

Timely generation and implementation of countermeasures reduces accidents, rework, and plan failures. The return on investment makes this something everyone should do, and allocating capacity for such analysis is a vital management act.

Capturing reasons for breakdowns over time provides teams with trends, which can be used to develop strategies to prevent re-occurrence of the same failures in the future. It should not be a “blame and shame” tool or be used as a weapon.

Countermeasures developed through analysis of breakdowns are tested using Plan-Do-Check-Act. PDCA was developed by Walter Shewhart at Bell Labs in the 1930s, and popularized by his student, W. Edwards Deming. Sometimes PDCA is referred to as the Deming Cycle.

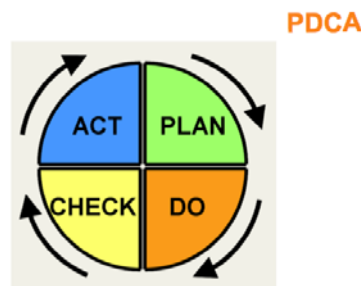


Figure 3: PDCA

PDCA is a rough and ready method of formulating and testing hypotheses, and is the tool most commonly used to test the effectiveness of countermeasures identified through 5 Whys analysis of plan failures. Suppose a commitment, made to remove a constraint on a scheduled task in the project’s lookahead plan, was not successful, and the task had to be delayed and rescheduled. 5 Whys analysis identified the root cause as assuming that soil conditions would be the same as on a nearby project. We might propose that people ought not to make assumptions, but that’s hardly an effective countermeasure. For the sake of this illustration, suppose that the countermeasure proposed was to incorporate into design reviews a checklist that called for listing all relevant assumptions and their bases. The hypothesis to be tested is: If <checklist>, then fewer unfounded assumptions, and so fewer plan failures in design. Developing the hypothesis is the PLAN in PDCA. The DO in Plan-Do-Check-Act is to perform one or more experiments to see if the hypothesis is supported. CHECK is checking to see if using the checklist reduces plan failures, and ACT is declaring the checklist a standard requirement and implementing that standard.

Detect-Correct-Analyze-Prevent

A connected problem solving cycle is Detect-Correct-Analyze-Prevent (DCAP). This was formulated primarily with quality defects in mind, but applies also to plan

failures and accidents/near misses. The idea is to DETECT breakdowns (variations from target) as close as possible to their origin, to take CORRECTive action so production can continue, to ANALYZE the breakdown to root causes (perhaps using 5 Whys), then develop and test countermeasures in order to PREVENT reoccurrence. An example: Suppose an error on a drawing is discovered after the drawing has been issued for fabrication, but before fabrication starts. The corrective action is to stop the use of that drawing, collect all previously issued drawings, correct and distribute the corrected drawing. That enables fabrication to resume, but does nothing to prevent similar errors from happening in the future, so an analysis of the breakdown is needed in order to discover why it happened. Analysis reveals that the drawings were issued late, and the urgency for speed contributed to the error. Countermeasures could be developed for such situations, but further analysis is needed to determine why the drawings were late. Eventually it is discovered that key vendor data was delayed, and a countermeasure was developed to incorporate vendors into LPS and engage them in the practice of reliable promising.

A construction example: A construction worker was injured when struck by a wrench dropped from a higher elevation. In this case, correction consists in providing medical treatment to the worker and alerting the work area from which the wrench came that there had been an injury. Further specifics depend on the situation, but one likely possibility is to stop work in areas below higher work until steps are taken to prevent repetition of the incident.

The relationship between PDCA and DCAP is shown in the following diagram:

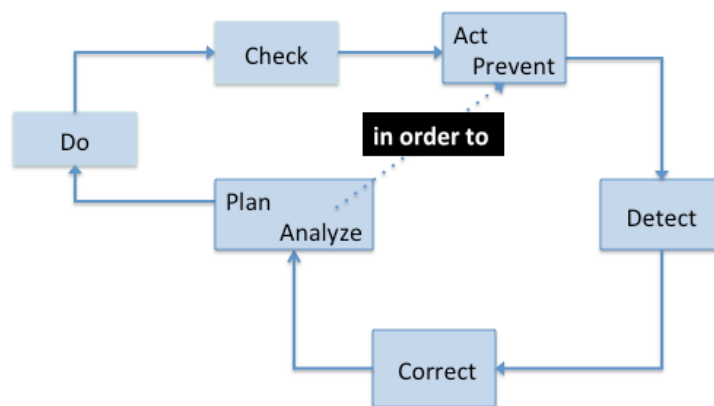


Figure 4: DCAP/PDCA combined cycles

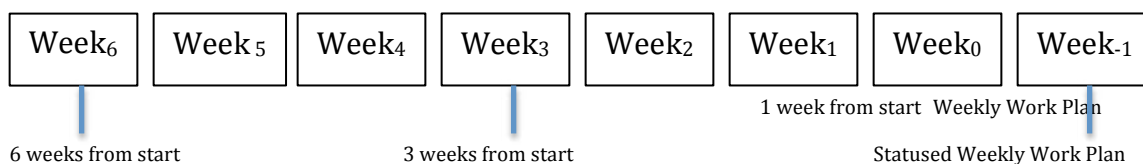
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Metrics

Currently, there are four established metrics to measure the effectiveness of LPS implementation:

- PPC
- TA
- TMR
- Frequency of Plan Failures

The first three of these metrics involve comparison of task sets in different weeks of the lookahead window. In the figure below, a six week lookahead window is assumed, beginning 6 weeks ahead of scheduled start.



Percent Plan Complete (PPC) – PPC measures workflow reliability; i.e., the predictable release of work between work groups. is generally tracked on a weekly basis. PPC compares the tasks that were completed (Week₋₁ in figure above) against the tasks in the weekly work plan for that week (Week₀). At the end of the plan period (day, week, shift, etc.), PPC is calculated as the percentage of completed tasks relative to those that were planned at the beginning of the week. PPC compares the stated weekly work plan (Week₋₁) against the weekly work plan (Week₀).

Tasks Made Ready (TMR) – TMR is the same measurement as PPC, only done earlier in the lookahead process, comparing the weekly work plan (Week₀) against an earlier week in the lookahead window (Week_n). TMR measures the ability of the team to identify and remove constraints ahead of the scheduled start of specific work tasks.

Tasks Anticipated (TA) – TA measures the percentage of tasks for a target week that were anticipated in an earlier plan for that target week. The objective of this indicator is to provide a relative measure of how well the team is able to cause what is actually going to happen on the project within the next few weeks. This planning ability is critical because without it, the right work cannot be made ready.

Measurement of TA and TMR starts by comparing task sets at Week₁ (the last week in the lookahead window prior to scheduled start) against the task sets at Week₀ (the weekly work plan). Suppose the task set at Week₁ is ABCDE and the task set in the weekly work plan (Week₀) is ACEFG. Only A, C and E appear in both, so $TMR = ACE / ACEFG = 60\%$. F and G are in the weekly work plan, but were not in Week₁, so $TA = FG / ACEFG = 40\%$.

As TMR and TA approach 100%, measurement shifts to comparison of Week₀ against Week₂. How far to extend TMR and TA is an empirical question at this point, as we are not aware that anyone has ever measured beyond Week₁. Note also that there can be good reason for changing committed tasks; for example, when external conditions change, making it imperative or beneficial to change course; or when constraints reappear that we thought had been removed. Of course, we want to learn how to prevent negative changes, but learning how to accommodate necessary changes or opportunities is equally important.

Frequency of Plan Failures – As discussed above (see Percent Plan Complete – PPC), during execution tasks are annotated as to whether or not each was completed when planned. Those not completed when planned are assigned to a category which describes in general the cause of the plan failure or variance. For example, some usual categories during construction are “Owner Decision,” “Engineering/Design,” “Weather.” These categories are generally established prior to the start of the project and reflect the broad categories of plan failure that might be expected during execution of this type of project. However, as the project evolves the categories can be refined to bring added insight to the causes of plan failure. As plan failures occur, a frequency chart is updated to visually indicate the relative frequency of each category of plan failure. When frequency of specific categories of plan failures are tracked over time, it reveals the extent to which root causes have been identified and countermeasures taken to prevent reoccurrence.

These categories, often called “Reasons for Variance”, are useful to identify weaknesses in specific support systems or flows. For example, recurrent problems with materials may signal a failure in the materials management information system or in supplier/site coordination. The actual source of plan failures has to be discovered by analysis. Identification of a category is like giving bloodhounds the socks of a lost child in order to put the hounds on the scent. Categorization without analysis does not prevent reoccurrence of plan failures.

H. Implementation

This section has two parts. First, the design of a project production planning and control system is described, then the deployment of a project production planning and control system is described.

Design

Due to the inherent complexity of project production (multiple stakeholders, different locations, alternate sourcing options, etc.), the means through which production is planned, executed, controlled and improved must be tailored to the

type of work and workers that perform it¹⁵. Therefore, a cookie-cutter approach or replicating another project's control system should be avoided. The allowable amount of *variability* in the production system and the corresponding allocation of buffers should determine which control protocols the production control system should enable including the level of detail and frequency of planning, control and feedback. In this regard, the production control system can use one or a combination of physical control, software (control solutions including sensors) and human control. As is done to prevent accidents, where possible, they are engineered out of the system. When that is not possible, to prevent human error, software is used to control actions. Finally, where dependence on human judgment is necessary, the production system is structured and managed to facilitate judgments that advance the system towards its goals. When errors are made, that triggers a search for countermeasures to prevent reoccurrence.

LPS enables control of work execution by providing the functions, principles and processes each individual last planner involved in the delivery of a project must follow in order to optimally achieve the desired project objectives. However, this is not done in isolation. The conventional scheduling system sets the baseline schedule and measures progress. This baseline schedule and associated milestones serve as objectives for project production. If they are flawed, that cripples production control. When this happens, teams either tend to give up on LPS and return to traditional behaviors, or recreate the project schedule themselves using pull planning.

The role of the last planner is to align the actions of individuals (craft workers and knowledge workers) involved in the project to deliver the objectives. Seen from a value stream perspective, the relationship of craft workers and knowledge workers are typically intertwined, therefore, the design of LPS for a given project must incorporate both types of work.

In addition, depending on the type of project, the amount of inherent variability is vastly different. For example, a greenfield residential project typically experiences less variability than a turnaround project in a refinery, where the scope is expected to constantly change based on what's discovered when equipment is dismantled. The penalties of not managing the sources and associated implications of variability also differ tremendously. For example, a week delay in turning a refinery back on will have direct implications on revenue and valuation of that company. The same amount of delay typically has less implications for the owner of residences. Therefore, the frequency of control and adjustment due to variability (re-planning) must be aligned with the type of work.

¹⁵ "Contrasting Project Production Control With Project Controls", Project Production Institute 2015

Since the purpose of the phase schedule is to specify the handoffs and conditions of satisfaction between processes within a given project phase, planning needs to be performed sufficiently ahead of the phase to allow lookahead planning to be effectively performed and when there is change in scope or allocation of scope. During the course of executing the phase plan, when replanning is needed, the team tries to recover to the original phase schedule as soon as possible, but may need to replan the remaining work to complete within the phase milestone. If that is not possible, the team planning the next phase will have less time within which to execute their phase of work. Everyone does what they can to hold the completion date.

Critical Notes on planning windows: lookahead and commitment planning

The lookahead is the main mechanism used to determine how and what work should be done when by whom. To reiterate, the work here is not limited to craft or knowledge work, but the lookahead should allow enough time to identify and manage engineering, fabrication and/or delivery of any long lead-items that the project team needs to coordinate. Therefore, if the strategy is to do just-in-time fabrication of certain material, the optimal scenario is that the lead time associated with fabrication and delivery should be less than the lookahead of the installation. If the strategy is to build inventory of the material on site ahead of the installation based on forecasted usage, the lookahead window associated with that work can be shortened to cover the delivery of the material to the installation area.

The window of commitment planning also must vary based on the type of work. Typically for knowledge work (such as design), where cycle times for generating outputs are more than a few days, the commitment planning process should be performed weekly or bi-weekly. For craft work, where work content is generated on a daily or shift basis, the commitment planning process should be performed at the same pace, daily or by shift.

Deployment

The deployment of LPS should incorporate the means to assess if project teams are performing its functions, and adopting and using its principles and processes effectively. If the deployment approach selected for a given project is knowledge transfer, users of LPS can be assessed based on a developmental framework that incorporates development stages such as aware, understand, capable and master. By doing this, the effective development of technical competence can be monitored. In addition to technical competence, the level of commitment to the effort should also be assessed and monitored. At the end, commitment is needed to develop

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technical competence. To do this effectively, a whole approach including frequency of assessments and assessment tools must be developed and implemented.

In order to configure LPS for a specific project, the following questions must be answered:

Relationship of the Last Planner System to other Project Management Components

- Is the Last Planner System defined and understood as something distinctively different than Project Controls?
- What is its interaction with Project Control, especially with higher level schedules?
- What is the scope (all phases or just construction) of LPS implementation?
- What role will physical controls, sensors and automated equipment play in controlling work, resolving constraints and ensuring quality of work?

Configuration of the Last Planner System

- Who has what roles and responsibilities?
- How will the Phases be defined?
- How many weeks ahead of scheduled start will each phase be planned?
- How long will the lookahead schedule be? Note: This may vary by phase, depending on the lead time required to remove constraints.
- How far in advance of commitment planning will the tasks be broken down to appropriate level? e.g., 3 weeks ahead of scheduled start, 2 weeks ahead of scheduled start.
- How long is the planning horizon for commitment planning; one shift, ½ day, 1 day, 1 week, etc. ?
- What will be the weekly, monthly cycle of LPS events?
- What are the standard agendas and participants for phase planning, lookahead planning and commitment planning meetings?
- What plan failures will be analyzed in search of countermeasures? Who/how will the decision to analyze be made? How will analyzes be carried out?

Implementation

- How will the work of project team members offsite be incorporated into the Last Planner system?
- Will the implementation be done top down or bottom up?
- How will education & training be done?
- How will the effectiveness of implementation be assessed and improved?

I. Future Research

We do not believe that the current benchmark is the best that can be achieved, especially as regards methods. Indeed, given the lean principle of continuous improvement, better practice is always possible. Based on research to date, we offer the following tasks to be performed and hypotheses to be explored and experimentally tested:

1. Develop and test potential high leverage drivers of LPS performance. The critical question to be answered is “What are the few actions or behaviors of the project team, while working in the process, that are highly correlated with desired project outcomes?” The next step then would be to develop metrics to measure these desired actions and behaviors. Some preliminary thoughts in this area, which are based on field experience with successful and unsuccessful LPS implementations, are centered on the team’s ability to make the right tasks sound in the right sequence and rate. It appears that the key factors involved are to adequately identify and remove constraints in advance of scheduled work and to learn from plan failures. Teams that do well with this tend to have high PPC and are meeting or exceeding schedule and budget targets. The crucial underlying abilities seem to be (1) having stable lookahead schedules, (2) requesting and obtaining reliable commitments to remove constraints, and (3) developing and implementing countermeasures to prevent repeated plan failures. The hypothesis to be tested would be that focusing on the improvement of these three abilities will result in improved PPC and better attainment of intermediate schedule and budget targets. To help focus teams on improving these fundamental abilities, indicators are needed. The existing Tasks Anticipated metric (TA) measuring the changes in each week of the lookahead window may serve as an adequate indicator in regards to (1). For (2), perhaps measuring each week “Percent Promises Made” (number of reliable commitments to remove unresolved constraints/total number of unresolved constraints), “Percent Promises Kept” (Number of constraints resolved in the week as promised/Total number of constraints promised to be resolved in the week) will focus the team on the desired behaviors. For (3), a potential metric might be a measure of the number of countermeasures implemented relative to the number of plan failures over some past time window. *Courtesy of John Draper, Lean Project Consulting*
2. Develop means to assess the qualities of phase plans. When a team engages in phase planning, participants explore options for how work can be structured and they define hand-offs between their so-

defined chunks of work. That planning process all too often ends when one feasible plan has been identified.

If the team finds one plan that is feasible, might they be able to find additional ones that are feasible as well? If so, might some of these plans be better than others? We need metrics to assess the qualities of phase plans so we can discriminate between them and choose the one most suitable to deliver the project at hand.

Metrics may pertain to the degree of flow that has been achieved, for example by gauging the extent to which trade crews will be able to work without interruptions (e.g., don't have to leave the site and due to lack of work return only several days later). In our ongoing research on takt time planning we are developing other metrics so that we can gauge how well a plan meets the following objectives: Have trades work in a way they prefer

- Aim for constant crew sizes and continuous work flow
 - Avoid trade stacking
 - Use timely on Takt handoffs
 - Balance the whole while pushing for speed
3. Develop more standard work
Work that rolls over (it passes the screening process) from the phase plan into the lookahead schedule, will then be made ready over the course of the duration of the lookahead time window. Work chunks (“boulders”) get broken down to smaller ones in the process (to “dust”) until they are of a size a Last Planner can commit to when making their weekly work plan. At present, we are not aware of their being a standard methodology for conducting this breakdown nor of a standard work description that results from it. Some standardization is being done, for example, a work standard gets established after a First Run Study. Developing more such standards, and doing so consistently, will help with learning on how work can be done within and across projects.
 3. How do current policies and practices, including commercial contracts, obstruct successful LPS implementation?
 4. Extend reliable promising to direct workers. This has previously been recommended for design, where more work is done by individual specialists than in construction, so the ability to assess capacity when responding to requests calls for individual work plans at the commitment level. A process for soliciting and getting commitments from individual construction workers is now in use by Veidekke and Skanska in Norway. The research could start by examining current practices, assessing their impact, and experimenting with refinements as needed. How to overcome obstacles to extending reliable promising to direct workers, such as frequent change in direct workers on projects, could be included in the research.

5. Resource load commitment plans; i.e., plans to complete and release work next week, next day, next shift. Commitments should be made within available capacity and all capacity should be committed, mindful of underloading to assure reliable workflow. [This is being done already, but is not a universal practice.]
6. Increase use of visuals to communicate information. For example, leading indicators that provide information what needs to be done now to move the project toward its objectives.
7. Benefits and challenges of LPS software solutions. This research would begin by specifying the criteria for evaluation; generally, do they help promote the practices advocated in this LPS Benchmark, and in what conditions are they most effective or needed.
8. Relationships between LPS and safety, quality, cost and time performance. “Does LPS, properly implemented, reduce illness and injury on construction sites? Does it reduce defects, reduce cost, and reduce time?” There is some evidence regarding impact on safety (MTH, a Danish contractor, reported a 75% reduction in lost time accidents on projects using LPS), quality (on the Temecula Valley Hospital Project, 1 of 1300 inspections failed first time), and cost (Liu et al.’s 2009 paper reporting a positive correlation between LPS and labor productivity; Gonzalez et al.’s 2008 paper), and project durations (Boldt Construction’s world record on a Stora Enso project). But more data is needed. With the broader take up of LPS, statistical analysis should now be possible with larger data sets.
9. LPS is designed to be an engine for continuous improvement, the mechanism of which is shrinking buffers by reducing variation. To what extent is that potential being exploited in the industry?
 - a. Has anyone reduced capacity buffers in response to consistently achieving near-100% PPC?
 - b. Has anyone reduced their schedule (time) buffers in response to consistently hitting phase milestones?
10. Conversations for action (reliable promising) play a central role in LPS as currently designed, but language action also includes conversations for possibility. How might conversations for possibility be incorporated into LPS? What benefits are realized from that incorporation?
11. Given the increasing use of relational contracts that involve designers and constructors in the early stages of projects, collaborative generation of project master schedules is an appropriate research topic--how to do it, whom to involve, critical preconditions, etc. And on projects where the participants share risk and reward, the search for better phase plans, plans that optimize work flow, is clearly appropriate--beyond simply squeezing the work within the available time.
12. Extension of managerial responsibility to front line supervisors was one of the motivations for the creation of LPS. However, that does not mean there is

- no role for other levels of supervision. More explicit specification of those roles and responsibilities could be helpful in getting LPS to function properly, and to facilitate its use in continuous improvement through systematically 'lowering the river to reveal the rocks'.
13. Planning and control is focused on delivery of what's needed by clients to accomplish their purposes, and their conditions of satisfaction (for cost time, etc.). In the construction phase, it may be assumed that delivery of value to customers is accomplished by building to the design documents. Consequently, deciding what work is to be done in what sequence is achieved in the construction phase by consideration of project cost and schedule objectives--what's the best way to move toward those objectives from where we are now and with what we now have in hand. When designing the asset, that obviously cannot be assumed. What is done now, with various degrees of success, is synchronizing drawing delivery dates with construction's execution times, but that's done late in the design process. How are sequencing decisions best made in early design before production of construction documents?
 14. Several methods from software development are now being used in planning and controlling design work in the construction industry; e.g., Scrum and David Anderson's Kanban. A description and evaluation of these methods should be done to decide if to incorporate into future LPS Benchmarks.
 15. When a committed task cannot be completed, ask the direct workers involved to explain what happened; to take the first steps in a 5 Whys analysis. Prearrange who has responsibility for continuing the analysis depending on the category of reason for plan failure.
 16. Explore how to better produce proactive project execution strategies and milestone plans, that make use of established knowledge about planning under uncertainty on where and when to develop flexibility and buffers, *and* the proper relationship of those strategies and project control schedules.
Courtesy of Hajnalka Vaagen, NTNU
 17. How does Last Planner work to enable resilience in projects, what are the social-behavioural prerequisites for successful Last Planner implementations, and does/how does Last Planner strengthen social networks and thus increase resilience? *Courtesy of Hajnalka Vaagen, NTNU*
 18. Everyday improvement: what can be done to improve the way project teams and trade teams learn and improve on a daily and weekly basis with the Last Planner System? *Courtesy of Alan Mossman, The Change Business*
 19. LPS can influence a variety of social dynamics within a construction organisation Social dynamics refers to the resulting behaviour of groups from the interactions of its individual members and the analysis of the connections between individual interactions and group level behaviours ([Durlauf and Young, 2001](#)). At this point, trust has been one of the more relevant social dynamic variables studied to date. But the LPS can endanger

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synergies and feedback loops with other social dynamics variables such as Power Distance and Goal Setting. This research could start applying a variety of social science techniques to explore the following questions: what specific social dynamics variables and mechanisms are endangered by LPS in a construction organisation? and how do they interact (synergies and feedback loops)? The questions established in an exploratory phased can be further studied by using computer modelling techniques such as Agent-Based Modelling or System Dynamics. Empirical data and experimental settings can demonstrate that LPS social research go beyond that traditional focus on language-action-perspective, people development, culture and transformation, and integral theory, and pay attention to specific social dynamics variables (other than trust) that can promote a more effective adoption of lean-based tools such as LPS in a construction organisation.

Durlauf, S. and Young, H. P., 2001. *The new social economics*, Cambridge, MA, USA: MIT.

González, V. A., Sacks, R., Pavez, I., Poshdar, M., Priven, V. and Ben Alon, L. (2015). *Interplay of Lean Thinking and Social Dynamics in Construction*. Proceedings 23rd International Conference for Lean Construction, Perth, Western Australia, 28th – 31st July. *Courtesy of Vicente Gonzalez, Univ. of Auckland*

J. Frequently Asked Questions

- A. Why should LPS be considered a lean method? Answer: Lean is a philosophy of management dedicated to increasing value delivered to customers and stakeholders, and to decreasing waste. Value is increased when projects deliver what customers need to accomplish their purposes, within customer constraints (of time, cost, location, codes, etc.), and when what's delivered enables expansion of customer purpose. LPS is a method for deciding how to achieve these objectives, and for steering projects toward them. In the Toyota Production System, three types of waste are identified: muri, mura and muda. Muri is overloading, mura is unevenness, and muda is what is unnecessary. All are to be avoided to the extent possible at a specific time and place. LPS addresses all three. Overloading is avoided when tasks are designed to the capabilities of the resources assigned to their execution. Unevenness is avoided when the release of work is made more predictable. What is unnecessary is avoided when tasks are executed in a sequence that reduces/eliminates rework, and also when resource utilization is increased.
- B. What is the right target for PPC? Answer: 100%. The goal is reliable release of work, so anything less than a PPC of 100% is a failure to fully achieve that goal. Some people think that a 100% goal encourages sandbagging, but that's

- true of any goal, and the only effective countermeasure is persuading project team members that PPC measures the effectiveness of the planning system; though supervisory oversight can also help. Don't confuse a 100% PPC goal with overloading resources; i.e., not allowing any capacity buffer for variation in process durations. We always want to underload when making assignments, but with the goal of perfect workflow reliability. As countermeasures are developed for plan failures, actual capacity will increase. As PPC approaches 100%, increase the load placed on capacity and reduce the time slots in planning; i.e., plan to the ½ day rather than the day.
- C. How much should capacity be underloaded? Answer: Given the importance of workflow reliability, where feasible, we should underload so that there is a 99% chance that the assigned capacity will be sufficient to complete the task as scheduled. But to do that precisely requires information concerning the standard deviation for the relevant operations. 2 standard deviations corresponds to a 95% confidence level. 3 standard deviations corresponds to a 99% confidence level--meaning that the underloading (capacity buffer) will be sufficient 99 times in 100 in achieving target completion dates. This shows how valuable it is to reduce the standard deviation! In practice, the standard deviation may not be known, in which case, we learn from our experience and make adjustments accordingly.
- Another relevant point here is that we tend to waste something on the order of 30% or more of labor capacity when workflow reliability is low. That can be considered a built-in buffer for underloading. Underloading implies some loss of labor capacity, but that loss will be less than what has happened historically because underloading helps improve workflow reliability.
- D. How many weeks should we look ahead when doing constraints analysis? Answer: That number of weeks required to remove the constraint with the longest lead time. Example: A construction task first enters the lookahead window. If the needed design information is behind schedule, a 6 week lookahead provides 6 weeks to expedite production and delivery of that information. If the design resources are not dedicated or otherwise have uncertain capacity, more weeks may be needed. Note that constraints such as design information and materials have already been synchronized with the construction schedule because they have lead times far exceeding 6 weeks. The relevant lead time here is for solving problems with design information, materials and such. Items with lead times for production and delivery exceeding the lookahead window are to be embedded in higher level schedules.
- E. How to select which plan failures to analyze in search of countermeasures? Answer: As many as you have capacity to analyze. Assuming limited capacity, select those with the biggest impact on project performance.

- F. How is PPC measured? Answer: At the end of the commitment plan period (1 shift, 1 week, 1 day, etc.) , the team notes which commitments have been met and which have not. A commitment is understood to have been met when it was done as planned e.g., started and/or finished as planned. This is usually done by asking the question “Did we do what we said we were going to do?” i.e. “Did we start the task as planned?” “Did we finish it as planned?” The appropriate response is either “Yes” or “No.” There is no partial credit. It is important to realize that PPC is a measure of a team’s ability to reliably plan and execute work and is NOT a measurement of completed work. Nor is PPC a measure of productivity. It is possible to have 100% PPC and poor productivity if capacity exceeds ready work. The recommended planning precision is to plan to the day or shift (although after achieving near 100% PPC, that can change to the ½ day, etc.). Counting tasks finished by the end of a week involves committing only to tasks that are fully sound at the beginning of the week. The larger the batch size of commitments, the longer the project will take to complete.
- G. Should early finishes be counted as completions? Answer: Yes, if tasks are completed within the committed time frame, they should be counted as completions. To increase the probability that committed tasks will be completed on time, we advise underloading; i.e., assigning more capacity (labor hours) than might be needed, allowing for variation in processing durations. Completing early is expected and desired. What we want to focus attention on is excessively early completions. That can be done by tagging tasks completed early and discussing in the daily or weekly planning meetings if there is an opportunity for adjusting future task durations or capacity allocation. That is the job of the manager of the planning meetings and the last planner’s immediate supervisor. To avoid loss of capacity, it is advised to include in commitment plans both priority tasks and others available as follow-on or fallback. Take care not to use capacity to perform tasks that are otherwise ready, but doing now causes more pain later in the project--for example, using temporary hangers (#9 wire) to put pipe spools into their final position in order to claim more progress and hence payment. When the pipe supports arrive, they will be more difficult to install than was expected in budgeting. Another possible use for excess capacity is to have workers participate in problem solving; e.g., 5 whys analysis of plan failures or revisions of operation designs that have been shown to need improvement.
- H. Is LPS a scheduling system? Does it replace project controls? Answer: No, LPS is a production control system with elements of planning, scheduling and execution. A distinction should be made between planning and scheduling – planning is the upfront activity of determining what should be done, in what sequence, how it should be done, and lining up the resources to do the work. The plan becomes a schedule when commitments are made to accomplish

- certain work on certain days. LPS functions in the dimensions of planning, scheduling, execution of work, and learning from planning/execution variances. LPS does not replace project controls, the function of which is the establishment of cost, time and other performance targets (See “Why Last Planner?” at the beginning of this document). LPS is then used to steer project performance towards the objectives set by the project controls.
- I. How many more meetings and employees will we need if we do LPS?
Answer: None. In fact, you may be able to reduce indirects as workflow reliability increases, reducing the amount of firefighting.
 - J. Should we have crews do more work if they complete committed tasks sooner than anticipated? Answer: Yes, but only if that work does not cause more harm downstream than the benefit provided by using otherwise lost capacity. What’s needed is to specify on commitment plans Plan B tasks available for each work group should they complete committed tasks early or should they be unable to perform committed tasks.
 - K. Why the name “Last Planner”? Answer: The name designates the front line supervisors whose plans initiate production as opposed to feeding lower levels of planning. “Last Planner” was used because the position that functions as front line supervisor can vary from place to place, and the names for those positions also vary. For example, “capataz” in South America corresponds roughly to “foreman” in North America, but in many South American projects, engineers actually function as last planners. The front line supervisors of all companies involved in design and construction are included as last planners, both those employed by the company leading design (e.g., an architectural firm in a building project) and construction (a general contractor), and the front line supervisors of engineering consultants and of specialty contractors. The expression “Last Planner” was also chosen to emphasize that front line supervisors have managerial responsibilities and are not simply cogs in a machine.
 - L. Does implementation of LPS transfer power over project progress to subcontractors? Answer: No. In a traditional contracting structure, general (main) contractors have financial interest in delivery of projects on or ahead of schedule, while the financial interest of subcontractors is to use their crews productively. When LPS is used on construction projects with such traditional contracting structures, the parties retain their different interests, but act together to achieve both. General contractors control progress by assuring that tasks are made ready in the needed sequence and rate in lookahead planning, and by releasing tasks into workable backlog. They have more control over flows of design information, materials and equipment than subcontractors. Subcontractors control productivity by participating in lookahead planning, which gives them foresight of future workload so they can make better decisions about bringing labor to site, by designing operations and by including on commitment plans only tasks that are well

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defined, sound, sequenced and sized to the capabilities of performers. If the project schedule is well formed, and lookahead planning and commitment planning do their jobs, both progress and productivity will be better.

Courtesy of Carina Schlabach, Zublin Construction

- M. Who leads lookahead planning? Answer: In design, lookahead planning is usually led by the design project manager. In construction, lookahead planning is usually led by the project general superintendent. On larger projects, lookahead planning may be divided between areas or systems, in which case the design manager or superintendent over the area or system provides leadership.
- N. Who leads commitment planning? Answer: Same leaders as for lookahead planning. When LPS is working well, the last week of the lookahead is the default commitment plan for the following week, and commitment planning meetings are devoted to making any needed changes, and to deciding about Plan B (fallback/follow-on tasks 'below the line').

K. Acknowledgements

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L. Glossary

Activity Definition Model (ADM):

An input-process-output representation of work to be done in design or construction. The model depicts the specification of directives (entering the process rectangle from above), prerequisites (including materials and information to be transformed into the desired output, entering the process rectangle from the left), and resources (entering the process rectangle from below). It also shows an inspection process resulting either in redo or release to the customer process. The

model is used as a guide to exploding scheduled tasks into a level of detail at which their readiness for execution can be assessed and advanced.

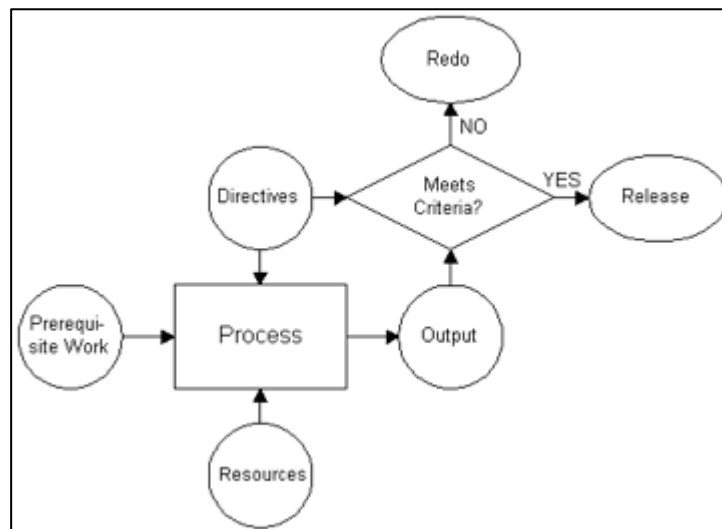


Figure 5: Activity Definition Model

Breakdown: Deviation from target outcome(s). Plan failures, errors and defects, and occupational illnesses and injuries are common breakdowns in construction.

Buffer: A mechanism for deadening the force of a concussion; e.g., a capacity buffer is created by scheduling less than all the time available (aka. **underloading**). If production falls behind schedule, there is **capacity** available for catching up. Capacity buffers may be preferred over inventory buffers. In addition to capacity and inventory buffers, other types of buffers are time buffers, monetary buffers (contingency), and spatial buffers (tolerances). Arguably, monetary buffers can be converted into, e.g., capacity buffers or inventory buffers.

Commitment Planning: Near term (day, shift, week) plans that consist of tasks that have been screened for definition, sequence, soundness and size, and have been negotiated between immediate requester and performer using reliable promising.

Conditions of Satisfaction: Conditions that a requestor places on performance of a promise; e.g., when it is to be completed, how much the requestor will be asked to pay, etc.

Commitment: A promise made between a 'supplier' and a 'customer' to perform an agreed task by a certain date. Commitments are made to the day or shift, depending on the nature of the project. As we learn how to be reliable planning to the day, we can begin learning how to be reliable planning to the half day, and so on.

Constraint: Something that stands in the way of a task being executable or sound. Typical constraints on design tasks are inputs from others, clarity of requirements criteria for what is to be produced or provided, approvals or releases, and labor or

equipment resources. Typical constraints on construction tasks are the completion of design or prerequisite work; availability of materials, information, and directives. Screening tasks for readiness is assessing the status of their constraints. Removing constraints is making a task sound.

Daily huddles: Brief, typically stand-up, meetings each day by groups of interdependent players, at which each, in turn, shares what commitments they have completed, what commitments they need help with or cannot deliver. This can be done within a design squad or construction crew, and between front line supervisors of design squads or construction crews.

DCAP (Detect-Correct-Analyze-Prevent): A process for reacting to and learning from breakdowns. Detect breakdowns as close to the source as possible. Take corrective action so the operation can be restarted. For example, correct errors on drawings and replace previous drawings with corrected. Analyze the breakdown to find countermeasures. Implement the countermeasures to Prevent reoccurrence of the breakdown.

First run studies (FRS): First trial execution of an **operation** as a test of capability to meet safety, quality, time and cost targets. The FRS begins several (e.g., 2 or 3) weeks ahead of the first run with a planning session in which the team that will do that work is involved in developing a detailed work plan at the 'step' level of task breakdown, so each person on the team knows what they are to do. First run studies follow the **plan-do-check-act** cycle. The plan is developed, the first run is carried out, the results are checked against the targets. If the results are inadequate, the operation design is replanned and the test performed again. This continues until the operation is considered capable, then that way of doing that type of work is declared the standard to meet or beat. First-run studies are done ahead of the scheduled first start of the operation, while there is time to acquire different or additional prerequisites and resources. First run studies are one of three ways in which operations can be designed: the other two are virtual prototyping (virtual first run studies or VFRS) and physical prototyping (mock ups).

Five Whys: Asking *why* repeatedly to help uncover countermeasures to reoccurrence of a problem. Usually the 'root cause' is identified within 5 "whys".

Frequency of plan failures: The percentage of total plan failures from each primary category; e.g., lack of prerequisite work, lack of design information (none or defective), lack of materials, changed priorities, or failure in execution.

Lookahead planning: The level of planning between phase schedules and daily/weekly work plans, dedicated to making scheduled tasks eligible for commitment. That is done through constraints analysis and removal, breaking down tasks into operations, and collaboratively designing those operations. When constraints cannot be removed on critical tasks, replanning is initiated.

Master schedule: Schedule covering an entire project start-to-finish, then further detailed and validated in phase scheduling, the activities in which are then exploded when creating the make-ready schedule.

Milestone: Completion point of project phases such as substructure, superstructure, utility rough-ins, and finishes on a building project.

PDCA (Plan-Do-Check-Act): Process for learning from experiments. Experiments start with a hypothesis about the consequences of an action, formulated in a Plan. For example, it might be hypothesized that improving workflow reliability increases productivity. Do is performing the experiment; i.e., taking the action. Check is assessing the consequences of the action, in this case measuring if productivity increases with better workflow reliability. After appropriate revisions and retests, Act consists in standardizing practice. The Analyze step in DCAP is the PDCA process, in which the hypothesis to be tested is the countermeasure proposed to prevent the breakdown being analyzed.

Percent Plan Complete: Metric used in the LPS to gauge plan reliability. The percentage of actual completions to planned completions in a daily or weekly work plan.

Phase Scheduling (also called Reverse Phase Scheduling): One level in LPS, where a phase gets broken out from the master plan, in which milestones define phases, and people responsible for the work in that phase jointly develop the plan. People in a “design phase” may include engineers, architects, owners, designers; perhaps also constructors and permitting agents. People in a “construction phase” may include designers, the general contractor and specialty contractors, perhaps also owners, inspectors and commissioning agents. Pull planning is used to identify, define and sequence tasks, creating a logic network. The phase schedule is produced by assigning durations to tasks and arranging them on a calendar.

Physical prototyping: Testing a product or process design using mock-ups.

Production control: Steering toward project safety, quality, time and cost targets

Project controls: Setting project time and cost targets and tracking progress toward them.

Pull planning: A method of planning collaboratively with those who are to do the work being planned. Features include first doing a backward pass from the target completion date or time of the work being planned and creating a schedule buffer that is allocated to critical and risky tasks in the plan. The initial output is a logic network showing the temporal dependence of tasks to be performed in the phase, process, or operation being planned. A schedule can be produced by estimating task durations.

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Reliable promising: Promise reached by sticking to the steps of the Language-Action cycle (aka, Workflow Loop): (1) Making a request, (2) Negotiating (clarifications, conditions of satisfaction, and counteroffers), (3) Committing, (4) Executing, (5) Declaring Complete, and (6) Declaring Satisfaction.

Resources: Labor or instruments of labor, including tools, equipment, and space. Resources have production capacities as well as costs. Consequently, materials and information are not resources, but rather what resources act on or process.

Task breakdown: The tasks involved in executing a project can be usefully described at different levels of detail, but there is no generally accepted standard. We propose the following: projects are composed of phases, phases are composed of processes, processes are composed of operations, operations are composed of steps, and steps are composed of elemental motions. An example: Calhoun 101 Project consists of phases, including the Substructure phase. The Substructure phase consists of processes, including Place Drilled Caissons. The process for Place Drilled Caissons includes the operation Fabricate Cage. Fabricate Cage consists of steps including Fit and Tack Lifting Bands, which could be (but rarely is) further analyzed into elemental motions such as grasp, lift, rotate, etc.—how a robot would be programmed to do that task.

Task definition: A requirement for inclusion on daily or weekly work plans is that tasks are defined so that performers understand what is to be done, where, when, by whom; can determine what is needed by way of materials, information, tools, and equipment to perform the task; and task completion can be easily assessed.

Task sequence: The order in time of a set of tasks. A requirement for inclusion on daily or weekly work plans is that tasks can be performed now without incurring a penalty later.

Task size: A requirement for inclusion on daily or weekly work plans is that tasks are sized to the capability of those who are to perform them within the time constraints of the plan. This improves workflow reliability. As performers increase their capability, more work is assigned to them.

Task soundness: A requirement for inclusion on daily or weekly work plans is that in general tasks have had all constraints removed prior to start of execution. Note however by exception reasonable bets can be made; for example, regarding the reliability of suppliers delivering materials needed in time to perform the task.

Tasks anticipated (TA): A metric in the LPS that measures the percentage of tasks for a target week in the lookahead that were anticipated in an earlier plan for that target week. The objective of this indicator is to provide a relative measure of how well the team is able to predict for the lookahead time horizon what is actually going

to happen on the project. This planning ability is critical because without it, some of the tasks that need to be done cannot be made ready. In other words, TA measures the instances when tasks drop into the WWP that were not anticipated at the beginning of our lookahead planning window.

Tasks made ready (TMR): TMR is a metric in LPS that gauges the ability of the plan(ner) to forecast (predict) accurately in week i what tasks will take place $j-i$ weeks into the future (TMR_{ij}). It gauges the percentage of tasks in an earlier plan for a target week that are included in a later plan for the target week. Together with TA it characterizes the ability of the planning team to make work ready.

TA measures how well we are anticipating what tasks need to be executed within the lookahead window, and consequently is driven by task breakdown. TMR measures how well we remove constraints from those tasks so they can be executed, and consequently is driven by constraints analysis and removal.

Underloading resources: To allow for variation that cannot be reduced at a moment in time, resources are asked to produce less than what they could produce if there were no variation in arrival times of inputs or in processing durations. These capacity buffers are to be reduced as variation is reduced; e.g., by analyzing breakdowns and implementing countermeasures.

Variation: Occurrence of non-uniformity. For example, processes can vary in their durations, deliveries can vary in their arrival relative to due date, products can vary in their defects, workload can vary from one day or week to the next, resources can vary in their relation to available workload, etc. Reducing variation is usually possible, but there will always be some residual variation in production systems. As a result, buffers of time, cost, or capacity are needed in order to absorb that variation and allow the system to function.

Variability: The spread in a set of data points; measured by extent above and below a mean, by variance (the average of the squared differences from the mean), and by standard deviation (the square root of the variance).

Virtual prototyping: Testing a product or process design using computer modeling.

Visual controls & Visual displays¹⁶: Visual controls are used to manage input resources; e.g., color coded hats, zone plans, lines sprayed on the floor. Visual displays are used to communicate process status; publically placed and easy-to-interpret information regarding the state of a project relative to target (e.g., 71% complete, 5% below budget, only 1 lost time accident in the last 500,000 labor hours worked), the need for help with a problem (e.g., a light in the project office that flashes when workers need bricks delivered to the 7th floor), the status of a

¹⁶ Distinction courtesy of Steve Ward, 6ix Consulting.

problem-solving effort—in short, anything that gives people on the project team information they need.

Workable backlog: This term has been used in two ways in LPS; 1) to name tasks that have been released for commitment in daily and weekly commitment plans (see Figure 2 in Section F: Processes), and 2) tasks that are available as fallback or follow-on options should specialists be unable to complete tasks on commitment plans, or can do more tasks than planned, respectively. We recommend using “workable backlog” in the first sense, to refer to tasks that have been released for commitment, and “Plan B” for tasks included on commitment plans to serve as fallback or follow-on work.

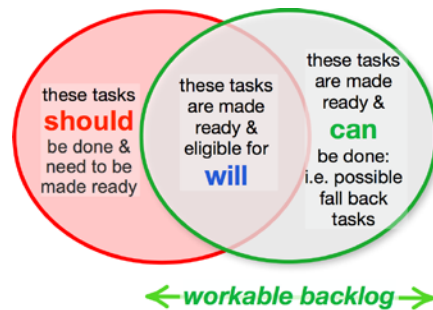


Figure 6: Forming Commitment Plans (*courtesy of Alan Mossman*)

All tasks on commitment plans are to be selected from workable backlog, and tasks are placed into workable backlog only if they satisfy criteria for definition, soundness, sequence and size. Tasks that are not critical, and hence are not included in SHOULD on the left hand side of Fig. 6 above, may be placed into workable backlog if they can be executed now without incurring a penalty later¹⁷.

Commitment plans may consist of a Plan A and a Plan B. Plan A tasks are those which are truly speaking commitments; others are depending on them being completed within the plan period. Plan B consists of fallback/follow-on tasks in case Plan A tasks cannot be completed, or as follow-on work in case Plan A tasks are completed earlier than expected. It is important for all interdependent players to understand both Plan A and Plan B, to avoid conflicts over space or other shared resources and to mitigate safety hazards from working in nearby spaces.

When forming commitment plans, Plan A tasks are selected first from tasks that SHOULD be done (as shown in the middle of Fig. 6 above). If there is additional

¹⁷ An example of ‘a later penalty’: In pursuit of more reportable progress and hence payments, when pipe supports are late arriving, pipe spools might be erected with #9 wire. This usually increases the difficulty of installing the pipe supports when they finally arrive and must be threaded through a maze of pipe, cable tray, conduit, and structures.

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capacity, non-critical tasks that can be executed in the plan period without incurring a later penalty (as shown in the right hand side of Fig. 6 above) can also be included in Plan A.

Workflow reliability: A metric in LPS measured by Percent Plan Complete (PPC). It measures the extent to which a current commitment plan accurately predicts the state of the project at the start of the next plan period, and hence what workload will be available at that point in time for the various specialists working on the project. On different types of projects, different choices may be made about the timing of commitments. On most construction projects, the recommendation is to plan to the day, though once daily plans approach 100%, the target should change to planning to the half day. On very detailed operations, planning may be to the hour or even to the minute.

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BUILDING A LEAN CULTURE

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Abstract: To accelerate understanding and implementation of Lean throughout a large general contracting company, the Lean leadership group, with the support of management at all levels, shifted from training employees on tools and solutions, to educating them about Lean principles as an overarching way to run their projects. This industry paper describes the work that the company has and is currently doing to train professionals in all its business units. It explains why and how the effort started, the feedback received from participants who have attended a new course in Lean leadership, and the plans to expand this program to increase and sustain Lean implementation. The paper provides a contribution to the literature on Lean implementation and change management and underscores the importance of creating a culture based on solid understanding of the Lean vocabulary, principles, and goals to create a critical mass across projects.

Keywords: Lean leadership, Lean education, Lean culture.

1 INTRODUCTION

This industry paper describes a General Contractor's effort to establish a Lean culture, which enables their project teams to deliver greater value to customers. The goal is to share what was learned from this experience and benefit from the feedback that will result from discussing what is being presented within the IGLC community and beyond.

2 LEAN IMPLEMENTATION IN CONSTRUCTION COMPANIES

In their roadmap for Lean implementation Ballard et al. (2007, p. xi-xii) suggest several actions for organizations to implement Lean in capital projects: select partners who can adopt lean project delivery, structure project organization to engage downstream partners in upstream processes and vice-versa; encourage thoughtful experimentation and celebrate breakdowns; build quality and safety through the work of those designing and making; amongst others. Along these lines, another example found in the literature includes Izquierdo et al. (2011)'s work, which proposed the development and implementation of a 'Basic Management Functions Workshop' with the goal of training a company's employees and aligning them towards a way of doing business using Lean principles.

A common thread in the literature about Lean implementation is the idea of aligning those working for a company, and its extended network of partners, toward common goals and purposes that matter for their clients (value), as well as creating a critical mass of stakeholders who understand Lean principles. Alves et al. (2012) suggested that

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developing professional curriculums that teach Lean and its related vocabulary is an important step to creating a platform that to consistently communicate overarching Lean goals and principles. Similarly, the use of examples grounded in practice, metaphors (e.g., lower the river to reveal the rocks), and simulations are also important ways to help practitioners understand how they can think and apply Lean practices in their daily work. The case presented here reflects many of these recommendations and builds on previous experiences and lessons learned about implementing Lean. More importantly, it recognizes the need to explain Lean within the context of company's business environment and culture so that people can plan and act to make value flow on their projects.

3 CHANGING DIRECTION

This company's project teams have used Lean principles well on specific large and complex projects over the years. One such example was the case described in Britt et al. (2014) when the company's project leaders led the creation of a high-performance team based on collaboration and alignment, shifted focus from tools to outcomes, and enabled rapid problem solving.

The company's philosophy embraces the inverted pyramid for leadership to manage complexity and the risk that it spawns by enabling people executing projects closest to problems to solve them. Attention is focused on developing people above processes and procedures, which has made many leaders suspicious of the heavy emphasis Lean Construction places on processes and tools, and the discipline required to apply them consistently. The company culture is one of openness and accessibility versus authority and hierarchy. The company works without a CEO, and relies on a Management Committee, which helps business leaders in different offices to make decisions (Feintzeig, 2016), exemplifying shared governance and collaboration. It was in this environment that the informal Lean leadership group started a new training program aiming at shifting the focus of previous efforts from tools to Lean thinking, leadership and problem-solving.

3.1 Phase 1 – Testing a Different Approach

Initially, the Lean champions recognized that their focus on processes and tools was not sufficient. They decided to shift attention to teaching the fundamental ideas of Lean, i.e., focusing on respect for people and continuous improvement, value stream thinking, flow, problem-solving, and Lean leadership and management. Two of the Lean leaders, enrolled in 8-week facilitated online course on Lean Leadership offered by a Lean logistics company (<https://leancor.com>) and reported that they found it quite rewarding. They saw that being able to study each week's material online over the 8-week course gave participants the opportunity to think about the concepts, put them into practice, and share stories during the weekly conference call.

The course did and continues to blend weekly online training sessions with mentoring/coaching sessions, and requires participants to read the book, *People: A leader's day-to-day guide to building, managing, and sustaining lean organizations* ("People book") by Gran et al. (2012). Learning comes through coaching by the class facilitator in applying Lean concepts during the weekly conference call.

The Lean group decided to sponsor a private course for themselves and other like-minded company managers as an experiment. They launched it with an in-person workshop with people from two other business units attending remotely. Business unit

leaders were also invited to participate. It became clear during workshop, led by an experienced facilitator from the company that had developed the material, that if the 8-week course was to succeed, people who understood how to apply Lean concepts to managing construction projects would need to facilitate the 1-hour weekly conference calls. This also meant that they needed to teach people using ideas and examples that individuals could relate to and build on.

3.2 Phase 2 – Deploying the Lean Training Course

The 8-week course was and is offered to employees, from offices across the company. The course covers a range of topics covered in the People book such as: "Characteristics of a Lean Leader", "Leading with Purpose and Principles", "Focus and Alignment", "Value Stream Thinking", "Effective Measurement Systems", "Reflection", and "Building Teams". Every week, participants work through assigned reading and questions at their own pace whenever they find time, Every Friday they join a 1-hour conference call with their facilitator to discuss what they learned and how they might apply it on their current or a future project.

The People book is continuously referenced within the course content, which allows participants to review the material before and after meetings. For example, one project team has been passing the People book around to help disseminate these concepts. An observation of this team's planning meetings revealed that concepts discussed in the People book are being applied to their project. The team has defined a baseline to keep improving upon, as they work to employ better management systems. They have continued to educate all team members in the topics covered by the course content and the book.

From the outset, the two facilitators used the Plan-Do-Study-Act (PDSA) method to improve the way they taught the course. A key early improvement was to have students send in their "apply your learning" homework, for others to see. The facilitators also worked on a teachers' guide and decided to use their own questions to provoke discussion of how students could use each chapter's concepts to improve delivery of their projects. Each student answered five to ten questions on the chapter, then the instructors posted everyone's answers in a shared location. Later, participants and teachers would have a designated call once a week to discuss the answers. Each student was given five to seven minutes during the weekly call to discuss one answer that they felt passionate about, and to go deeper into the way it impacted them or how they are now doing something different based on the coursework. This shifted responsibility for learning to the students, and allowed the facilitators to help each student become a teacher. Highlights from each chapter were also taken and improved and posted as examples for other classmates and future students to see.

The facilitators created the illustration in Figure 1 to help students understand how they can use the information during and after they completed the course. It shows a constant PDSA cycle of learning through the entire lifecycle of their project. The graphic also communicates that the company leaders want them to continue learning and mastering Lean thinking and leadership.

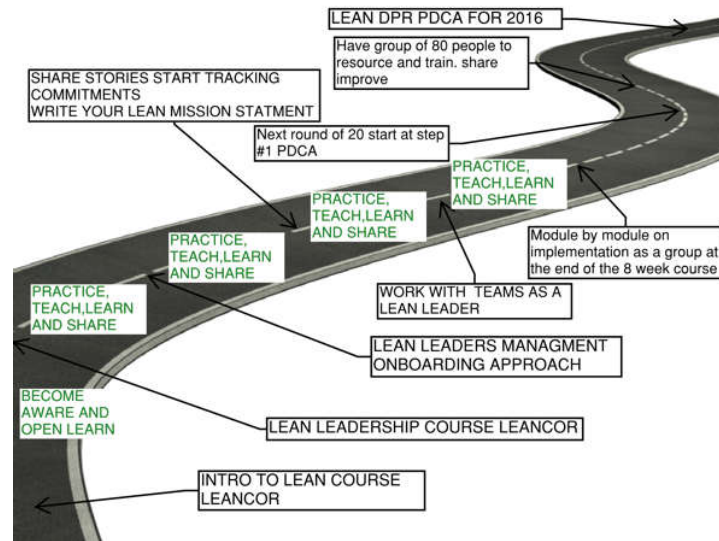


Figure 1: Road map of the Lean Leadership training

3.3 Phase 3 – Learning and Creating New Opportunities

A major challenge of this course was to educate people across the country and in different roles. The course material and its related examples had to be relevant to a wide audience, yet be consistent. As the course unfolded, and participants engaged with the instructors and coaches on learning and applying the material, the facilitators started collecting feedback and compiling a list of lessons learned to improve future offerings. They started working on examples of the principles in practice and how Lean leaders could approach problems.

A sign-up list for future offerings was opened after Phase 1 and employees from across the United States signed up for three additional course offerings. In the meantime, as the word spread and the waiting list grew, the facilitators were busy compiling feedback from participants and adjusting the technology platform hosting it to improve course delivery. This encompassed new ways to teach and support the needs of the field supervisors, project managers and project office staff taking the course. Participants willingly provided feedback. Some excerpts of the feedback received (verbatim) are transcribed below:

- *“Many of the tools we have been learning are straightforward concepts. I think the biggest challenge is taking the time and putting forth the effort to apply these tools to our daily work habits. But we also need to promote them to our other team members. One person cannot make a project lean. But one person can promote lean philosophies to a project team and foster a collaborative environment where these principles take root and are applied.”*
- *“I feel that this was a great course to encouraging and fostering being a lean leader. I think that the instructors did a great job of coaching and teaching. I do not know if this is a game changer - business system. Time will tell on this.”*
- *“Five things learned in the lean core academy: 1. Expect difficulties when implementing change. It is just part of the process; 2. Using inquiry to gain perspective; 3. Exposing rocks by not throwing resources at problems when they arise; 4. Plan, Do, Check, Act – just creating a lean workflow doesn’t mean your job is done. Implementing is the difficult part. It requires follow-up and re-*

follow-up; 5. Measure performance of the process, not performance of the people. In the end, it is always a PROCESS that caused the failure by allowing someone who was able to fail to be in that position.”

- *“Five things learned in the lean core academy: 1. Lean Concepts that work in a manufacturing setting can apply to construction; 2. Focus on being lean to better meet the client expectations rather than DPR’s; 3. Exceeding goals and expectation is not lean. (overproduction); 4. It is important to understand “purpose” (i.e. what the customers wants, not what we perceived they want); 5. Do not do things for the sake of being what you think is “lean” if it does provide value at the end.”*
- *“I’m looking forward to learning how to be a more efficient and effective leader”, I really feel like this class and the information and tools I’ve gained form the course have and will continue to help me improve upon my leadership skills. I also feel like the course has helped me see things from a very different perspective, to ask more questions and involve more of the team before developing an opinion.”*

In addition to providing feedback about the course, participants conducted a self-evaluation of their performance. Participants evaluated their own capabilities compared to the understanding they gained of the qualities of a Lean leader, and the facilitators produced a radar chart, shown in Figure 2, for each student and combined for all students in each course, and overall for the year. This evaluation helped participants identify the areas in which they needed to improve.

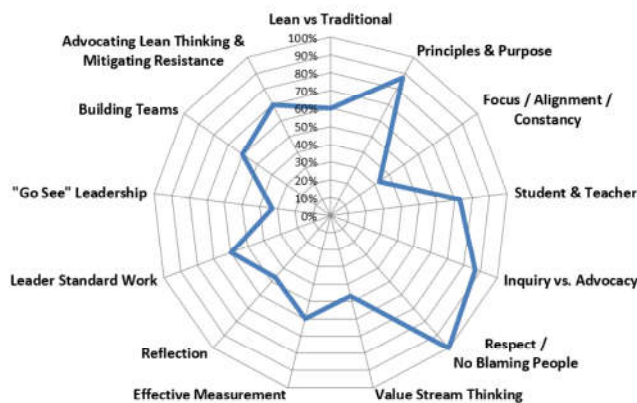


Figure 2: Lean Leadership categories average scores for Round 1 – Radar chart

During the weekly calls, especially in the second and third courses, participants began relating how they had applied one or more concepts. For example, a project engineer explained how he gathered his team together and convinced them that they had to rethink how they had been working and develop a different process for distributing RFI's to the field. The solution included needing paper copies in the field and a discussion of what changes were made to the drawings, so the field and the office were aligned prior to completion of the work. The team made the necessary changes and continued to use the PDSA cycle on their job for the remaining work.

The course content resulted in “a-ha” moments and students started seeing the value of the coursework. For example, one student realized that they were more of a traditional

leader after completing the Chapter 2 module on Traditional Leadership versus Lean Leadership; the student then realized that they should work on new Lean habits. Additionally, the self-paced online content made it easy for students to attend, while the weekly check-ins keep it personal and hold people accountable for delivering their assignments and attending the meetings.

Momentum built as participants from multiple business units and backgrounds signed up to attend the course. Currently, the facilitators and students believe that silos are breaking down as people from different functional groups go through the course together and share their knowledge with others. As the courses are not offered to any single group or managerial level, participants are part of a diverse group of backgrounds and ideas, which serves to spread knowledge throughout the company.

3.4 Phase 4 – Expanding the Offerings

Corporate leaders committed to the team's idea to license and deploy the online Lean Leadership course (Lean Leadership Certificate, <http://academy.leancor.com>) company-wide after seeing metrics collected throughout the first two offerings of the course. The marketing efforts for the course were improved to consistently reach out to employees interested in attending the course. This helped make it easier for the students to sign up because the message was clear, and a sign-up link was embedded in the email notices. Students could read a "what's in it for me" message, recognize the value of the offerings, and sign up for the courses all in one document. Currently, the students sign up directly through the company's internal learning center, which is a system they are already know how to use.

At the close of 2016, over seventy people had been through the course, and another 230 were signed up for the next three offerings. The number of individuals interested in taking the course increased rapidly due to very positive reviews from the graduates. The survey feedback from students, along with the radar charts, was shared across the company's business units, whose leaders also promoted the course. As demand grew, so did the need to train more instructors, which has produced a bottleneck because of the scarcity of experienced Lean practitioners with both the time and facilitation skills.

Early in 2017, the two facilitators arranged for another course called "Lean Fundamentals" to be uploaded to the learning management system to serve as a starter for those who are either waiting, undecided, or unable to commit to the 8-week long course.

Focusing on Lean thinking and leadership has increased interest in learning and applying Lean practices and tools. In the past six months, the Lean Leadership facilitators and other members of a formal group focused on planning and scheduling, have trained 80+ operations people to apply Lean principles and practices, particularly pull planning to plan and manage production. 150 people signed up for the three 30-minute Lean Fundamentals modules within the first week after it was announced in January 2017 and 30 completed the course in the following 2-months.

3.5 Looking Forward

Currently, the goals for 2017 are: to leverage the on-line content now available. This will allow 150 people to go through Lean Leadership and another 100 to complete the Lean Fundamentals by the end of the year. The facilitators anticipate 200 will complete Lean Leadership and 200 will work through Lean Fundamentals in 2018.

Other goals the team expects to achieve include: creating a scorecard to reach out to graduates and measure their improvements; helping the graduates define Lean goals and check-in monthly to review their progress towards meeting these goals; improving communication and promoting the use of an internal Wiki to disseminate what teams are doing and what they have learned; identifying Lean champions in each region who lead by example, educate, coach and mentor others; requiring the Lean Fundamentals course for all new hires as they join the company; and educating the group on Lean tools. The team is also looking for new and innovative ways to share stories.

4 CONCLUSIONS

As demand for construction grows across the country, and the company's offices continue experiencing high growth rates in the number of projects, the company is working to build a Lean culture to promote consistency across its offices. More importantly, the team is focused on how the company's employees interact, learn, and teach each other Lean across the country. The course facilitators together with the Lean group have drawn several lessons from their experience so far, as follows.

- Employees from all functional groups and levels are interested in learning about Lean.
- Training on Lean tools is necessary but training on overarching Lean concepts, principles, and goals is essential.
- Make training interactive and allowing people to be heard reflects respect for people, and are great ways to accelerate learning.
- Consistency and support are required to expose many people to Lean ideas.
- People need a common vocabulary to share knowledge and gain enough confidence to put them into action.
- Offering courses at different levels to engage participants improves understanding. Not every person has the time to engage in multi-week training sessions. Creating short courses with practical examples breaks the inertia and potentially the fear of changing or having to learn something new. Opening the class to employees at all levels and responsibilities increases understanding of the problems others face, and relatedness between people.
- The PDSA cycle can and should be used to continuously improve Lean education and training.
- Educating employees about Lean principles and leadership may be the most effective means, acting as a bridge, for incorporating Lean thinking into the company's culture of collaboration, individual initiative and accountability.

This is an ongoing change process that will be evaluated along the way, and new findings will be reported in the future.

5 ACKNOWLEDGMENTS

The authors acknowledge the efforts of those who have participated in the courses and helped improve outcomes along the way. The views, comments, and opinions expressed are those of the authors.

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CASE STUDY FOR WORK STRUCTURING: INSTALLATION OF METAL DOOR FRAMES

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ABSTRACT

Work structuring means developing a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts. The goal of work structuring is to make work flow more reliable and quick while delivering value to the customer. Current work structuring practices are driven by contracts, the history of trades, and the traditions of craft. As a result, they rarely consider alternatives for making the construction process more efficient. To illustrate current practice and the opportunities provided by work structuring, this case study discusses the installation of metal door frames at a prison project. Because the project is a correctional facility, the door frame installation process involves a special grouting procedure which makes the installation process less routine. Those involved recognized the difficulty of the situation but better solutions were impeded by normal practice. This case study thus provided the opportunity to illustrate how one may come up with alternative ways to perform the work without being constrained by contractual agreements and trade boundaries. By doing so, we illustrate what work structuring means. Local and global fixes for the system comprising walls and doors are explored. In addition, we discuss the importance of dimensional tolerances in construction and how these affect the handoff of work chunks from one production unit to the next.

KEY WORDS

lean construction, work structuring, process design, operations design, first run study, methods analysis, precast concrete, door installation, planning, coordination

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WORK STRUCTURING

According to the Lean Construction Institute (Howell and Ballard 1999), work structuring means developing a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts. The goal of work structuring is to make work flow more reliable and quick while delivering value to the customer. In particular, work structuring views a project as consisting of production units and work chunks (Ballard 1999). A production unit is an individual or group performing production tasks. Production units are recipients of work assignments. A work chunk is a unit of work that can be handed off from one production unit to the next. In the process of performing a production task, each production unit may or may not make changes to the boundaries of the work chunk before handing it off to the next production unit. Production units continue adding value to a work chunk until it becomes completed work.

Work structuring involves determining:

1. In what chunks will work be assigned to specialists?
2. How will work chunks be sequenced?
3. How will work be released from one production unit to the next?
4. Will consecutive production units execute work in a continuous flow process or will their work be de-coupled?
5. Where will de-coupling buffers be needed and how should they be sized?
(Howell et al. 1993)
6. When will different chunks of work be done?

Current work structuring decisions are governed by contracts, the history of trades, and the traditions of craft, that is, decision makers rarely consider how to optimize the entire production process. Projects that use design-bid-build contracting separate design and construction into two distinct non-overlapping processes. In an attempt to fast track a project, designers and general contractors often view a project as an assembly of pieces. They release each piece and then assign contracts to fabricate and install it separately.

This view is reinforced by work breakdown practices such as those used in estimating according to the 16 divisions outlined by the Construction Specifications Institute's (CSI) and Construction Specifications Canada's (CSC) 5-digit MasterFormat system of classification and numbering (Means 1997). In anticipation of this piece-meal decomposition, designers focus primarily on optimizing the design of parts rather than the overall system. They leave interface resolution, including dealing with issues of scope gap and scope overlap, to the contractor because they assume that the pieces they have designed will be relatively simple to identify and fit together. By viewing a project as an aggregation of parts, designers may not realize that they can—and we think should—design the project as an assembly of *interacting* pieces all the way from design through construction. While each part design may appear to be reasonable and logical upon inspection, the design of the overall assembly may actually be inefficient. Not only may it fail to take advantage of overlapping disciplines, the uncertainties and errors created upstream (e.g., during design) may prove to be detrimental to performance downstream (e.g., during installation) (Tommelein et al. 1999). This piece-meal contracting mentality prevents the development of a comprehensive design for the project that supports the entire process. An alternative approach is to involve specialty contractors early on in the design process to take advantage of the insight they have into process efficiencies and

improvements in product quality (Gil et al. 2000). Work structuring supports this approach to setting up the construction production process.

This case study will illustrate how current work structures are driven by contracts, trades, and craft. It will describe problems the construction crews faced, examine what solutions they came up with, and then explore system design decisions that shaped operations. The aim of this paper is to illustrate the kind of reasoning that underlies the work structuring process. We apply the quality management technique known as the “5 WHYS” to get to the root causes of the problems. Unfortunately, page length and time limitations have prevented us from including a more detailed benefit/cost analysis of alternative work structures in this paper, but further research will include such a quantitative analysis. However, we anticipate that the alternative work structures outlined in this paper can lower the cost and duration of door installation from 5% to 30%.

PROJECT BACKGROUND

This case study focuses on the construction of the Redgranite Correctional Institution, located in Wisconsin. This project consists of 2 housing buildings that cover a total of 140,000 square feet (13,500 m²). Additional facilities cover another 140,000 square feet. These buildings are 2 stories tall and their walls are made from precast concrete panels. The first-level floors are slab-on-grade while the second-level floors are precast concrete slabs. In particular, this case study investigates the installation of 510 hollow metal door frames into the housing buildings. For many building projects, the creation of open spaces is the primary activity that brings value to the owner. As the purpose of a prison is to keep inmates confined, on this project, it is the creation of walls and doors that brings value to the owner. Recommendations to improve door frame installation would thus be of interest to both the contractor and the owner.

The owner of the project is the Department of Corrections of the State of Wisconsin. The Oscar J. Boldt Construction Company is the construction manager. Venture is the project architect. The State awarded Boldt this design-build project based upon a guaranteed maximum price bid of \$48 million. Construction of the Redgranite Prison began in February 1999 and is to complete by October 2000. Prior to this project, Boldt already built 4 similar prisons.

Figure 1 illustrates the key supply and contractual relationships on this project using Rother and Shook's (1998) technique for mapping value streams. The State holds a contract with Boldt. Boldt, in turn, holds a contract with Venture. Boldt also holds a contract with Spancrete Industries Inc. to supply the concrete panels as well as with Laforce to supply the doors and door frames. Laforce is a licensed manufacturer of the Ceco brand doors specified by Venture. While Boldt hired Central City Construction Inc. to install the concrete panels, they self-performed the installation of the door frames. Later, Boldt hired R.J. Jacques to caulk around the door frames, and then they decided to self-perform the injection of grout into the door frames.

On this project, there were four primary design packages: footings and foundation, superstructure, electrical and mechanical, and finishes. Venture released design information to Boldt in a piecemeal fashion. This allowed contractors to begin fabricating pieces early.

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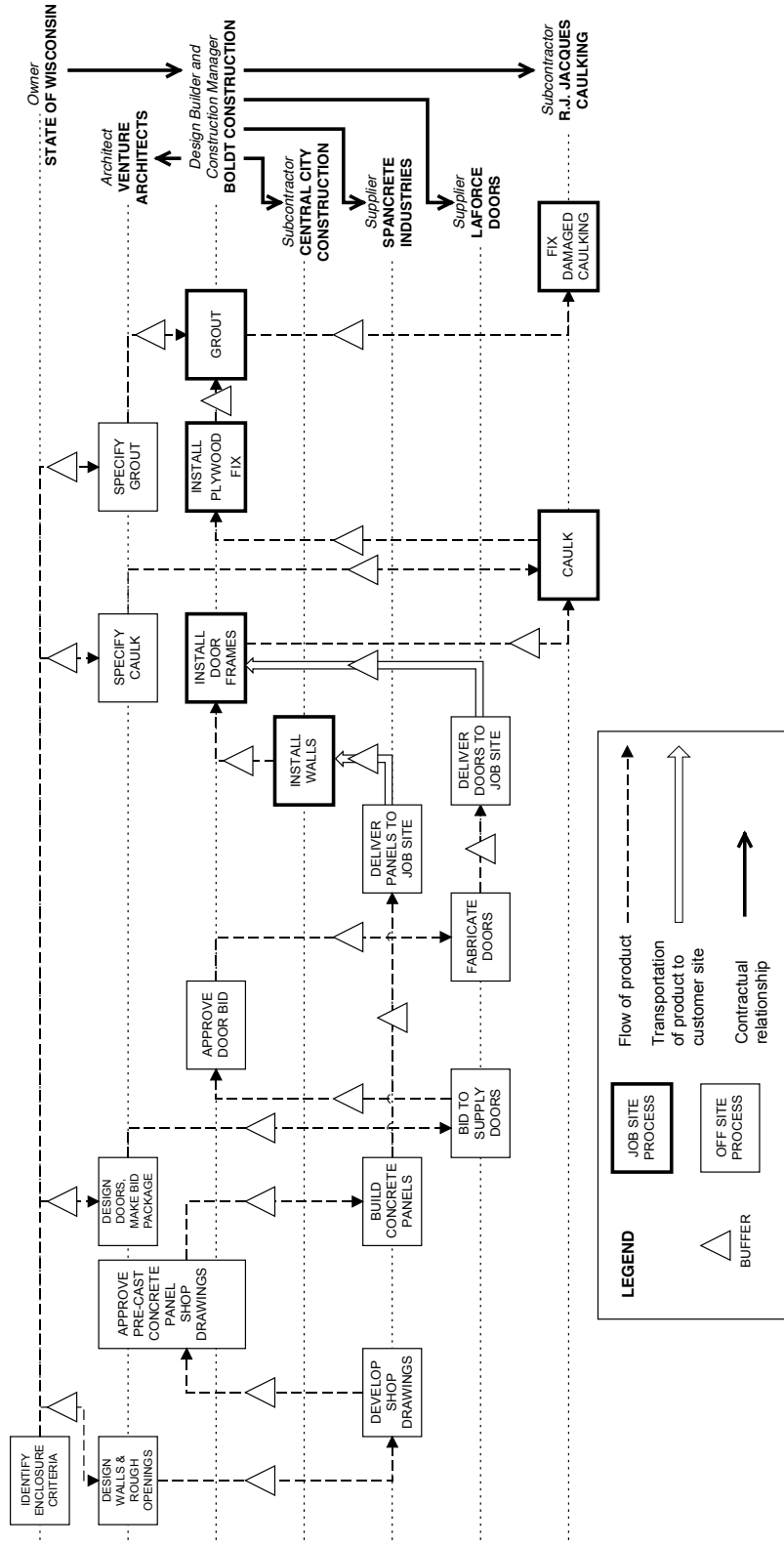


Figure 1: Supply and Contractual Relationships on Redgranite Correctional Institution

The concrete panel supply chain was as follows. First, the State determined its enclosure criteria. With that information, Venture developed an initial wall design with rough openings. Using Venture's initial design, Spancrete developed shop drawings for approximately 3,000 precast concrete pieces and submitted them to Boldt. Venture and Boldt reviewed the shop drawings, approved them, and gave permission to Spancrete to proceed with manufacturing. After Spancrete built the concrete panels, they delivered them to the job site. The lead time from receipt of the shop drawings from Spancrete to site delivery of the panels was 12 weeks. In many situations Venture specified the panel size although they did not have details on the mechanical requirements (e.g., louvers, air intake and exhaust duct) for the panel. As some early design data was changed later, several mechanical openings had to be cut on the job site.

The door frame supply chain was as follows. With the State's enclosure criteria, Venture developed the door bid package that contained the door and door frame designs. The door bid package was developed 5 months after the concrete panel shop drawings were developed. Then, Laforce submitted a bid to supply the frames. Boldt approved Laforce's bid and gave permission to Laforce to proceed with manufacturing. From shop drawings to site delivery, door frames take about 6 weeks and door hardware takes about 10 to 12 weeks.

Central City installed the concrete panels and Boldt installed the door frames. Following Venture's caulking specifications, Jacques caulked the door frames. Boldt subsequently installed a Plywood Fix (which will be discussed later) and pumped grout into the door frames. Finally, once the grout had set and the Plywood Fix was removed, Jacques returned to fix any damaged caulking.

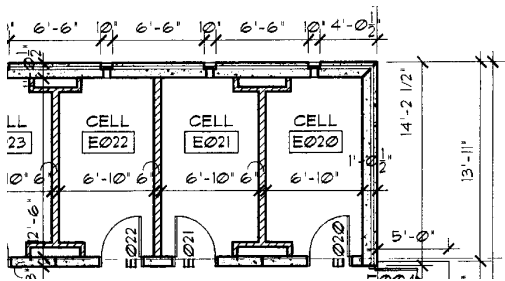


Figure 2: Plan View of Prison Cells
(From Housing Building E, Sheet A-1)

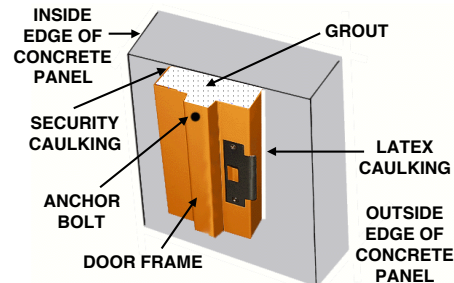


Figure 3: 3-D Diagram of Frame Design
(Adapted from detail from Ceco 2000)

DOOR FRAME INSTALLATION: CURRENT PRACTICE

HOLLOW METAL DOOR FRAMES

Door Frame Installation

As mentioned, Boldt was responsible for installing the hollow metal door frames according to prison plans (Figure 2). Figure 3 is a 3-dimensional rendering using a detail from Ceco doors (Ceco 2000). Boldt's installation procedure is the following. First, a worker moves a frame into the cell and leans it against a wall beside the opening. He then uses a level to draw a plumb line along the wall opening to mark where the frame should

be installed (Figure 4). Then, he positions the frame into the door space and lines it up against that plumb line. He aligns and squares the frame by using a level and wooden shims (Figure 5). While holding the frame in position, he drills holes into the frame, installs anchor bolts (Figure 6), and tightens them. The worker then adds wooden shims to ensure that the frame is square and plumb, and he turns the bolts as tightly as possible. Finally, he grinds the heads of the bolts down, and applies Bondo over the ground bolt heads to create a smooth finish.



Figure 4: Drawing a Plumb Line



Figure 5: Inserting Wooden Shims



Figure 6: Drilling for Anchor Bolts

Caulking Procedure

Once a frame is installed, the next step is to caulk the seam that separates it from the precast concrete panel. Jacques' procedure is the following. First, a worker cuts the shims off with a hand chisel, a procedure called "trim out", so the shim will not protrude through the caulking surface. Then, he inspects the gap between the frame and the wall to see if the caulking can stay in place. If the gap is too wide, the worker inserts a foam backer rod (Figure 7). He jams it into the crevice and caulks directly over it. On occasion, the backer rod may fall into the frame channel. When that happens, the worker does not try to remove it and installs another backer rod in its place. The worker usually caulks along the sides of the door and then runs the caulking along the top (Figure 8). Finally, he brushes the caulking, a procedure called "feathering" (Figure 9).



Figure 7: Installing a Foam Backer Rod



Figure 8: Caulking along the Top



Figure 9: Feathering

PRISON CELL DOOR FRAMES

Caulking and Grouting Procedure

On prisons, the door frame installation process differs from usual door frame installation processes due to added security measures. For Redgranite Prison, Venture specified that the frames were to be filled with grout. In addition, Venture required that security caulking be used along the frames. In response to a request for information submitted by Boldt, Venture allowed for two kinds of caulking: security caulking on the inside and latex caulking on the outside. Latex caulking is the type used in bathrooms and kitchens. It is not used inside prison cells because inmates may attempt to eat it. Latex caulking contains ethylene glycol and eating large amounts of it can result in serious illness or even death (USDHHS 2000). Moreover, inmates may try to store items in a void they create after scraping latex caulking away. Security caulking is about 8,000 psi (55 MPa) in strength, so it can resist inmate tampering better than latex caulking.

Venture specified a grout with a strength of at least 2,000 psi (14 MPa) and left it up to Boldt to develop the grout mix. Boldt was also responsible for inserting the grout into the frames. Boldt developed the mix by means of trial and error. The grouting crew developed an initial mix, tested it, and found that it did not pump well into the frame because it contained too much aggregate. After consulting two other contractors who had performed similar work, they tried 4 other mixes until they found a good ratio of sand, cement, and water. Boldt decided that this mix was adequate and proceeded to use it. Boldt informed Venture of their mix design and Venture has not objected to its use.

Boldt's procedure for inserting grout makes use of 2 to 4 holes in the frame called "grout ports". A worker first fills the sides of the frame halfway with grout. Once this grout has set, the worker then fills the other half of the sides of the frame. After the second grout pass has set, the worker finally grouts the top of the frame. Unfortunately, this situation still had problems. During placement, grout leaked through the cracks between the frame and the wall, blowing out the backer rods and caulking.

Plywood Fix: As the frames were already installed at the time of the grouting, any leak prevention system had to be applied to the outside of the frame. At first, Jacques' crew tried to use the caulking as a barrier, but there was nothing to prevent it from blowing out. To alleviate this blowout problem, they devised a Plywood Fix. They cut two large U-shaped pieces of plywood (sized slightly larger than the frames) and fit each piece directly against the caulked frame. They built C-clamps out of plywood and used them to hold the two U-shaped pieces in. The workers added wooden shims between the C-clamps and the U-shaped pieces to tighten the fit (Figure 10). After pouring the grout and allowing it to set, they removed this fix. Sometimes, the plywood damaged the caulking, so the workers had to re-caulk the frames. Figure 1 includes this rework procedure. However, after becoming experienced in applying the Plywood Fix, the workers learned to remove it without damaging the caulking. As a result, Jacques did not have to come back and re-caulk everywhere.

This Plywood Fix was unwieldy and time-consuming. Boldt's workers take about 20 minutes to install it and 5 minutes to remove it. As a result, Boldt identified the Plywood Fix as a good candidate for a First Run Study (Howell and Ballard 1999). A First Run Study accepts the existing design and develops solutions that can work within the existing contractual relationships. However, as aspects of the Plywood Fix got unraveled, it became apparent that the problems were rooted in work structuring. Work structuring

challenges the existing product and process design and comes up with solutions that may shift contractual obligations. This case study is a means to understand what happened and determine how to eliminate the need for “Plywood Fixes” on future projects.

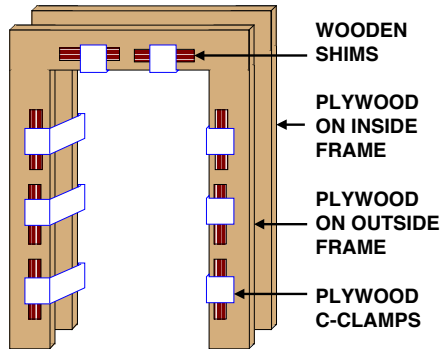


Figure 10: Diagram of Plywood Fix

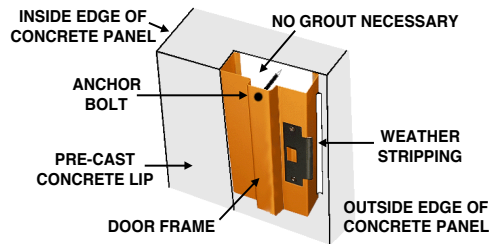


Figure 11: Concrete Lip Fix
 (Adapted from detail from Ceco 2000)

5 WHYS

In order to get to the root cause of this problem, we apply a common quality management method of problem solving called the “5 WHYS”. When a problem occurs, a worker should ask “Why did this problem develop?” After coming up with an explanation, the worker should ask again “Why is that the case?” The worker should continue with this repetitive inquiry until at least five “Why?”s have been asked and answered. The answer to the last “Why?” will give insight into the original cause of the problem. The strategy for fixing the system is to then eliminate that original cause (Koskela 1992). The “5 WHYS” are an integral part of the Toyota Production System (e.g., Shimbum 1995). On this project, the “5 WHYS” is appropriate to use to understand why the door frame installation process was structured as it was and why it ran into the problems it had.

LOCAL AND GLOBAL FIXES

The following local and global fixes were developed by the authors. Typically, the local fixes are feasible within the existing contractual arrangements whereas the global fixes are not. Many local fixes fall under the category of “productivity improvement” efforts as explored by Oglesby et al. (1989). Each section begins with a discussion of the “Why?”. Then, individual fixes that address the question are explained in detail.

Why did caulking and foam backer rods blow out? Caulking and backer rods blew out because of the hydrostatic pressure developed by wet grout during the grouting process.

Grout Pump Fix: Boldt used a variable air-pressure powered grout pump that operates at about 4,350 psi (30 MPa). Hand-operated grout pumps on the market operate up to a pressure of 725 psi (5 MPa). These low pressure pumps are capable of up to 20’ (6.1 m) of horizontal push and 10’ (3.1 m) of vertical lift. Use of a low pressure grout pump may have reduced the number of blowouts.

Caulking Fix: We are assuming that caulking and backer rod blowout is independent of the type of caulking used. It is conceivable that security caulking is more resilient to blowout because it is stronger and adheres to surfaces better. If this is indeed the case, and blowout only occurs on the side with latex caulking, then the solution is simple: use

security caulking everywhere. Venture's favorable reply to Boldt's request for information then had undesirable consequences and may not save Boldt any money in the long run. However, if neither one of the two types of caulking resists blowout, then Boldt might inquire if any other type of caulking would meet all requirements.

Why did grout leak through the cracks? Grout leaked through the cracks because of the pump pressure and thin grout mixture. With those two factors, the cracks were not tight enough to hold back the grout. This lack of tightness is the reason why backer rods were used to provide support when caulking over wide cracks. Because backer rods and caulking could not hold back the grout, the caulking crew introduced the Plywood Fix.

On-site Weather Stripping Fix: Boldt can attempt to tighten the seal between the frame and the wall. If access to the inside of the frame had been easy, then some sealant could have been applied at the inside without compromising the appearance of the door on the outside. For example, some kind of weather stripping material might be glued to run along the outside edges of the frame prior to frame installation so that it would be compressed when tightening the anchor bolts, thereby providing a tight seal. Security caulking would still have to be applied to the inside edge of the frame to prevent tampering by inmates, however the need for aesthetic caulking along the outside edge may be eliminated. This fix appears to be easy and cheap and could be applied on site.

Why was grouting of the hollow metal door frame needed? We do not know the origin of the grouting requirement but speculate that grout adds to prison security by (1) protecting the anchor bolts that connect the frame to the wall, (2) providing a bond between the frame and the wall while also making the frame heavier should an inmate try to push the frame out, (3) preventing inmates from hiding objects in the hollow frame, and (4) making it more difficult to disable the electrical lock mechanism inside the frame of some security doors.

Concrete Lip Fix: An alternative to eliminate the need for grouting is to prefabricate the walls with a concrete lip that protrudes on the inside of the cell wall (Figure 11). The inmates would then see only a recessed door and concrete walls, and the lip would block their access to the frame completely. This fix would not remove the need for caulking. By anchoring the frame against the lip, the contractor would still have to apply aesthetic caulking on the outside. The inside seam between the concrete lip and the frame should still be caulked with security caulking to prevent inmates from hiding weapons in it.

When asked if such an alternative is possible to manufacture, Spancrete replied that concrete panels of at least 8" (20.3 cm) thick could accommodate a 3" (7.6 cm) lip, assuming a frame was at most 5" (12.7 cm) thick. A wider frame resulting in a more narrow (e.g., 2" or 5.1 cm) lip would not work well because the lip might get damaged during shipping and handling. The addition of a lip would not violate any building codes because that area of the precast concrete panels is not designed to meet load-bearing requirements. The manufacture of such a lip involves adding an extra block to the wooden forms before pouring the concrete panels, slightly increasing the amount of concrete used, and adding a piece of reinforcing bar and meshing to strengthen the lip.

Why were there cracks between the door frames and precast panels? First, door frame installers need to have a 1/8" (3.2 mm) or so opening between the frame and the wall to make it possible to slide the frame into the panel opening and plumb it properly. Second, this opening will vary in size along the frame as a result of dimensional tolerances (stochastic variation relative to the design dimensions of a product) during

manufacturing and placement of the concrete walls and metal frames. Openings are to be expected when surfaces touch each other in any assembly of parts. It may be difficult to manufacture each part with a smooth surface as smoothness is a relative concept. Materials change in dimensions over time (e.g., shrinkage cracks, deflection and settlement cracks, and cracks resulting from items that wear out). They also may expand or shrink with temperature changes throughout the day and vary with the season.

The construction industry has developed many kinds of materials and techniques to fill cracks, to cover them up, to make them water- or air tight, to provide structural integrity to the assembly, or to meet other functional requirements.

Tolerance Fix: Tolerances are specified by contract. They represent acceptable variation. Nevertheless, if not managed properly, they may compound problems as design and construction progress. As mentioned earlier, variation has the greatest detrimental impact on those downstream in the supply chain.

For this project, Venture developed design drawings that showed the rough openings in the walls. Then, using those rough openings, Spancrete developed shop drawings for the walls. The American Concrete Institute recommends a tolerance of 1/4" (0.64 cm) for openings in precast wall panels (ACI 1994). Because Spancrete builds walls within a tolerance of 1/8" (0.32 cm) and because of the previously mentioned field installation requirements, its rule of thumb is to increase the given dimensions by 1/4" (0.64 cm) on each side of the door opening so that the door opening is 1/4" (0.64 cm) taller and 1/2" (1.27 cm) wider than Venture's design. After Boldt and Venture approved Spancrete's shop drawings, Spancrete proceeded with manufacturing (Spancrete 2000).

A few months after Spancrete's shop drawings were approved, Venture developed a bid package that specified the required door frames. Laforce submitted a bid to supply the frames using the door openings shown in Venture's initial design drawings and the bid package. Laforce builds frames within a tolerance of 1/32" (0.08 cm). A door specified as 3' (92 cm) to be used in a door frame that is 2" (5.1 cm) thick on each side, is built with a matching frame width of 3'-4" (101.6 cm). Spancrete's corresponding opening would then be 3'-4-1/2" (102.9 cm) wide, leaving a gap of 1/2" (1.3 cm) (Figure 12).

We have not yet investigated the quality of these manufacturers' products to determine what percentage of their products indeed falls within the tolerance range as specified and if all dimensions match those on the door schedule. Poor quality would lead to frames not fitting in the panel opening or leaving an excessively wide gap. Both situations occurred on this project. Sometimes, door openings had to be widened by grinding down the concrete in order for the frame to fit. Other times, masonry in-fill had to be used to narrow an opening that was too large. This uncertainty made it difficult for Boldt to anticipate which cracks would require the Plywood Fix. As a result, they installed this fix to all frames because doing so was easier than judging which caulking jobs would hold up against the grout and then dealing with occasional blowouts later.

Similarly, we have not yet investigated the quality of the design, that is, the extent to which the door schedule's dimensions are correct. Poor quality would lead to drawings that do not show door openings, or the door schedule listing extra doors.

Considering these tolerances, the computed range in dimensions for the opening between the wall and the frame are:

$$\begin{aligned} \text{lower bound} &= (\text{mean value}_{\text{panel}} - \text{tolerance}_{\text{panel}}) - (\text{mean value}_{\text{frame}} + \text{tolerance}_{\text{frame}}) \\ &= 3/32'' (2.4 \text{ mm}) \end{aligned}$$

$$\begin{aligned} \text{upper bound} &= (\text{mean value}_{\text{panel}} + \text{tolerance}_{\text{panel}}) - (\text{mean value}_{\text{frame}} - \text{tolerance}_{\text{frame}}) \\ &= 13/32'' (10.3 \text{ mm}) \end{aligned}$$

These numbers assume that the frame is perfectly centered in the door opening. If not, the lower bound may be 0 and the upper bound up to twice as large. Note also that the tolerance range may be exceeded on occasion, which is why Figure 12 shows bell curves (normal distributions) to depict the range of variation. Consequently, some frames and panels may not fit together at all, but swapping them out may result in a fit.

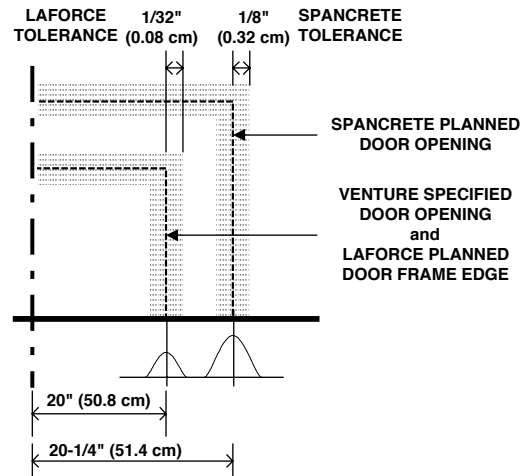


Figure 12: Tolerances on Door Frame and on Precast Concrete Panel

Why are door frames and panels manufactured separately? These two parts are manufactured separately because they require different materials, knowledge, skills, and fabrication tools. Industry specialization has further led to this division of labor. Much of the way work is done is governed by this fragmentation. It will come as no surprise that through such fragmentation, valuable opportunities for integration are lost.

Precast Fix: Taking the Concrete Lip Fix one step further, why not cast the frame into the walls, i.e., use the frame as part of the formwork? Again, the feasibility of this fix will depend on field quality issues.

WORK STRUCTURING REVISITED

To improve the process of installing frames, different perspectives are to be considered. Each of the parties involved have key roles to play. The owner, the architect, and the fabricator negotiate their needs and resources to develop the design. The construction manager, the panel erector, the frame installer, and caulker negotiate their standard work procedures to develop the operation design. However, since all parties rarely have the opportunity to consider work structuring together and early enough in the process to decide what would work best for the system, the engineering design is usually developed without any consideration for the operation design. As a result, the system is inefficient.

The system studied at Redgranite Prison, comprising precast concrete wall panels, door frames, caulking, and grout, is about as simple a system can get. Nevertheless, this system was plagued with problems as revealed by the introduction of the Plywood Fix.

Table 1 lists the fixes that were discussed in this paper and the parties involved. Additional fixes listed in Table 1 that were not discussed in this paper are discussed in Tsao et al. (2000). Very few fixes are local, that is, very few are under the control of a single party. All parties are involved in at least one fix. A more detailed investigation for each fix and additional ones should assess their feasibility and the benefits relative to costs and timing in terms of system design and operation execution. This is the very task of work structuring.

The likelihood of recognizing and then implementing one fix or another is highly dependent on the contractual organization of the project. For instance, had Spancrete also been responsible for mounting the frames, they would have had an incentive to work towards a more global fix. The issue thus is: Who owns/controls the supply chain? In the existing situation, as Boldt is the construction manager who self-performs a considerable portion of the work, Boldt owns and controls a significant part of the supply chain.




Fixes require change but not necessarily an increase in cost or time. In fact, the opposite should be true: fixes should yield cost and time savings.


































The “5 WHYS” is a practical technique to determine root causes. However, the “5 WHYS” is rarely applied in practice in the architecture-engineering-construction industry. People seldom get the opportunity to take the time and question why things are the way they are. Trades do not necessarily complain about site problems because (1) contractually speaking, site problems may be considered theirs to resolve, (2) they may have more important problems to address such as developing bargaining tactics and determining which battles to fight, and (3) complaining might reflect poorly on their trade skill and pride (“tricks of the trade”) so they believe workarounds are what they are supposed to do.

Different planning techniques are used in construction. The contractual planning method asks, for example, “You have 30 doors to install. Finish this task.” The next level of planning asks, “You have 30 doors to install. What are your constraints?” The final level of planning asks, “You have 30 doors to install. How are you going to do it?” The latter question is rarely asked by high level planners and left to the installers. However, if the system design is bad, the installer works around the design with ingenious solutions. Such workarounds are costly and time consuming. However, they are an accepted way to perform work. If there is a problem due to missing details or interference with other pieces, a worker complains about the design and works around it. Workers do not question the design because their contracts have already been signed and work must proceed according to the original design. Therefore, it would be interesting to investigate how to determine when it is appropriate to release less complete designs earlier versus more complete designs later.

While the “5 WHYS” is a good approach to begin developing a better work structure, it is hardly enough to cover all aspects of work structuring. The “5 WHYS” addresses the following questions of work structuring: (1) In what chunks will work be assigned to specialists? (2) How will work chunks be sequenced? and (6) When will different chunks of work be done? Future research efforts will explore how to deal with the previously listed questions as well as the other work structuring questions: (3) How will work be released from one production unit to the next? (4) Will consecutive production units execute work in a continuous flow process or will their work be de-coupled? (5) Where will de-coupling buffers be needed and how should they be sized?

Table 1: Fixes and Responsibilities (* indicates fixes discussed in Tsao et al. 2000)

 perform fix
  work affected by fix
  approve fix

	FIXES	Venture Architects	Boldt Constr.	Spancrete Industries	Laforce Doors	Central City Panel Erection	Jacques Caulking
Prevent Caulking Blowout	Grout Pump Fix						
	Caulking Fix						
	Grout Fix *						
	Foam Fix *						
	Hydrostatic Pressure Fix *						
Prevent Grout Leakage	Plywood Fix (Actual Fix)						
	Bungee Cord Fix *						
	On-site Weather Stripping Fix						
	Off-site Weather Stripping Fix *						
Eliminate Grouting	Solid Frame Fix *						
	Concrete Lip Fix						
Manage Cracks	Field Sequencing Fix *						
	Tolerance Fix						
Combine Components	Precast Fix						

SUMMARY

This case study illustrates typical problems encountered in the architecture-engineering-construction industry today, where a contracting mentality hampers thinking about system-wide solutions. The case illustrates the consequences of poorly made work structuring decisions. Work structuring decisions regarding the system of walls and doors were made by Venture. Spancrete and Laforce together might have come up with a better system design. The involvement of specialists/suppliers in design is advocated by lean practices (Tommelein and Ballard 1997, Gil et al. 2000). Perhaps it would have been worthwhile for all parties to participate in a “Schematic Design In A Day” (SDIAD) exercise (Miles 1998). However, this type of collaboration is unlikely to happen due to contractual restraints. Spancrete and Laforce hold contracts with Boldt. If they developed a system design together or with other parties, the issue of assigning liability for the design would likely be disputed.

ACKNOWLEDGMENTS

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WORKING NEAR THE EDGE: A NEW APPROACH TO CONSTRUCTION SAFETY

Gregory A. Howell¹, Glenn Ballard², Tariq S. Abdelhamid³ and Panagiotis Mitropoulos⁴

ABSTRACT

Construction safety has substantially improved, but has reached a plateau. Further improvement will come from spreading Best Practice throughout the industry, or from Breakthrough that transcends Best Practice. We are working on Breakthrough and propose that what is needed is a new theory of accidents. Current Best Practice is described along with its underlying theoretical assumptions. An alternative theory is proposed, based on the work of Jens Rasmussen, a leading thinker on risk management in dynamic environments. A research program is proposed to test that theory and to develop a new approach to safety management.

KEYWORDS

accident, accident theory, decision making, hazard, risk, safety

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INTRODUCTION

Lean advocates minimizing waste and continuously improving. Incidents that disrupt the flow of work or lead to injury are waste, so the relationship between lean and safety is clear. Ohno's rule that a worker stop the line rather than release a defective part downstream also resonates here. It is one thing to focus on the worker facing a hazard (a hole in the deck) and another to require the person who completed the previous work to assure such hazards are not left open before declaring completion and allowing the next crew onto the deck. Making work flow more reliable seems an obvious way to reduce the unexpected events that lead to incidents, but so far we have only anecdotal evidence that more reliable planning does reduce incidents.

We have long understood the 'soundness' quality criterion for assignments as applied in the Last Planner System to include consideration of safety issues. A number of proposals have been put forward to make such consideration more explicit. For example, if a pre-task hazard analysis were required before an assignment was released, both inspection and root cause analysis would be improved. Inspectors who found people in hazard could take the appropriate immediate steps and then determine if the hazard had been identified in planning or not. If not, the planning should be improved and reasons for ignoring the plan could be investigated and action taken to reduce recurrence.

Despite such innovations that reconceive the relationship between planning and safety, no systematic theory or practice has yet been developed, yet improving safety performance remains a high priority. In 1996, the fatality rate in the U.S. construction industry was 13.9 deaths per 100,000 workers and the injury rate was 9.7 injuries per 200,000 laborhours. By 2000, fatality rates had fallen to 12.9 and injury rates to 8.2. OSHA legislation, increased litigation, and increasing worker medical expenses and compensation insurance costs gave the advantage to safer contractors. People at every level became less willing to accept the carnage. Construction users began to include safety performance in selection criteria and contractors began to take action. As one contractor executive put it, "No more funerals, I have attended too many. This has to stop." With increased attention on safety, company wide safety programs became the norm. Many employ full time safety officers or employ consultants to assure legal requirements are met and hazards and incidents are reduced.

These programs paid off but the industry remains one of the most dangerous. Construction still kills or injures more than eight percent of its workers each year. There has been insignificant further improvement in safety statistics since 1996. Further improvement is needed now as improvement has leveled off.

Further improvement in national statistics can be achieved by spreading Best Practice throughout the industry. The larger, more sophisticated companies have much better safety records than the national averages. For example, OSHA reports that in 2,000, the injury rate for construction companies with more than 1,000 employees was 4.3 while the construction industry rate was 8.2.

But spreading Best Practice throughout the industry will not help those who already use Best Practice. Significant improvement for industry leaders requires a new approach, a breakthrough beyond current best theory and practice. Of special concern are accidents that occur through workers putting themselves at risk, which appear to be resistant to current approaches. This paper briefly reviews the state of theory and current practice, and argues that a new theory is needed, which we propose to take from the work of Jens

Rasmussen. A new approach is developed and described, and experiments are proposed to test the new approach in action.

ACCIDENT THEORY

There have been a number of accident causation models put forward. The most prominent and widely disseminated models include the domino theory developed in 1930 by Heinrich. His theory included five dominoes: ancestry and social environment; fault of person; unsafe act and/or mechanical or physical hazard; accidents; injury arranged sequentially. His work, while criticized, has been updated to focus on management's responsibility for accidents. Other models evolved separate from the domino theory but still based on Heinrich's work. These models can be classified as behavior, human factors, systems, epidemiological, and decision models. (Heinrich 1980).

Workers are the main cause of accidents in behavior models because people make errors under various situations and environment conditions, with the blame mostly falling on the human (unsafe) characteristic only. A number of efforts have devoted great time and effort defining and categorizing human error (e.g. Rook, Altman, and Swain 1963, Recht 1970, Petersen 1982, and Reason 1990).

Accident proneness is a foundation of most behavior models (Klumb 1995). The main idea is that a permanent characteristic of some people leaves them more likely to have an accident. And it is true that a small number of people are involved in multiple accidents. The reasoning follows that this small group must possess personal characteristics making them prone to accidents (International Labor Organization 1983). Other theories in behavior models include the Goals Freedom Alertness Theory (Kerr 1957), the Life Change Unit Theory (Alkov 1972), and the Motivation Reward Satisfaction Model (Peterson 1982). For other behavioral models see Krause, Hidley, and Lareau (1984), Hoyos and Zimolong (1988), Dwyer and Raftery (1991), Friend and Kohn (1992), and Krause and Russell (1994). O'Hare et al (1994).

The human factors approach holds that human error is the main cause of accidents but the design of workplace and tasks that do not consider human limitations also contribute. These models study the effect of a particular situation or environment on human performance and their limited ability to perform. Cooper and Volard (1978) state environment and human characteristics (both physical and psychological overload) as factors that contribute to accidents and to human error. These ideas are common to the field of human factors engineering. Examples of human factor models include, the Ferrel Theory (Heinrich 1980), the Peterson model (Peterson 1982), the McClay model (McClay 1989), and the DeJoy model (DeJoy 1990).

A review of the literature on construction safety reveals that significant research effort has been directed at examining accident records to categorize the most common types of accidents that occur to a specific trade, and how these accidents happen (Fullman 1984, Goldsmith 1987, MacCollum 1990, La Bette 1990, Rietze 1990, Davies and Tomasin 1990, Peyton and Rubio 1991, Helander 1991, Culver et al. 1992, Hinze 1997). Despite the importance of such study findings to guide accident prevention plans, construction accident investigations appear to conclude at a premature level or are missing important steps to identify the root causes of accidents. As summarized by Brown (1995), "Accident reporting is a means to an end, not an end in itself".

Despite the contributions of these causation models to both understanding accidents and current safety programs, no model provides an understanding of the underlying

causes of construction accidents sufficient to prevent the kinds of accidents that now plague the industry.

BEST PRACTICE

The Lean Construction Institute conducts research workshops with its member companies on various project and production management issues. A recent workshop was devoted to safety. Documents and descriptions from that workshop are the basis for this description of current practice, in which contractor safety programs are the norm.

All of the construction companies supporting the Lean Construction Institute maintain active programs. These programs have similar approaches and components, although each is unique in its application. All of these companies have shown significant improvement and are well under the average rates experienced in the industry.

A TYPICAL PROGRAM

A medium sized mechanical contractor working in a large city provided this description of their safety program.

“A full time Safety Director (SD) was hired as the company grew and it became apparent that safety performance needed greater attention. Prior to that safety was a part time concern of the safety “manager” who also worked in purchasing. The new SD is a safety professional by education and has years of experience in safety with a major contracting and construction management company.

The SD reports directly to the CEO. He is charged with (and does a very good job of) working with each department to service their unique safety related needs, as well as with the overall company safety program. Coincident with arrival of the SD, the CEO instituted a Safety Committee (SC), comprised of employees representing the various levels and job functions in the company (Project Managers, Foreman, Superintendent, etc.). The SC worked with the SD to develop a comprehensive safety program. This program started with formal training by job and function and now includes:

- Targeted formal training (OSHA 10 Hr, plus required number of 1-hour safety seminars per year, based on employee’s role in the company). All taught internally and supplemented at times by outside sources such as the power company on overhead power line safety.
- Toolbox talks reviewing tool use, project hazards and accident reports
- Bimonthly safety review meeting discussing current performance and any special safety issues. Chaired by the CEO and SD, and attended by substantially all management and supervisory level employees from both office and field.
- An incentive system that includes both spontaneous “ataboy” recognition for observed good safety performance, and a company wide monetary reward safety “lottery” for eligible people on project teams that meet or exceed the formal safety objectives for the lottery period.
- A citation program where both good behavior and bad behavior can be cited. A book of “tickets” is issued to all supervisory parties, which can be used for this purpose.

- Inspections and visits by safety professionals are typical. The company SD visits sites soon after the mechanical contractor mobilizes on site. He also will come to site when particular safety concerns or problems are identified by the project manager. While he does not conduct routine safety inspections, the project manager is expected to regularly walk the project. Their work is also inspected by the safety staff of the general contractor and inspections from owner safety representatives are becoming more common. General Contractors often take advantage the OSHA consultation program aimed at solving problems rather than enforcement actions.
- Post incident analysis is conducted by the SD with the project manager and supervisors to determine how to prevent recurrence. While not a formal root cause analysis, these efforts document the accident and provide feedback to the planning, training and toolbox components.

The first end of year review showed clear improvements in terms of reduced incidents and revealed that incidents were still occurring because trained people chose to perform tasks in an unacceptable manner. Some of these cases occurred because people thought that they were doing either themselves and/or the company a favor by cutting corners to save time or expense. For example a worker finds that they are unable to reach something from their ladder and so climbs above the allowable level because it will take extra time to find another ladder and moving it will require extra work. As a result, more rigorous pre-task safety planning and hazard analysis, and root cause investigations have been instituted.

DISCUSSION

The program described above contains the essential elements of most safety programs; i.e., training, responding to regulation, motivation, planning, investigation and incident analysis. This section will discuss these elements and argue that they rest on an implicit worker centered causal theory as described in the Accident Theory section. Worker training and motivation is assumed to be the key to preventing accidents. Typical program elements include a person assigned to manage the program, a multi-level and cross functional steering committee, training, both carrot and stick motivational techniques, awareness, pre task hazard planning, inspection, and incident analysis and prevention planning.

A variety of other techniques are employed in other companies, but most fall within the categories apparent here. For example, one company conducts an annual “Safety Art” for the young children of employees. A calendar is prepared using the 12 winning entries and distributed to all employees. This company links employee safety to their family with the reminder that “Your Families Love You”. Some companies “brand” the safety program and provide work shirts and safety equipment with a logo stressing awareness.

A more sophisticated approach to pre-task hazard analysis is reported by another company. Their safety program is aimed at convincing employees that the acceptable level of risk on site is much lower than employees accept working at home. Since this level of risk can’t be quantified, the company considers this a cultural issue. The level of acceptable risk is developed and communicated through pre-task hazard analysis. It works like this: The pre-task safety analysis prepared by the foreman is reviewed by the

supervisor to determine if hazards that pose risks beyond those considered acceptable have been identified and preventive action is taken.

Other companies use more formal and detailed approaches to identify root causes of incidents. A variety of forms are used but most appear to focus on the situations where hazards exist and on the actions of the workers. For example, a plumber installing fixtures falls to his death through an unprotected opening on a floor deck. One identified cause is the existence of the opening and the other is a worker's failure to see it while walking backwards. Of course both the situation and the behavior contribute to the incident but no mention is made in the analysis as to why the worker was on such a deck, the failure of the person creating the hazard to correct it instantly or to "lock out" workers from the area, or the failure of the worker's partner to alert him to the danger.

While there is no standard practice for identification of root causes, the practice is common and provides feedback to training and planning functions. Some companies distribute abbreviated accident reports to every crew on the morning following each incident. While it seems an obvious idea, we have not yet found safety programs that evaluate the quality of pretask planning against the root cause analysis.

From the research perspective, root cause analysis provides important insight into how incidents and their prevention are understood. In current practice, root cause analysis often determines that an incident resulted from an error. The concept of an error as a deviation from normal practice makes sense in well structured systems where a correct sequence can be identified. But such well structured systems are not common in construction and while correct procedures may be developed for the use of tools, they are very difficult to prescribe for construction work which often takes place in complex, dynamic conditions. In these circumstances, the specific sequence of steps can rarely be predicted and controlled precisely. It is not possible to establish rules for how to behave in every possible condition in less structured situations. Thus tracing incidents to the root cause of failure to follow standard practice is often impractical.

Jens Rasmussen argues in "Cognitive System Engineering" that there are no objective stop rules for tracing the upstream causes for downstream events (Rasmussen 1994). Rather, the analysis stops once an explanation makes sense to the analyst from their perspective or because the trail of information goes cold. The perspective of the analyst going in limits the range of potential "causes". Rasmussen identifies six common perspectives (Page 138, Rasmussen 94).

1. The Common sense explanation of what happened. Analysis stops when the act or event is identified that offers a reasonable explanation and is familiar to the analyst.
2. Understanding human behavior: The Scientist's perspective. This approach seeks to understand the inner mechanism of human behavior. The stop rule is to identify any actor in the flow of accidental events that did not maintain control even though they may not have started the flow and then to explore their cognitive processes. But even these inferences depend on the psychological approach taken. A number of distinctions internal to this approach are also made, such as the difference between a slip which is the wrong execution of a proper intention, and a mistake which is the correct execution of a wrong intention.
3. Evaluating human performance: The reliability analyst's perspective. This approach attempts to predict the effects of likely errors on larger system

performance. Tracing here moves downstream to assure dangerous outcomes do not follow from likely errors. This approach requires highly structured work situations as in power plant operation. It is very difficult to apply in less structured work and is made more complex because humans adapt to the situation and often push for performance beyond that predicted by the designer.

4. Improving performance: The therapist's perspective. The availability of a cure determines when the search for cause stops. The bias of the therapist will likely affect the selection – trainers will see the problem as a lack of training, while the psychologist or safety officer may see it as a lack of motivation or awareness. Of course, it is possible for more than one such stance to be “correct” within limits.
5. Finding somebody to punish: The attorney's perspective. The stop rule is to identify a person who was in control of their behavior and therefore guilty of the act.
6. Improving system configuration: The designer's perspective. The job here is to find changes in the work system that will improve its performance. This is tricky business as the system are “designed” by a number of people with different perspectives from legislators to machine designers. Reports on single accidents do not provide good models of the system and repetition of the precise sequence is rare. The ability of people to adapt makes this task even more difficult.

The examples of root cause analysis provided by LCI members were prepared from the therapist and attorney's perspective and offered little direction for significant improvements in the design of the work itself. Safety programs such as those described above appear to rest on the following beliefs:

1. Rules and procedures can be developed which if followed will keep people safe.
2. Incidents happen because of worker error; i.e., failure to follow the rules.
3. Reducing incidents will flow from improved motivation and training; i.e., getting people to follow the rules.

We do not argue that worker motivation and training are unimportant, or doubt that people make mistakes and choices that lead to tragedy. But we do not believe that the worker centered cause and effect model, coupled with the violation of procedures, explains how incidents occur or provides the leverage required for further improvement. Additional reasons for moving beyond a worker centered model include:

- Motivation and training have been a primary focus of efforts to improve productivity beginning at least since 1970. We now find that redesigning the production system using lean theory has greater impact.
- Programs in general make us suspicious. More than a few corporate programs have been created to solve a problem without requiring deeper change. Productivity programs were tried extensively beginning in the 1970's but made only modest gains and rarely caused a fundamental shift in the way work was done. It has been said that all programmatic fixes to organizational

problems eventually pass away; they either cause a change in the fundamental practice they were chartered to affect or they become obviously impotent and are cancelled. We expect safety programs will continue because they are almost required by regulation, and no better approach is yet apparent.

- There appears to be a more powerful theory and approach.

A NEW THEORY FOR CONSTRUCTION SAFETY

“In a modern dynamic environment where discretionary decision making to a large degree is replacing routine tasks, definition of a correct or normal way of doing things is difficult, and the focus of research should be on understanding of the way in which features of the work environment shape human behavior and the conditions under which normal psychological mechanisms result in unsuccessful performance. The aim in the present context, therefore is not to analyze human errors and to create data bases so as to remove errors by proper work system design but, instead to design work systems that support the actors in coping with the effects of their actions when their performance under particular circumstances turns out to be unsuccessful. In this respect, we have found that a better understanding of the relationship between human adaptation to dynamic environment and human errors is required.” (Page 143, Rasmussen 94)

The framework proposed by Jens Rasmussen in *Cognitive Systems Engineering* offers a broader and more powerful view of the relationship between individual and work environment, and of the primary factors that lead to incidents. In this model, represented in Figure 1, the way work is done migrates away from the organization’s boundary (fear) of economic failure and the individual’s boundary of (distaste for) excessive effort (Figure 6.3 page 149, Rasmussen 94). Accidents, defined by Rasmussen as “loss of control,” occur when work migrates to the boundary of functionally acceptable behavior and control is lost. This process was reflected in the last paragraph of the description of the Mechanical Contractor’s program. Rasmussen argues that “...the result will very likely be a systematic migration toward the boundary of acceptable performance and, when crossing an irreversible boundary, work will no longer be successful due to “human error.””⁵ (Page 149, Rasmussen 94). Safety programs are designed to counter the pressure to move into an area where control can be lost.

⁵ Rasmussen argues that accidents occur at the boundary in this model but in the text of chapter 6 he also notes that psychologists distinguish slips or lapses that occur when one makes an incorrect execution of a proper intention from mistakes that occur when people correctly execute an improper intention.

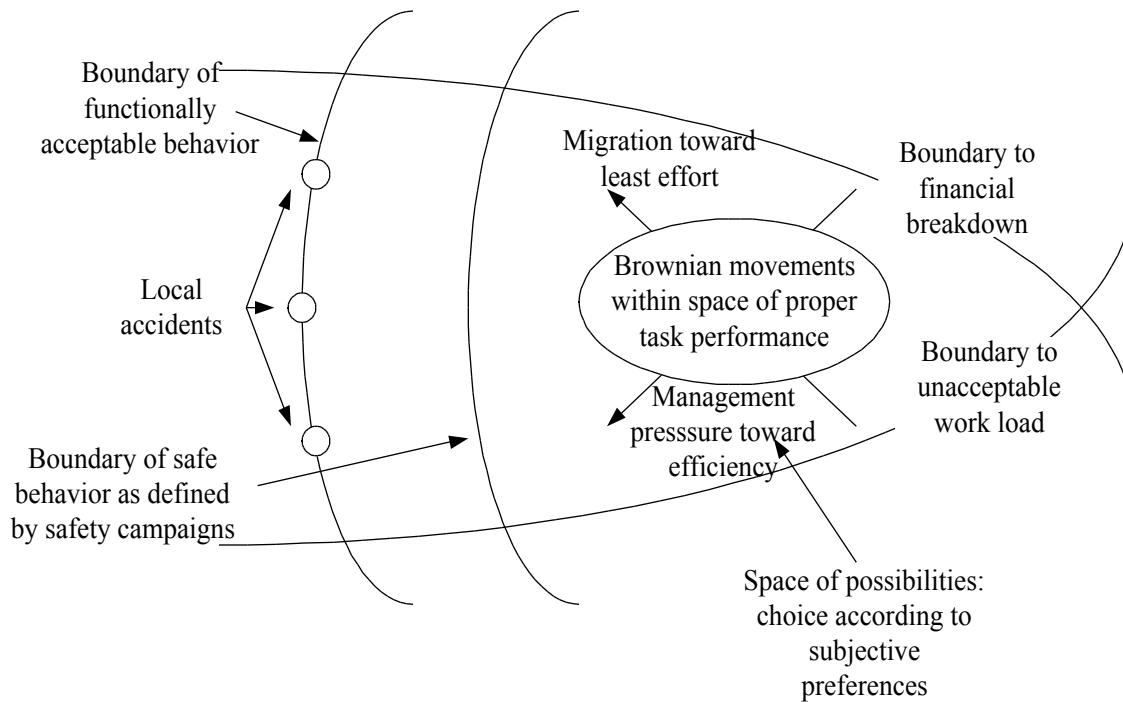


Figure 1: The migration of work toward loss of control.(Figure 6.3 Rasmussen 1994)

This model challenges current safety program practice on a number of fronts, including the concept of error based on standard procedure (described above). But the fundamental difference flows from the recognition that both individual tendencies and organizational factors push people to work in risky circumstance. Recognizing the inexorability of the forces at play, it appears necessary to develop coping behavior at the edge of control. This challenges the notion that workers can be kept inside the safe zone and should never enter the danger zone where loss of control is possible. Rasmussen's approach recognizes that people adapt to the circumstances and suggests that helping them develop and apply their judgment will be more successful than simply following rules. Rasmussen's model for causation leads to a three step approach to safety as shown in Figure 2. The actions taken in each zone are described in relation to an incident where a worker was injured when a wrench slipped while removing a toilet.

Zone 1 - IN THE SAFE ZONE: Enlarge the safe zone through planning the operation. NB: Identifying hazards in an operation assumes that the operation has been designed.

Zone 2 - AT THE EDGE: a) Make visible the boundary beyond which work is no longer safe (a hazard can be released) and teach people how to recognize the boundary. (Don't use an open end wrench on stuck nuts.) b) Teach people how to detect and recover from errors at the edge of control. (Increase pressure slowly when nuts are stuck or use a striking wrench to break them loose.) This may require practice in "simulators".

Zone 3 - OVER THE EDGE: Design ways to limit the effect of the hazard once control is lost. (Plan for what will happen if the nut breaks loose suddenly or the bolt breaks. Wear gloves.)

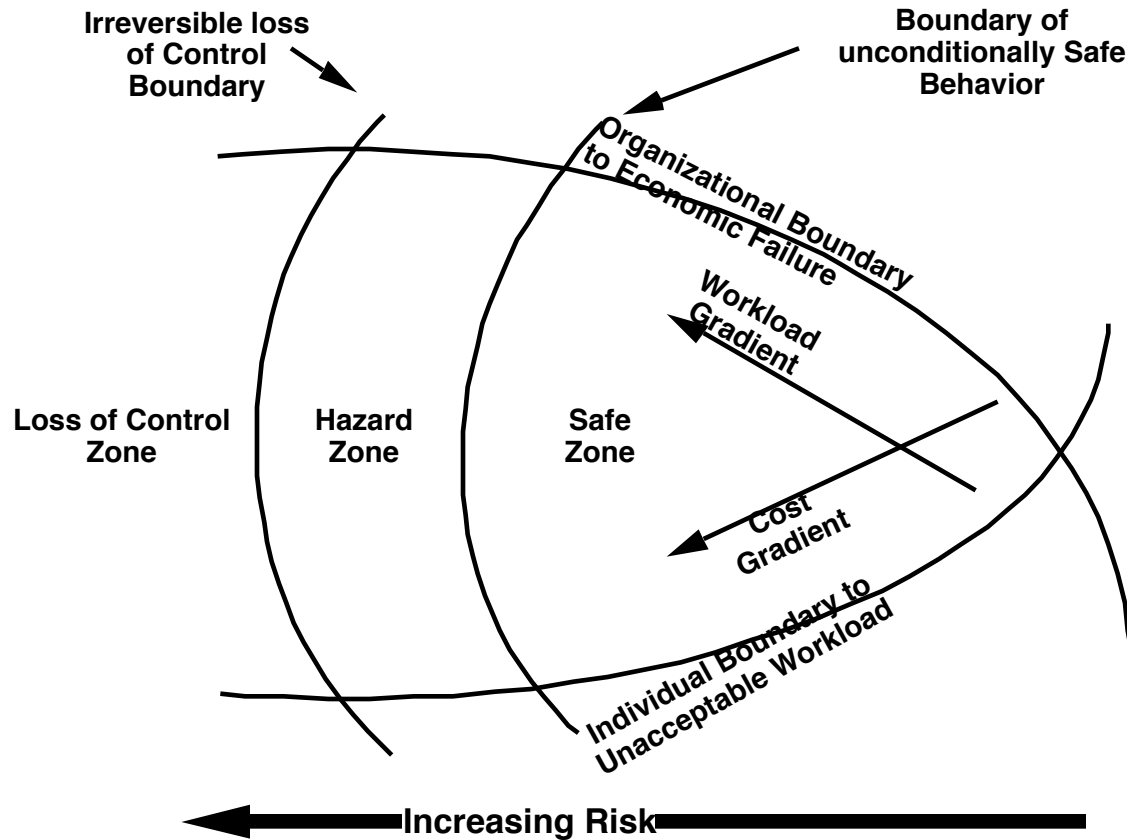


Figure 2: Three Zones of risk.

This model requires definition of “hazard” that recognizes its latent nature, how it becomes active and propagates to injury. Typical definitions such as "A condition or set of circumstance that has the potential of causing or contributing to injury or death" (Christensen 1987) are insufficient. We propose that a hazard is a condition, which if released can lead to injury unless the worker is able to detect and avoid it without increasing exposure to another hazard. This definition recognizes that the hazard is related to both the worker and the situation. Is a road hazardous? A mountain road? An icy mountain road? Under this definition, an icy road is in itself no more hazardous than a dry one if the driver adjusts his speed to avoid or be able to manage sliding. This definition also recognizes that hazards can lead to injury at different rates. For example, circular saws have guards that snap closed quickly when the saw is pulled from the wood. This guard is required because the worker cannot detect and respond to the situation quickly enough to avoid injury when a circular saw kicks back. Other hazards such as falls lead to an irreversible loss of control and so steps must be taken to prevent the propagation through loss of control to injury. Fall protection and nets provide just this service.

This definition of hazard is richer than the current working definition and can be applied in pre-task planning, where different strategies are appropriate depending on the nature of the hazards. Two examples illustrate the issue.

- Boundaries where hazards may be released are not absolute: For example, driving at or below highway speed limits does not assure safe passage and people break these rules because they do not accept their validity (especially when late for dinner.) The situation is similar in construction. Ladders slip or fall for a variety of reasons. Use rules may help if people accept their validity. A ladder fall simulator could demonstrate just how easy it is to release the hazard and how quickly it propagates. Some companies do teach people to drive in a variety of conditions on training tracks. These courses teach people how to recognize the situation determined boundaries to regain control when lost. Are there other situations where simulators could be developed for construction? This approach will certainly raise concern among many that people will take greater risks once they better understand the boundary conditions. This will be discussed in a section devoted to adaptation below.
- Boundaries are difficult to detect and sharp. Once crossed, recovery of control is impossible and limiting propagation cannot be assured. Current practice requires that electrical systems be locked out for just these reasons. Fall hazards such as the open holes in decks are similar but firm lockout policies requiring work to cease when the condition occurs do not appear to be the norm. (It would be interesting to see the data on how many electrical accidents are due to failed lockouts and compare that with falls through openings.) Where else might firm lockout procedures be applied? This approach will raise objections related to the boundary of economic failure. Should all work be suspended on a large deck because of an unprotected hole at the far end well away from the crew? If yes, who should have the firm authority to stop work?

Other ideas come to mind. Structural engineers design structures to hold loads. Good practice requires them to identify the likely failure mode of the structure if loads are exceeded and depending on the circumstance adjust the design to assure the failure is safe. The same principle could be applied to pre-task planning. We have long proposed the practice of carefully designing operations with First Run Studies and that this process should include careful consideration of the hazards involved. Could current practice and First Run Studies both be improved by asking the crew, “Where will accidents be likely to occur if people try to either improve productivity or reduce their effort?” Or, “How can we improve performance, reduce effort, and work in such a way that hazards can be eliminated?” In effect, “How can we expand the safe zone?”

ADAPTATION

At this point, we hope to have legitimized ‘working near the edge’. A Rasmussen-based approach suggests that improved safety and organizational performance can be achieved by learning to work close to the loss of control boundary. This approach contradicts current practice with its emphasis on eliminating hazards and following rules to stay well back from the boundary. Some safety professionals find the idea of increasing the individual’s ability to cope near the edge or to recover when a hazard is released unsettling. This fear is not groundless as it is well established that people adjust their behavior when new technology is developed to reduce risk. The effect is for people to

compensate in ways which keep the level of risk as they perceive it about constant. For example, people with 4 wheel drive tend to drive much more aggressively in icy conditions than those without. This compensating behavior can have ugly consequences when either the risks actually are increased due to overcompensation or when the resulting failures are worse. For example, even if the odds of going off the road were the same with a 2-wheel-drive car going slowly and a 4-wheel-drive going fast, the consequences of the higher speed wreck are likely to be worse.

Fear of compensation was a central issue in the debate over the use of nets to protect workers on building the Golden Gate⁶. Management feared that reducing the consequence would increase risk taking behavior. Similar concerns are raised in other risky settings such as sex education, needle exchanges and driver education. We come down on the side of teaching people to use their judgment rather than expecting them to blindly follow rules. Rules cannot be structured for all contingencies. Further, the very real pressures of work should not be ignored. The only alternative to rule making and enforcement is to cultivate judgment so people better understand the consequences of working near the edge and develop skills so they can work in hazard zones.

One interesting example of both improving ability and awareness of consequences is reported by Alison Muth of Messer Construction regarding fall protection. Like nets, body harnesses might be expected to increase risk taking because the protection reduces the consequences. A tripod was prepared that allowed people to fall from a ladder and be caught by the apparatus. The fall was limited to three feet but this was enough to convince people that falling even short distances with a harness is neither comfortable nor entirely without risk of injury. The simulation also emphasized the importance of checking safety equipment as it can be damaged in even minor falls.

A RESEARCH PROGRAM

Rasmussen proposes a different cause and effect model for the way incidents are caused and propagate to injury. We propose to test this model to see the extent to which it explains incidents in construction and then to develop ways to apply First Run Studies in operations design; ways to help workers better detect where hazards may be released, better cope near the edge, and recover if control is lost; and finally to minimize the effects if loss of control is irreversible.

The model proposed by Rasmussen appears to offer new and important leverage on safety, but it will require significant adjustments to current thinking and practice. We propose to first confirm that the model does in fact provide a sound theory for the way accidents occur in construction. We suspect that currently applied root cause analysis data will not provide definitive answers because the new model was not used to identify causes. New data will be required and a collection protocol established. We will structure a post incident evaluation procedure to determine what the employee understood about the loss of control boundary and the extent to which they were influenced by the pressure for production or desire to reduce effort. We hope to determine if there are ways to either reduce the pressure or establish lockout situations, if there are ways boundaries could be made more visible, and finally if there are ways to help people regain control when a

⁶ The Golden Gate is considered to be the first modern project to use nets and hard hats. When Brunelleschi constructed the dome of Santa Maria del Fiore in Florence in the 15th century he employed safety nets for the masons. Only one fatality was recorded on that project.

hazard is released. This first work will establish the extent to which further work can be expected to produce positive results.

Additional work will be required to complete the three level strategy:

1. IN THE SAFE ZONE: Enlarge the safe zone through planning the operation using First Run Studies. Identify the various boundaries and the appropriate way to work in relation to them, then check the actual method against the plan. Working further upstream, the concept of boundaries and the coping behavior required near them should better inform designers how to reduce accidents through product design.
2. AT THE EDGE: a) Make visible the boundary beyond which work is no longer safe (a hazard can be released) and teach people how to recognize the boundary. b) Teach people how to detect and recover from errors at the edge of control.
3. OVER THE EDGE: Design ways to limit the effect of the hazard once control is lost.

CONCLUSION

We suspect that ‘self inflicted wounds’ are a type of accidents that is resistant to current theory and practice, even best practice. The new strategy offered here recognizes that organizational and individual pressures push people to work ‘near the edge’. Standardizing procedures and enforcing work rules in dynamic work situations is impossible in the face of these pressures. Adopting a new definition of hazard and applying better planning can expand the zone of safety and increase the extent to which tasks are fail-safe. But hazards will remain and so workers need to be trained so they can always answer these questions.

- Where are you—in what zone?
- What is the risk or hazard you now face?
- What can be done to prevent releasing the hazard?
- What can be done to reduce harm should the hazard be released?

We must also adjust the post incident analysis to consider the design of the work system in relation to these concepts. Safety performance and productivity will improve as we learn from accidents how to extend the safe zone.

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LEAN SUPPLY SYSTEMS IN CONSTRUCTION

Roberto Arbulu¹ and Glenn Ballard²

ABSTRACT

This paper proposes a strategy to improve the management of supply systems in construction using lean principles and techniques. The objective is to assure on-time delivery of information and materials to project sites at least cost and maximum value for the final customer. The primary mean for achieving this objective is to accomplish supply management functions with least waste; e.g., low supply and demand reliability, large inventories not needed to absorb variability, and physical waste. The paper explores supply complexity in construction in order to better understand where certain types of waste are originated. The strategy proposes the use of a web-based tool based on the Last Planner System to improve planning reliability so demand variability is minimized, the use of regional logistics centers for distribution of materials to sites, the use of kanban techniques to pull selected materials on a just-in-time basis, and a link between production control and material management processes on site. It also highlights the importance of minimizing material lead times with emphasis on standardization and pre-assembly practices so supply systems are more effective. It concludes highlighting the most important challenges for the implementation of this strategy.

KEY WORDS

Assembly package, inventory, just-in-time, kanban, logistic centers, pre-assembly, supply chain management, value stream.

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INTRODUCTION

In recent years, there have been several efforts to better understand how to manage construction supply chains efficiently and effectively (e.g., Wegelius-Lehtonen 1995, O'Brien 1995, Wegelius-Lehtonen and Pahkala 1998, Naim et. al. 1999, Vrijhoef and Koskela 2000, Arbulu et. al. 2003). Achieving excellence in the management of construction supply chains represents a way of increasing competitive advantage in the market. The reality is that supply chain participants (i.e., owners, contractors, suppliers, etc.) are still in exploration towards a better understanding of what supply chain management is, how they can increase their competitive advantage by applying it, and the dynamics it involves.

Construction practitioners have been witnesses of how the construction industry has been bombarded with so many 'solutions' to the supply chain (this is the way they are being offered) creating confusion amongst supply chain participants regarding if these solutions should be adopted or not and how. A typical example of this is the introduction of standard solutions in the area of information technology. In most cases, solutions are not necessarily tailored to deal with the real problems of our industry leaving important gaps after their implementation (which indeed create opportunities for others to come to the party, and therefore the cycle never ends).

Instead of trying to identify which supply chain solutions should be adopted, practitioners in the construction industry should first get a basic understanding of how supply chains are configured first so a holistic view can be obtained. This is certainly not a task typically performed as part of standard procedures in construction. The use of value stream mapping represents an example of a tool to achieve this (e.g., Arbulu 2002, Arbulu et. al. 2003).

Construction is known as being ruled by schedules. It is not difficult to find management personnel arguing about working under so many pressures to achieve project milestones and not having the luxury of time to see the whole picture! This is, in part, a symptom from a construction industry dominated by extreme specialization within functionally stove-piped organizations. Everything is optimized to meet individual participant's performance objectives but far from optimal and from a systems perspective (e.g., Tommelein et al. 1999, Bashford et al. 2002). The question is: who is looking at the whole?

The management of supply chains is indeed a relatively new topic in the construction industry. Construction supply chains should be well thought-out networks of interrelated processes designed to satisfy end-customer needs (Arbulu et al. 2003). To achieve this, a holistic view needs to be adopted so opportunities for performance improvement at the systems level can be identified. Determining these opportunities will be difficult without understanding the dynamics of the network of interacting activities in the supply chain (system behavior). This paper explores some of these dynamics.

Along with supply chain complexity and dynamics, today's construction projects are known as 'complex, uncertain, and quick' (Shenhar and Laufer 1995). They require the definition, design, and implementation of temporary production systems that incorporate temporary flows of physical resources (e.g., labour, materials, equipment, etc) and information for the on-time completion of project milestones. These flows create what the authors name here as 'supply systems'. A supply chain may contain one or more supply systems.

This paper proposes a strategy to improve the management of supply systems in construction using lean principles and techniques. The objective is to assure on-time delivery of information and materials to project sites at least cost and maximum value for the final customer. The primary mean for achieving this objective is to accomplish supply management functions with least waste. The strategy proposes the use of web-based tool created using principles from the Last Planner System to improve planning reliability and to increase visibility across supply systems so demand variability is minimized. The use of regional logistics centers is considered for consolidation and distribution of materials to sites. The use of logistics centers is certainly not new. Other industries like retailing have incorporated logistic centers as part of their logistic strategies.

This strategy incorporates the use of lean techniques like kanban to pull selected materials on a just-in-time basis from suppliers or logistics centers to site. Linking production control and material management processes on site then become a must to achieve just-in-time deliveries. Finally, this paper highlights the importance of minimizing material lead times with emphasis on standardization and pre-assembly practices so supply systems are more effective. It concludes highlighting the most important challenges for the implementation of the strategy.

DEFINITION OF TERMS

This section is devoted to provide basic definitions for the following terms: supply chain management, supply chain, supply systems, and value stream. Definitions from recognized sources have been adopted. The intention is to bring some clarity to how these concepts differentiate and relate between each other.

SUPPLY CHAIN MANAGEMENT AND SUPPLY CHAIN

Tommelein et. al. (2003) performed an extensive study about supply chain practices in the U.S. construction industry. This study defines Supply Chain Management (SCM) as “the practice of a group of companies and individuals working collaboratively in a network of interrelated processes structured to best satisfy end customer needs while rewarding all members of the chain”. This definition implicitly defines Supply Chain (SC) as a group of companies and individuals working collaborately in a network of interrelated processes.

SUPPLY SYSTEMS

The authors realize that the term supply system has not been extensively used in the construction industry. It may be confused with supply chain but it actually means something different. The authors propose that supply systems are systems that need to be defined, designed, and implemented to deliver effective flows of materials, information, and capital across the supply chain. Supply systems are therefore part of a supply chain, and as such, must be considered as an important part of any supply chain management initiatives.

VALUE STREAM

This paper adopts the definition of value stream provided by Rother and Shook (1998), which states that a value stream is “all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the

production flow from raw material into the arms of the customer, and (2) the design flow from concept to launch”. While supply chain relates to a network of companies working collaboratively, value stream relates to the process across this network.

Other terms that will be used in this paper are: assemble, fabricate, pre-assemble, prefabricate, prefabrication, lead time, and fabricator lead time. These have been defined in depth in Ballard and Arbulu (2004).

TRADITIONAL SUPPLY SYSTEMS IN CONSTRUCTION

The construction industry is dominated by specialization within functions in organizations and great fragmentation (Tommelein et. al 2003). One of these functions is procurement (sometimes known as purchasing). Traditionally, procurement practices in construction focus on obtaining the lowest price possible for each product and associated services (e.g., transportation). Previous studies (e.g., O’Brien 1999, Naim et. al 1999) have highlighted barriers to adopt supply chain management practices in construction. Certainly, one of these barriers is the way commercial deals are managed which determines (almost by default) how supply systems are finally configured. It is not difficult to hear that ‘what happens after the procurement phase is a logistics problem’ due to the lack of focus on achieving continuous flow to deliver the maximum value to the final customer. The conclusion here is that supply systems are not defined and therefore not even designed, they just happen!

Rethinking the role of procurement should be one of the first actions towards a change on how to better deal with supply systems. Procurement teams should take a more proactive role towards a better understanding of supply dynamics and complexity which will make explicit that supply can and should be controlled (people in construction operate as if they cannot control supply). One of the targets should be to control deliveries like site activities. The next section illustrates some basic areas of supply dynamics and complexity.

UNDERSTANDING SUPPLY COMPLEXITY

The application of supply-chain management techniques in manufacturing environments has been widely recognized as a source of important cost savings (e.g., Hopp and Spearman 2000, Arntzen et. al. 1995). The understanding of supply complexity has been a key area for this success.

This section is devoted to illustrate how supply complexity impacts temporary production systems in construction creating waste and potentially affecting on-time project completion. Challenges across the construction industry may vary accordingly with the complexity of each project. However, a challenge shared by all projects is the match between site demand and supply. Any type of variability in both demand and supply will be critical to effective project management and will impact the total production system performance increasing cost and time and reducing quality and safety. Following are three scenarios that demonstrate the interaction between supply and demand and how the influence of variability in both will degrade project performance.

SCENARIO 1: UTOPIA

Variability is omnipresent in any production and supply system. “Variability is closely associated with randomness. Therefore, to understand the causes and effects of variability, one must understand the concept of randomness and the related subject of probability” (Hopp and Spearman 2000). Womack and Jones (1996) define ‘pursue perfection’ as one of the five lean principles. Variability will then block the road towards perfection unless it is minimized. A production system with few signals of variability is closer to perfection. A supply system that includes production systems with minimum variability will therefore be more effective and efficient.

Variability can be understood as the opposite to reliability. The greater the system reliability, the lower the variability present in the system. Scenario 1 assumes that both the reliabilities³ of supply and demand are 100%. It assumes a perfect and unreachable deterministic world (without variability). The end result is that materials and information - important components on any supply system - flow continuously. Figure 1 illustrates this scenario that represents utopia.

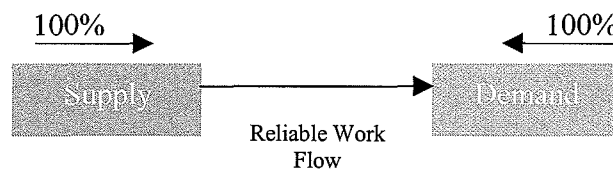


Figure 1: Matching Demand and Supply – Scenario 1

SCENARIO 2: RELIABLE SUPPLY – VARIABLE DEMAND

Independently of the complexity of the supply chain, scenario 2 assumes that suppliers are 100% reliable. Here variability comes in many forms and types, of which demand variability is one, and can be understood for our purpose as changes in requests after commitments have been made (Ballard and Arbulu 2004). One way to express the effect of demand variability is through the Percentage Plan Complete (PPC) that measures workflow reliability. In this scenario, $PPC_{\text{daily}} = 90\%$ (variability=10%). This means that 10% of the activities were not completed as planned. This implies that, if 100% of the activities were planned, the resources to complete those activities were available and ready to use on site. Therefore, 10% of the resources are not used when requested representing waste. The best-case scenario is when these materials can be installed the next day, but experience tells us that this is not always the case. The consequence is clear: materials accumulate on site (sometimes without control). Figure 2 illustrates this scenario with a triangle representing material inventories.

³ Reliability is the measurement of work committed versus work completed for a given period of time.

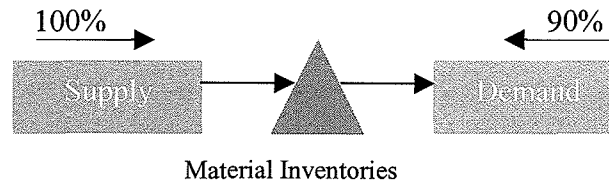


Figure 2: Matching Demand and Supply – Scenario 2

SCENARIO 3: VARIABLE DEMAND AND SUPPLY

In any production system, demand and supply vary. Figure 3 illustrates the details for this scenario with both the reliability of demand and supply less than 100%. The combined effect in this case is that work-in-process (WIP=materials inventories) increases as well as potential delays occur due to an unreliable supply. This increases cost and time (i.e., labour looking for materials not working, cost of managing material inventories) and also reduces quality and safety (i.e., space on site is used to storage materials potentially blocking workflow and risking product quality and safety).

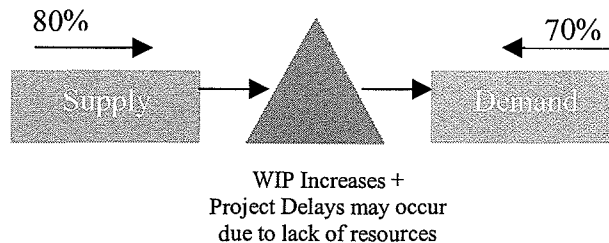


Figure 3: Matching Demand and Supply – Scenario 3

Scenario 3 is closer to reality in construction. However, scenario 3 is oversimplified and it does not take into account, for example, different sources of demand variability and how the complexity of the supply chain (e.g., number of supply systems) will impact cost, time, quality, and safety. Refer to Ballard and Arbulu (2003) for a more comprehensive description of different sources of demand variability.

The next section explore the supply part of scenario 3 in more depth by analyzing the effect of having a complex supply chain (made of several supply systems) in a temporary production system.

THE MATCHING PROBLEM

In *Factory Physics*, Hopp and Spearman (2000) describe the Assembly Operations Law as: “The performance of an assembly operation is degraded by increasing any of the following: (1) number of components being assembled, (2) variability of components arrivals, and (3) lack of coordination between component arrivals”.

In construction, site installation can be seen as series of site assembly operations. Several and simultaneous site assembly operation complicate physical flows in a production system because they involve matching. Processes can't start until all necessary materials are present. The matching problem (Hopp and Spearman 2000) is augmented due to variability on each supply system. The more complex the supply chain (directly proportional to the number of supply systems), the smaller the probability that all materials required to complete a task will arrive to site on a just-in-time basis.

To illustrate this effect, the concept of Merge Bias is used. Merge Bias is a system characteristic that applies when several flows join, and completion of all activities along these flows (e.g., deliveries) is prerequisite to starting the activity that follows (e.g., site installation). The presence of several flows creates a 'matching problem' that constrains the start of the activity that follows. From a supply system perspective, the matching problem then can be understood as the probability of on-time delivery from 'N' supply systems to site and it can be calculated as the product of the probability of on-time delivery for each of the supply systems.

Figure 4 presents a simplified representation of 'N' different supply systems targeting on-time delivery to site. The assumption here is that each supply system includes only one material.

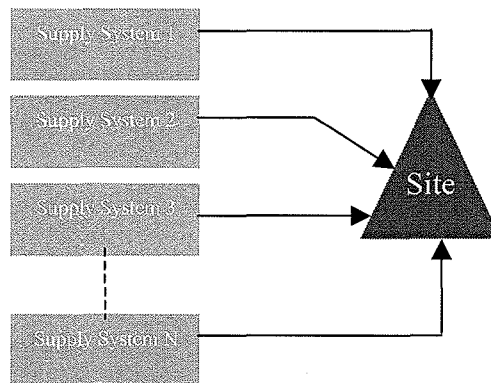


Figure 4: The Matching Problem

For example, if $N=10$ and the probability of on-time delivery for each of the 10 supply systems is 99%, then the probability of on-time delivery for all the 10 components or materials can be calculated as $P_{\text{success}} = 0.99^{10} = 90\%$. This indicates that independently on having a reliable supply (99%/supply system), our chances to succeed decreased to 90% due to the complexity of the supply chain. If the number of supply systems is doubled (20), the $P_{\text{success}} = 0.99^{20} = 82\%$. The bigger the number of supply systems, the lower the probability of success to achieve on-time site deliveries. Table 1 analyzes different scenarios up to 20 supply systems assuming equal probabilities of on-time delivery for each system as 99%, 95%, 90%, and 75%. Figure 5 then presents the results graphically.

From Figure 5, it can be concluded that a combination of low reliability of supply and a complex supply chain (e.g., high number of supply systems) work together as a constraint to achieve on-time deliveries. If the reliability of supply is 75% and the supply chain has more than 10 different supply systems, the probability of success is close to zero.

The reader may be thinking that if this is really true, how is supply being done so projects can be completed on time? Firstly, the matching problem is a real problem. Secondly, the authors believe that few people in the construction industry are aware of the matching problem. However, intuitively, decisions are made to solve it by accumulating large buffers of finished products (sometimes more than 2 weeks of work) close to the matching point on site to reduce the probability of supply failure. Ironically, the industry then has been solving the matching problem by creating considerable amounts of waste. This has important consequences in project performance because (1) time and cost will increase due to labour looking for materials not working, and management creating teams to manage the logistics of the inventories, and (2) quality and safety will be reduced due to damage of stored materials, and stored materials being at risk of design revisions and programme changes especially if design decisions are made at the Last Responsible Moment.

# of SS*	P _{success}			
	99%	95%	90%	75%
1	99%	95%	90%	75%
2	98%	90%	81%	56%
3	97%	86%	73%	42%
4	96%	81%	66%	32%
5	95%	77%	59%	24%
6	94%	74%	53%	18%
7	93%	70%	48%	13%
8	92%	66%	43%	10%
9	91%	63%	39%	8%
10	90%	60%	35%	6%
11	90%	57%	31%	4%
12	89%	54%	28%	3%
13	88%	51%	25%	2%
14	87%	49%	23%	2%
15	86%	46%	21%	1%
16	85%	44%	19%	1%
17	84%	42%	17%	1%
18	83%	40%	15%	1%
19	83%	38%	14%	0%
20	82%	36%	12%	0%

(*) SS= Supply Systems

Table 1: Probabilities of On-time Deliveries

Certainly, one of the solutions to the matching problem is to have a buffer of materials (or finished products) on site that absorbs the effect of supply variability and supply chain complexity, but the real question is: how big should this buffer be? Minimizing the size of this buffer is part of the discussion presented in the following section.

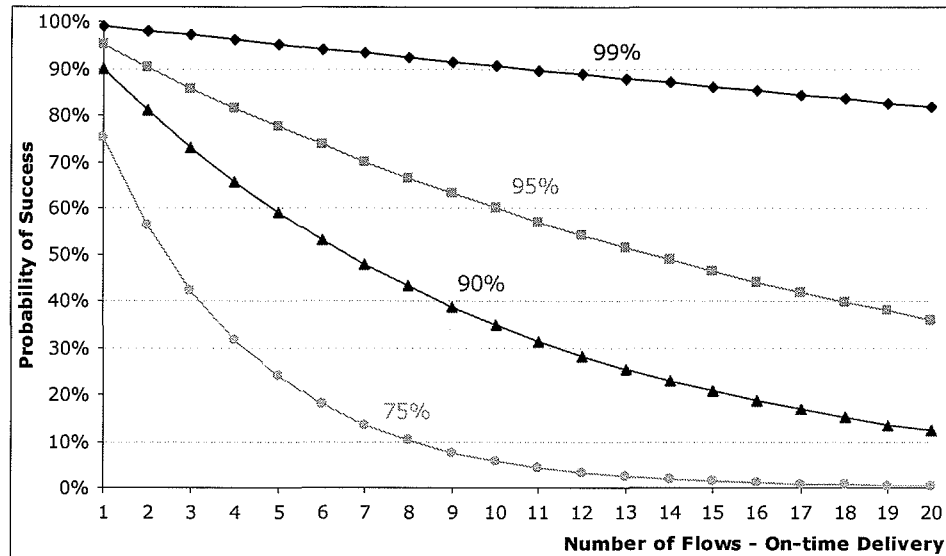


Figure 5: Graphical Representation - Probabilities of On-time Deliveries

THE STRATEGY: LEAN SUPPLY SYSTEMS

DEFINITION AND SCOPE

So far, the paper has illustrated some of the problem dynamics involved in supply systems and how the construction industry has been providing a solution far from optimal (an intuitive solution). The proposed strategy takes into account these dynamics focusing on achieving on-time delivery of information and materials to project sites at least cost and maximum value for the customer. The primary goals are to (1) simplify the configuration of construction supply systems, (2) to reduce variability embedded on those systems (including variability coming from site), and (3) to improve visibility across supply systems.

DESCRIPTION

This strategy proposes the implementation of the following:

1. Use of a web-based tool designed based on the Last Planner System (LPS) to control production on site on a daily basis increasing workflow reliability, therefore reducing demand variability. This tool should not replace planning, forecasting, and scheduling, but rather works in conjunction with them. Working with weekly production plans will not necessarily deliver the value expected to achieve just-in-time deliveries. Planning tools such as process mapping and scheduling are still required to properly manage workflow.

2. Link the web-based production control tool with the material management process. This way, engineered-to-order⁴ and made-to-order products can be pulled from suppliers. This will also trigger the delivery of materials to Logistic Centres. This is better explained as follows.
3. Use Logistics Centers (LCs) as part of the definition and design of supply systems. A LC is defined here as a permanent consolidation point, where materials from different supply systems are assembled in packages before they are delivered to project sites. LCs can be seen as decoupling points in supply systems. Naim et. al. 1999 further discusses the use of decoupling points through an application to the UK housebuilding industry. It is suggested that LCs are located within a radius defined by 1/2 day's delivery duration. If this cannot be accomplished, special considerations need to be taken when designing the supply systems to avoid delays in transportation to site.
4. Kit today (at LCs) all information and materials in assembly packages for site installation tomorrow. The information required for kitting is sent via the web-based tool to LCs. The size of the buffer required to absorb variability is proposed as 1 day. This means that assembly packages should contain the materials required to complete 1 day of work for a specific task on site. The concept of single-piece-flow is applied here considering 1 day as the single piece.
5. Deliver assembly packages based on pull from site. The use of a web-based production control tool will provide the mechanisms and signals to trigger deliveries from LCs to site. This way the assembly packages will not be pushed to site without explicit request from site based on daily production plans. Waste in the system will be reduced and the use of space can be better controlled.
6. Define, design, and implement supply systems focused on replenishing selected made-to-stock materials using milk runs and kanban techniques. Arbulu et. al. 2003 proposes a strategy to implement this type of supply system. Wegelius-Lehtonen and Pahkala (1998) introduces standard materials (or made-to-stock) as a type of logistics chains in construction.
7. Define, design, and implement standardization and pre-assembly strategies. Pre-assembly can be performed at LCs or at suppliers' facilities as appropriate. Pre-assembly reduces the number of flows going directly to site therefore reducing the effect of the matching problem. Sometimes the matching problem can be moved upstream in the supply chain, but in that case, the scope is reduced (e.g., only materials required to assemble a package) and the environment can be more controlled than on site.

⁴ Construction deals with three general types of products: (a) Made-to-stock (e.g., consumables), (b) Made-to-order (e.g., standard materials from catalogs that require an order to be fabricated), and (c) Engineered-to-order (e.g., reinforcement – design information is required to start fabrication). Made-to-order and engineered-to-order products usually have long lead times.

8. Minimize material lead times and inventories not needed to absorb variability. Zabelle and Ballard (1999) highlight the importance of achieving a window of reliability greater than fabricator lead times by improving plan reliability and reducing lead time for supply. Lead times that exceed a site's window of reliability increase the probability of untimely delivery. A long lead time is determined relative to the ability of the customer (the construction site) to accurately forecast future states of the building process on site, and thus the ability to determine when a component will be required for installation. Ballard and Arbulu (2004) also discuss the drivers of prefabrication lead times.

From a supply chain perspective, a short lead time has the following advantages over a long lead time (after Koskela 2000 p. 60): (1) faster delivery of the product or service to the customer, (2) reduced need to accurately forecast future demand, (3) less opportunity for disruption in the supply chain due to (design) changes, (4) greater possibility that participants will interact in a timely fashion with other supply chain participants, (5) easier synchronization of one supply chain with others (e.g., merging supply chains at the site), and (6) less opportunity for products to become obsolete.

This strategy is probably better suited for adoption by general contractors. This will require that contractors move from a single-project to a multi-project view as shown in Figure 6. Owners may also adopt the proposed strategy for a single project according with its magnitude. In this case, the boxes depicting projects in Figure 6 would represent sub-projects.

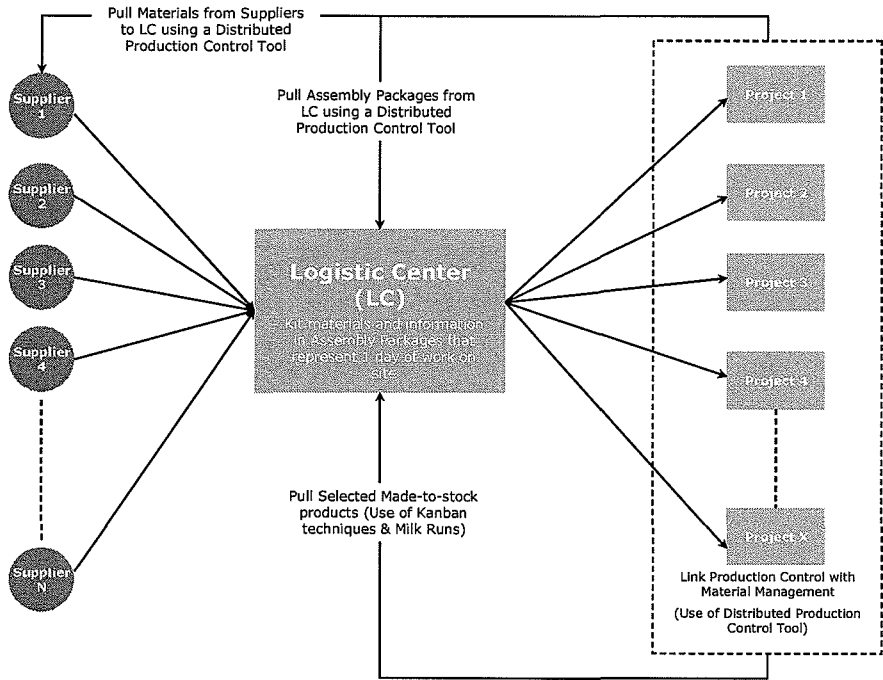


Figure 6: Lean Supply Systems Strategy

CONCLUSIONS

This paper has illustrated that the combination of variability in demand and supply will directly impact project performance increasing cost and time and reducing quality and safety. The proposed strategy targets the reduction of demand variability by stabilizing workflow on site. It also presented a way of reducing materials inventories on site by implementing pull techniques (i.e., use of kanban, pull assembly packages). It proposes the combination of the use of Logistics Centres and a distributed (web-based) production control tool that increases visibility across supply chains as well as provides better forecast information (live).

Successful implementation of this strategy will require a holistic view that includes not only a supply chain view but also a multi-project view. It is important to keep in mind that because of competitors' pressures, it is no longer sufficient to be the best. Companies must look for different and new ways to manage projects and for new techniques and tools to improve the reliability of supply and demand. The lean philosophy must be applied consistently to maximise the elimination of waste and increase workflow across the value stream. The conditions to achieve workflow should be set early in the process. Procurement should focus on sole sourcing and the creation of different supplier selection criteria including capabilities and culture (go beyond just lowest cost possible). A shift is required from purchasing thinking to system thinking. The lowest cost for each step in the value stream will not guarantee the lowest cost for the whole value stream! To adopt this view, this strategy requires the creation of a different environment where owners, construction companies, and material suppliers do business based on mutual trust and respect. Strategic relationships are therefore pre-requisites to extending lean concepts to supply systems and supply chains.

This strategy is being implemented in the construction of a major international transportation hub in the U.K. The authors will publish complementary papers to further detail the results of this implementation as well as different material management strategies within supply systems.

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IN SEARCH OF LEAN SUPPLIERS – REPORTING ON FIRST STEPS IN SUPPLIER DEVELOPMENT

Jan A. Elfving¹ and Glenn Ballard²

ABSTRACT

This paper reports some early findings related to supplier development: the result of prequalification, performance evaluation and supplier development from 5 pilot regions in 3 countries. It is a follow-up to an IGLC paper presented in 2011. Supplier development can be seen as a third option when make or buy options do not lead to desired results. It seems to be a little used option in the construction industry. This paper reveals that, at least in the pilot regions, supplier development needs to start from very basic things such as helping to fulfil legal and company requirements, and setting standards for measuring quality and delivery reliability. Over half of the supplier base does not fulfil the basic requirements. When suppliers do measure quality and delivery, measurements often do not capture issues important to their customers, the projects. The findings have resulted in re-defining supplier segments, presented in this paper along with next steps in supplier development.

KEYWORDS

Lean, supplier, supply chain management, preferred supplier program.

INTRODUCTION

Confronted with inadequate supply of goods or services, a buyer has three choices: 1) change to a more capable supplier, 2) provide the goods or services internally, or 3) develop the supplier's capability (Handfield, et al., 2000). This third option lies between hierarchies and markets, between make and buy. This third option has rarely been chosen in the construction industry, and, when chosen, incompletely implemented. Examples to date have not gone beyond pricing agreements or supplier evaluation.

There has not yet been a satisfactory answer to the question 'Why should the construction industry embrace supplier development?' We explore this question, principally through sharing details of an approach to supplier development currently being implemented by Skanska, led by its Nordic Procurement Unit. The case illustrates how a construction company has adapted supplier development to industry peculiarities.

This paper is a follow-up to Elfving & Ballard (2011), which presented the concept of the preferred supplier program, now tested in real life and refined. We have been testing both prequalification and performance evaluation. In supplier development proper, the focus has been on quality and delivery reliability. We

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actually started already 2005 with standardizing production management then moved to logistics (Elfving et. al 2010), and this is the third phase, the suppliers. The paper starts with a short literature review, then presents the structure of the preferred supplier program, followed by results and finally conclusions and next steps.

WHAT IS SUPPLIER DEVELOPMENT?

According to Handfield, et al. (2000) supplier development is “...any activity that a buyer undertakes to improve a supplier’s performance and/or capabilities to meet the buyer’s short-term or long-term supply needs.” Evaluation, incentives, competition, and consulting are among the means used to develop suppliers.

Supplier development belongs to supply chain management, which also includes procurement, the design and operation of supply chains, and logistics. With a few exceptions (O’Brien, et al., 2008; Gil & Beckman, 2010; Basu, 2011; Elfving & Ballard, 2011), the literature on supply chain management in general and supplier development in particular has neglected the construction industry (Johnsen, 2011). The construction industry has returned the favor by virtually ignoring supply chain management.

Speaking about industry as a whole, Ketchen & Giunipero said nine years ago: “The intersection of strategic management and supply chains offers implications for managers. To the extent that competition is ‘supply chain versus supply chain,’ a new way of thinking is necessary. This thinking seems to be at an embryonic stage today.” (p.55, Ketchen & Giunipero, 2004). Is it true in the construction industry that competition is ‘supply chain versus supply chain’? Consider large international companies such as Skanska and others among the largest 500 construction contractors in the world (ENR, 2013). You can be sure that every one of them has ambitious goals—for increased profitability, for growth, for zero accidents, zero defects, zero environmental damage. Is it even conceivable that such goals could be achieved without improving the suppliers to those companies?

STRUCTURE OF THE PREFERRED SUPPLIER PROGRAM

3 years ago the company began developing a preferred supplier program in order to systematically improve the supplier base. The program includes both goods and services suppliers. The preferred supplier program has four goals:

- Reduce risk
- Consolidate the supplier base
- Incentivize suppliers to work better
- Improve performance

The starting point and foundation of the program is to ensure that the company is working only with legal and financially sound suppliers. The general conception about the construction industry in the Nordic countries is that there is a very large grey market, which our pre-study confirmed. We want to rate suppliers based on their performance (not only price) and treat suppliers differently depending on their performance. We want to expand work with well functioning suppliers and reduce or cancel work with non-functioning suppliers. Finally, we want to help suppliers to

develop further, where baselines are defined based on actual project performance, and where long-term relationships with selected suppliers are developed not only with high strategic importance but also with based on performance.

There are four pieces in the program, pre-qualification, on-site performance evaluation, performance measurement, and supplier development. The aim of pre-qualification is mainly risk management, to secure that suppliers fulfil legal and company specific requirements before request for quotation documents are sent. We use a self-evaluation with around 80 questions about basic company information, safety, environment, quality, ethics and risks (www.skanska.se/leverantorer).

The aim of the on-site performance evaluation is to reduce cost by assessing supplier and Skanska project performance. The evaluation is conducted by project personnel and consists of eight parts; time, quality, cost, safety, environment, complaints handling, co-operation, and development (Figure 1).

The aim of supplier development is to improve performance. We have three types of supplier development. The first one is to make wanted suppliers fulfil legal and company requirements. The second level is to improve framework suppliers' quality and delivery precision. The third level is to work with innovations. For framework material suppliers, monthly performance measurement on quality and delivery precision is requested. At this time, nearly all effort is on the two first types of supplier development.

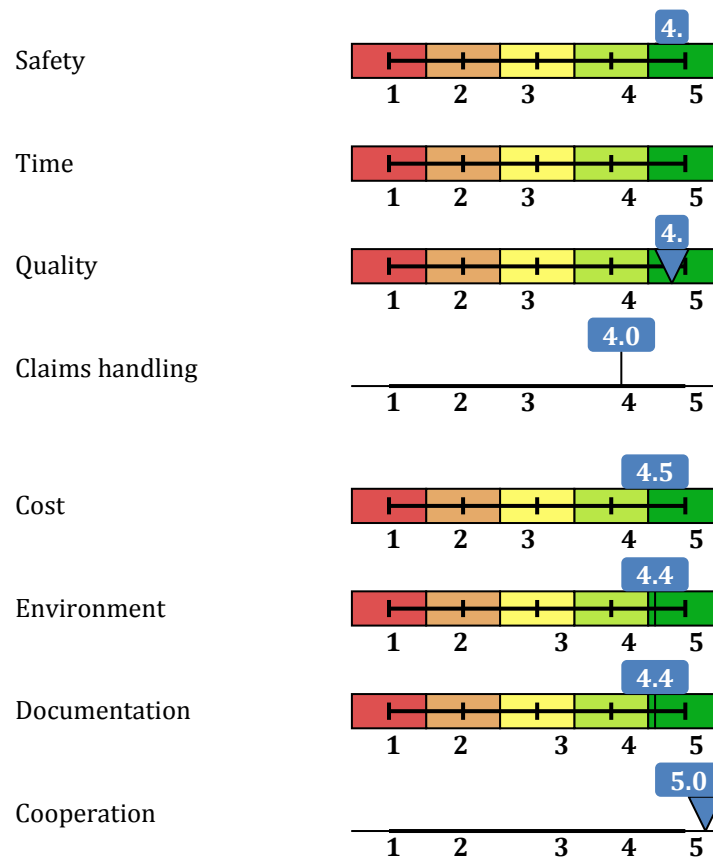


Figure 1: Example of supplier evaluation

Suppliers are classified on four levels, potential, registered, approved, and preferred (Figure 2). If a supplier has completed the prequalification questionnaire, regardless if it does not meet legal (red supplier) or company requirements (yellow supplier), it is classified as registered. If a supplier meets both legal and Skanska requirements it is a green supplier. But in order to be an approved supplier, it needs to be both green and have an average performance score of 3 or more (scale 1-5). Framework suppliers need, in addition, to provide performance measurement data. In order to be preferred, supplier performance evaluation data needs to be among top 30% of all suppliers and framework suppliers have to show a trend in improved performance.

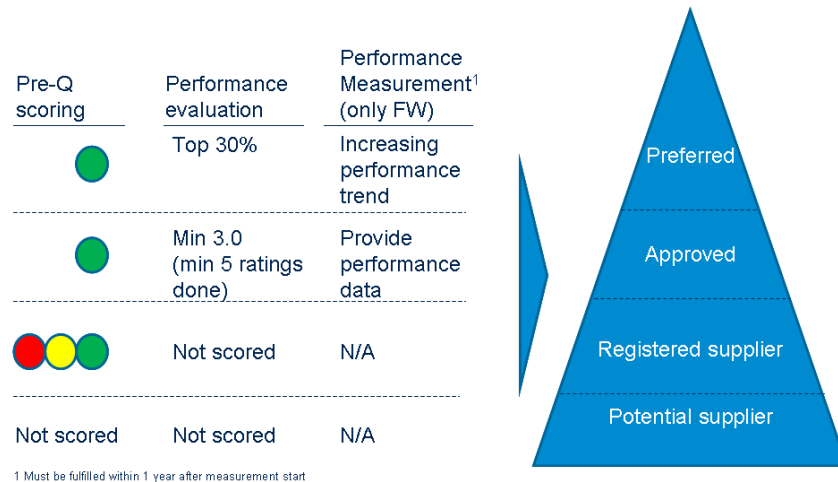


Figure 2: Supplier segmentation

FINDINGS

THE CASE COMPANY AND SCOPE

Skanska is an international development and construction company headquartered in Stockholm, and active in a variety of sectors, including residential and commercial buildings, civil infrastructure, and the processing industries. Skanska has operations in Europe, South America, and North America. In the latest ENR ranking of construction companies, Skanska was the 7th largest in the US by revenue. This paper focuses on the Nordic countries, where Skanska is the largest measured by revenue. In the Nordics, there are 50 operating regions with around 4000 construction projects ranging from less than 100,000€ to up to several billion €. The annual purchasing spend is about 5,4 billion € with 50,000 active suppliers of goods and services.

PREQUALIFICATION

In the first phase of development, we prequalified around 1500 material and service suppliers in 5 regions; 1 in Norway, 2 in Finland and 2 in Sweden. The legal requirements are quite the same in all three countries, with some slight differences in certificates and employment terms and conditions. We knew based on ad hoc audits that the compliance to legal and company requirements is low but were surprised to find that over half of suppliers who completed prequalification forms did not fulfill these requirements (Figure 3).

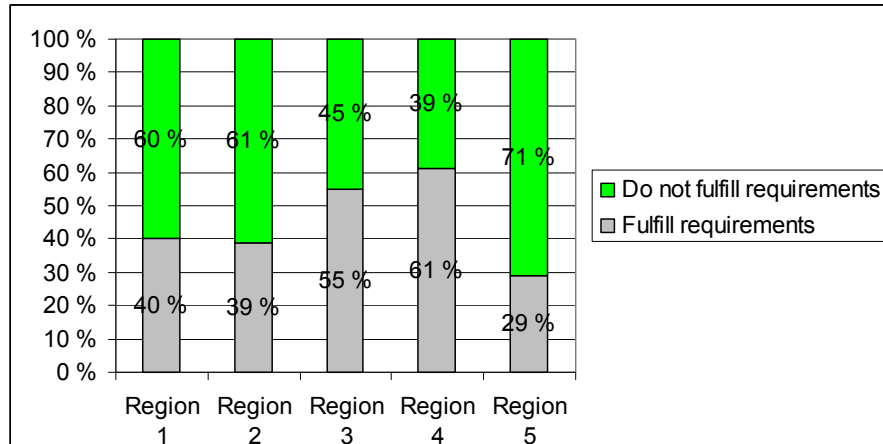


Figure 3: Results from prequalification.

The main reason, nearly 70%, for not fulfilling legal requirements was missing safety documents, but the range was very large; some even lacked a business license. Safety and electronic invoicing were the primary non-compliance issues for company requirements. We could not identify any major difference between material and service suppliers, but did find a large difference between framework (long-term contract) and spot (short term contract) suppliers. With few exceptions, the framework supplier met all legal requirements. About 10% of framework suppliers did not meet Skanska requirements, significantly better than non-framework suppliers of goods.

With a ‘quick fix’, contacting the suppliers and explaining the situation and how to fix it, we were able to reduce the number of suppliers that do not fulfill requirements by 10-50% depending on the region. Those remaining require more support or in worst case the suppliers become blacklisted.

The main support provided suppliers is explanations of requirements and forms they need to complete. In fact, it is fairly complicated to keep track about all the requirements and the updates in them. 55% of our suppliers have less than 50 employees, which means that it is rare that there are fulltime dedicated support people for safety, environment, quality, and legal issues. In Finland, we also open our in-house online safety training for selected suppliers. The training will include more than 25 modules by the end of 2013.

PERFORMANCE EVALUATION

Evaluation of performance occurs after completion of work on a project, and involves both the project evaluating suppliers and the suppliers evaluating the project and Skanska. Projects’ average rating of supplier performance was quite high, even when there had been a lot of problems with those suppliers during project execution. For example, in one case, a supplier had to change all window fittings, causing major disturbance for the project and still the supplier got a 3.76 rating (1 to 5 scale, with 5 highest). This shows that the projects are accustomed to poor performance and find it acceptable that problems are solved through rework rather than avoided.

On average suppliers scored best on timeliness (4.01) and worst on safety (3.49). One reason for the low safety scoring and high timeliness scoring may be Skanska’s

strong focus on safety. Safety demands are much higher than for the other criteria. In timeliness, the accuracy is rarely by hour, rather by day or by week.

Framework suppliers appear to score lower in project evaluations than spot suppliers. It may be because they have little incentive to do otherwise, with contract in hand. Perhaps also framework suppliers get more muted feedback from project customers. Framework suppliers' feedback depends mostly on the purchaser in central procurement, who again has to rely on the project crew for the feedback. In many cases one of the parties forgets or neglects to relay the feedback, or it comes far too late. Also, it may happen that the project purchaser does not participate in the selection of framework suppliers, and thus may not favor them.

PERFORMANCE MEASUREMENT

In this report, we focus on the data from 25 material suppliers in the interior portfolio. The interior portfolio means all the suppliers that deliver and service the interior phase of a building excluding mechanical, electrical and plumbing suppliers. The focus is on delivery precision and quality. Of the 25 suppliers, which are large national or multinational companies, only three had good data available for both delivery precision and quality. About half (12/25) of the suppliers did not have data about delivery precision or quality when we made the initial request (Table).

In general, the suppliers reacted positively to the request. No general contractor had previously requested systematic performance measurement data, which also explains why many of the suppliers did not measure it. On the other hand, it also shows the immaturity of the industry. It is difficult to demand reliability and quality, not to say improvement, if the supplier does not even measure it for themselves.

Table 1: Performance measurement capability from the sample suppliers

Supplier	Can report delivery performance	Can report quality deviations
Supplier 1	No system in place	No data/info available
Supplier 2	No system in place	No system in place
Supplier 3	Good data quality	No data/info available
Supplier 4	Good data quality	No data/info available
Supplier 5	Poor data quality	No system in place
Supplier 6	Acceptable data quality	Acceptable data quality
Supplier 7	No system in place	Acceptable data quality
Supplier 8	Good data quality	Acceptable data quality
Supplier 9	Good data quality	Acceptable data quality
Supplier 10	Acceptable data quality	No system in place
Supplier 11	No data/info available	No data/info available
Supplier 12	No data/info available	No data/info available
Supplier 13	Good data quality	Acceptable data quality
Supplier 14	Good data quality	No data/info available
Supplier 15	Good data quality	Good data quality
Supplier 16	No data/info available	No data/info available
Supplier 17	Good data quality	Good data quality
Supplier 18	No system in place	Poor data quality
Supplier 19	Good data quality	No data/info available
Supplier 20	No data/info available	No data/info available
Supplier 21	No data/info available	No data/info available
Supplier 22	No data/info available	No data/info available
Supplier 23	Good data quality	Good data quality
Supplier 24	Good data quality	Poor data quality
Supplier 25	No data/info available	No data/info available

The good news: once we requested delivery precision and quality reports be sent in monthly by the supplier, and followed-up to see if they complied, we saw improvement.

Figure 4 shows that delivery precision has increased in the last six months from around 80% to nearly 95%. There is a large variation among suppliers and many low performing suppliers are submitting data only sporadically.

Interestingly both of these variations have significantly reduced over time. It seems that when there is competition between the suppliers, just measuring performance improves performance. The challenge is when there is no competition and the supplier has a monopoly, then there is little incentive for the suppliers to measure, send in the data, and improve. In Nordic countries, many of the large material suppliers have a monopoly or near monopoly. Locally many service suppliers have a near monopoly, particularly in certain special trades such as ceiling and balcony glazing. Unfortunately, some of these suppliers have stopped sending in performance measurement reports when they have seen a negative trend in their performance.

Next, we will try to put performance measurement demands in the contract language. One needs to be careful when it comes to a legal and binding document. Some suppliers may become shortsighted and report ‘too good numbers’. This requires very close follow-up and dialog with projects to triangulate the supplier performance data. The majority of the suppliers still think it is very good to demand the performance data, it gives them a clear signal what to do and they believe they can improve and be better than their competitors.

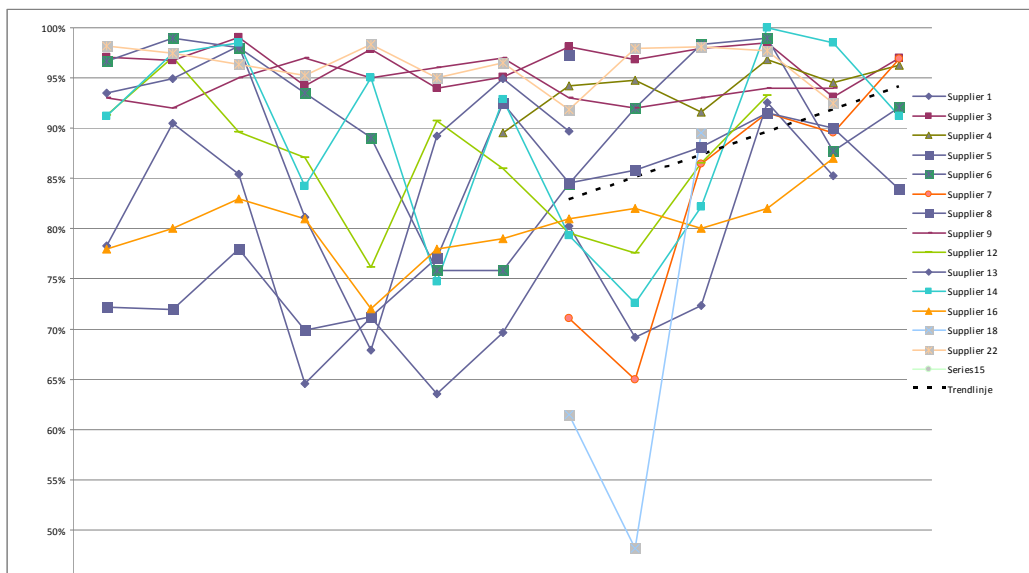


Figure 4: Supplier performance measurement data form 6 month period

Another interesting thing is that in most cases high performance measurement scores tend to correlate with high project evaluation scores. There are some exceptions, which indicates that supplier and project expectations are not aligned. This alignment

is one of the basic lean principles that needs to be in place in order to generate value for customers (Womack & Jones 1996).

CONCLUSION AND NEXT STEPS

Supplier development can be seen as a third option when make or buy options do not lead to desired results. In the Nordic construction industry, it seems that supplier development is a very little-used option. The construction industry seems to be quite far from many other industries that work with supplier development, where the focus is on capability development and joint innovation. The suppliers struggle with fulfilling legal and very basic company requirements, such as e-invoicing and measuring safety, quality and delivery precision performance. Also on the buyer side, there is a gap in competence in using other criteria than price as selection criteria. The more variables there are to compare and choose from, the more complex the selection becomes. However, there is a huge opportunity to get rapid improvement with fairly small effort. In one of the regions, after a phone call and an email, 80% of suppliers who initially did not meet the legal requirement did so within 2 months. Just measuring supplier performance, delivery reliability went up in 6 months from 80% to 95%. Our experience suggests that the place to start is making sure that basic things are fulfilled, that suppliers know projects' expectations, that buyers and suppliers track and act on performance measurements such as safety, quality and delivery precision. Once that foundation is in place, then more proactive supplier development can be launched. When there is a good routine and steady progress in the basics, then capability development and joint innovation have the proper prerequisites.

The next steps in development and deployment of the Preferred Supplier Program are:

- Rolling out the program to all remaining regions and business lines
- Control
- Improvement

This paper reported the rollout of prequalification and performance evaluation in 5 regions. Since the paper has been written, the number of roll-out regions has almost doubled and a systematic rollout for the remaining regions will take place in the next 18 months. We will also extend the performance measurement and supplier development to more suppliers. By control we mean that in those regions where roll-out has taken place, we make sure that the practice gets permanently rooted. By improvement we mean that for both framework suppliers that are managed centrally and for spot suppliers that are managed regionally, we develop methods and capabilities for continuous improvement of the supplier base; e.g., supplier associations. The authors will report in future papers about the findings from these further actions.

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