FRAMEWORK TO LINK LEAN SIMULATION PRINCIPLES AND THEIR MANIFESTATION ON CONSTRUCTION PROJECTS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2016

Major Subject: Construction Management

ABSTRACT

Simulations and lean project case studies have appeared in academic publications for over two decades. Yet novices to Lean Construction have expressed frustration over an inability to make mental connections between the principles illustrated by simulations and potential applications of those principles on actual construction projects. The question this paper seeks to address is: can the principles illustrated by Lean simulations be systematically linked to manifestations of those principles on actual projects? The purpose of this research has been to ease the transition between theory and practice by aggregating published case studies as well as lean simulations and making links between them.

The research method adopted for this study included: (1) preparing a systematic literature review sourced from LCI and IGLC databases; (2) working with the Lean Construction Institute to develop an understanding of the history of Lean simulations; (3) constructing an inventory of existing lean simulations and the principles they illustrate; (4) analyzing published case studies and simulations for the lean principles they embody; and (5) developing a matrix/framework to establish logic connections between simulations and case studies of actual projects. Findings were assembled onto a Simulation/Case-study matrix.

This research involved locating, translating, and organizing 23 years of published, organically developed, construction case studies from IGLC and LCI databases. Therefore, one limitation of this research is that it included only those simulations and case studies that had been published. One implication and value of this research is that it offers a framework to assist lean educators and facilitators when teaching Lean

Construction. This framework can also serve as a “seed” for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

DEDICATION

I dedicate my thesis work to the most important people in my life

Mr. Neeraj Kumar Gupta

Dr. Shubhra Garg

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor Dr. Zofia Rybkowski for the continuous support of my graduate study and related research, for her patience, motivation, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my graduate studies.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. José L. Fernández-Solís, Prof. Rodney Hill, and Prof. Joe Horlen for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

My sincere thanks also goes to Mr. Dan Heinemeier, Mr. Bill Seed and Ms. Cynthia Tsao who provided me an opportunity to join their team at Lean Construction Institute as an intern, and who gave access to the Knowledge Transfer Laboratory at Lean Construction Institute. Without their precious support it would not be possible to conduct this research.

Last but not the least, I would like to thank my parents for supporting me spiritually throughout writing this thesis and my life in general.

ABBREVIATIONS

CD – Construction Document

GC – General contractor

IGLC – International Group of Lean Construction

IPD – Integrated project delivery

LCI – Lean Construction Institute

LCJ – Lean Construction Journal

LC – Lean Construction

LPS – Last Planner System

MEP – Mechanical, Electrical, and Plumbing

PO – Purchase order

PPC – Percent planned complete

RFP – Request for proposal

5S – Sort, Set in order, Shine, Standardize, Sustain

SD – Schematic Design

TVD – Target value design

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CHAPTER I

INTRODUCTION

1.1 Purpose of the study

Simulations and lean project case studies have appeared in academic publications for over two decades. Yet novices to Lean Construction have expressed frustration over an inability to make mental connections between the principles illustrated by lean simulations and potential applications of those principles on actual construction projects. The purpose of this research is to ease the transition between theory and practice by aggregating published case studies as well as lean simulations and making links between them.

1.2 Background

Nofera et al. (2015) concluded that inadequate research has been conducted on Lean Construction (LC) teaching in existing literature published at the International Group for Lean Construction (IGLC) conference and Lean Construction Journal (LCJ). The existence of numerous theoretical interpretations of Lean Construction (LC) can be an important factor for the inadequate documentation on Lean Construction (LC) teaching in the published literature (Tsao et al. 2012).

To facilitate a holistic implementation of Lean concepts on construction projects, it is important to develop a unique learning process based on feedback from academia and industry practitioners (Hirota and Formoso. 1998). This learning process can serve as a platform to enable participants to understand and comprehend Lean Construction principles such as

Kaizen, Kanban, Pull Planning and approaches such as Target Value Design and The Last Planner system of production (Hirota and Formoso. 1998).

A typical course of Lean Construction requires accumulation of diverse database of publications that can facilitate a broad understanding of its application to construction contracts, design and office activities, field operations and supply chain relationships of capital projects (Tsao et al. 2012).

There is a gradual shift from traditional course delivery methods that primarily emphasized on textbooks as lean educators are evaluating other interactive approaches that encourage analytical thinking and discussion among educators and students (Tsao et al. 2013). A simulated environment is a better learning approach in analyzing decisions and their effects on a process because it is easier to understand the functionality of an actual system under real-time conditions (Caňizares and Faur.1997; Walters et al.1997). Similarly, Hamzeh used several in-class simulation exercises such as Airplane game, Magic Stick game, Parade of Trades, Red-Bead game, and Silent Squares among his students to facilitate a concrete understanding of lean concepts and their application to construction sites (Tsao et al. 2013).

Izquierdo et.al (2011) recommended that the development of real case studies is an ideal approach to impart knowledge about Lean Construction (LC) after analyzing feedback from a Basic Management Functions Workshop (BMFW).This workshop was developed to train construction industry employees in application of LC principles such as maximize value and minimize waste for their clients.

CHAPTER II

RESEARCH GOAL AND OBJECTIVE

Learning benefits achieved through Lean simulation cannot be found in textbooks (Rybkowski et al.2008). The objective of this research is to offer a framework to assist lean educators and facilitators when teaching Lean Construction. This matrix can also serve as a “seed” for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

Although there are numerous published case study articles describing productivity gains gleaned from lean methods implemented on construction sites, novices still express frustration about their inability to connect principles illustrated by lean simulations to their actual applications in construction. This research focuses on some of the simulations determined in part, by a recent Lean Construction Institute study conducted by the Knowledge transfer learning laboratory team from May 18-21 in Dallas, TX. The lean simulations determined from this study were published in August 2015 on the Lean Construction Institute website as a matrix titled “LCI Lean Simulation Matrix”. The simulations determined by this matrix illustrates critical aspects of lean processes that are applicable to the construction industry. Clarifying lessons illustrated by these fundamental lean simulations is an important first step in supporting the research question: Can the principles illustrated by Lean simulations be systematically linked to manifestations of those principles on actual construction projects?

CHAPTER III

LITERATURE REVIEW

3.1 Prior work on the problem

Structured literature reviews indicate that implementation of lean principles on a construction site are often incomplete or incorrect because the workers do not have a comprehensive understanding of lean construction and are therefore hesitant to apply lean methods and tools (Heyl. 2015).

Although several books such as *Modern Construction: Lean Project Delivery and Integrated Practices* (Forbes and Ahmed. 2010), *Factory Physics* (Hopp and Spearman. 2011), *The Toyota way* (Liker. 2005), *Toyota Production System: Beyond Large-Scale Production* (Ohno. 1988) have been published but not a single source exists that conveys a definitive interpretation of how to implement lean principles on a construction site (Tsao et al. 2012).

3.2 Need for the development of a teaching matrix tool

Successful implementation of Lean Construction (LC) requires a determined approach and committed project participants (Heyl. 2015; Hirota and Formoso. 1998). Some researchers identified inadequate technical skills and training as a major barrier towards effective implementation of Lean Construction (Sarhan and Fox. 2013; Bashir et al. 2010). Figure 1 illustrates inadequate knowledge of lean construction among project stakeholders as a major challenge selected by 39% to 43% of lean practitioners (McGraw Hill Construction. 2013).

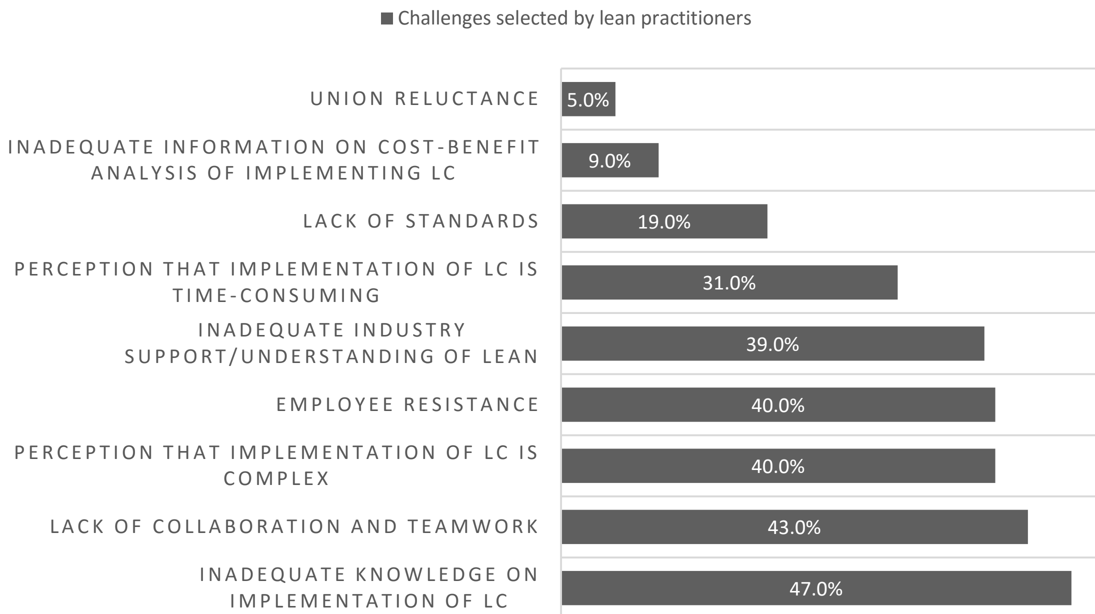


Figure 1: Major challenges encountered in the application of Lean approach on construction sites (according to Lean practitioners). Adapted from McGraw Hill Construction (2013, page 39).

Lean et al. (2006) identified the appropriateness of teaching methodologies and resources essential for the development and presentation of a particular teaching methodology. Lean et al. (2006) also identified the risks associated with using a pioneering teaching methodology as the major obstacles in imparting knowledge through simulation games.

Suitability of a teaching platform is essential in ensuring that the learning outcomes of a particular simulation are directed towards achieving the anticipated results and to ascertain its applicability in improving either skills or knowledge (Ellington. 2001). Wildman and Reeves (1997) stated that a simulation can keep a participant busy but not impart any knowledge. Rolfe (1991) states that the effectiveness of a simulation as an appropriate teaching methodology depends on the applicability of its associated learning outcomes to a real-time scenario. Analyzing the appropriateness of a methodology is essential before using a simulation as a teaching tool because its effectiveness depends on the applicability of its learning outcomes to a real-time scenario (Ashwin and Pitts. 2007). Teaching complex concepts such as Lean philosophy to students/employees that have no experience with Lean, is quite a challenging undertaking. When teaching students using lean simulations, it is imperative to develop a creative context so that they can observe and understand the importance and inner workings of Lean philosophy. However, when teaching employees/practitioners, it is also important to translate Lean thinking into an applied context using case study analysis so the lessons become relevant to those working in the construction industry.

3.3 Significance of this study and its original contribution

This research represents an important first step in systematically connecting principles of Lean game simulations to their practical implementation on construction sites. Most importantly, this research can assist lean educators, to make memorable (simple and clear) links between the lean principles illustrated by simulations and their actual implementation on construction sites, thereby also benefiting practicing construction professionals, architects, and designers.

CHAPTER IV

RESEARCH METHODOLOGY

4.1 Methodology

This research analyzed each lean simulation and its associated principles in terms of its influence on the performance of construction projects. Based on the outcomes of this analysis, a "Simulation/Case-study matrix" has been developed to quantify the effects of lean implementation.

This "Simulation/Case-study matrix" focused on some of the simulations determined in part, by a recent Lean Construction Institute study conducted by the Knowledge transfer team from May 18-21 in Dallas, TX. The lean simulations determined from this study were published in August 2015 on the Lean Construction Institute website as a matrix titled "LCI Simulation Matrix". The simulations determined by "LCI Simulation Matrix" illustrates critical aspects of lean processes that are applicable to the construction industry. "Simulation/Case-study matrix" provides an elaborate model approach that can be implemented to any construction project.

The method adopted for this study was Structured Literature Review. Various studies conducted in the area of the lean simulations were comprehensively reviewed to clarify the implementation of these techniques to the construction industry. The following procedure was followed:

- *Step 1:* Prepare a systematic literature review sourced from LCI and IGLC databases, and complete a table with the following headings: *Lean Simulation,* *Lean Principles Illustrated, Learning Objectives and Case Study Citations*. The terms used in the table heading was detailed as follows:

  - *Lean Simulation*: A methodology developed to imitate the processes of a real-time system that emphasizes the benefits and applicability of lean principles.
  - *Lean Principles Illustrated*: Specific theoretical principles from lean manufacturing theory that are illustrated by different lean simulations.
  - *Learning Objectives*: Lessons learned from different lean simulations that can be applied to the construction industry.
  - *Case Study Citations*: Construction case studies that have been published in the IGLC and LCI database.

- *Step 2*: Collaborate with the Lean Construction Institute to develop an understanding of the history of Lean simulations.
- *Step 3*: Construct an inventory of existing lean simulations and the principles they illustrate.
- *Step 3*: Construct an inventory of existing lean simulations and the principles they illustrate.
- *Step 4*: Analyze published case studies and simulations for the lean principles and learning objectives they embody.
- *Step 5*: Develop a “Simulation/Case-study matrix” to establish logic connections between simulations and case studies of actual projects.

4.2 Limitations

This research involved locating, translating, and organizing 23 years of organically developed construction case studies from IGLC and LCI Database. However, it is limited to only those simulations and case studies that have been published.

4.3 Delimitations

The scope of this study was determined to simulations in lean that are being applied to the construction industry, and not in any other industry.

CHAPTER V

RESULTS

Figure 2 illustrates a Pareto chart that categorizes the total number of times a particular lean principle is illustrated by the lean simulations. This Pareto chart focuses on some of the lean simulations determined in part, by “LCI Simulation Matrix” published at Lean Construction Institute website which illustrates critical aspects of lean processes that are applicable to the construction industry. This matrix provides a detailed explanation for thirty-three lean simulations such as lean concepts illustrated, learning outcomes and facilitation guidelines. The lean principles for this Pareto chart were identified after analyzing the thirty-three simulations determined by “LCI Simulation Matrix”.

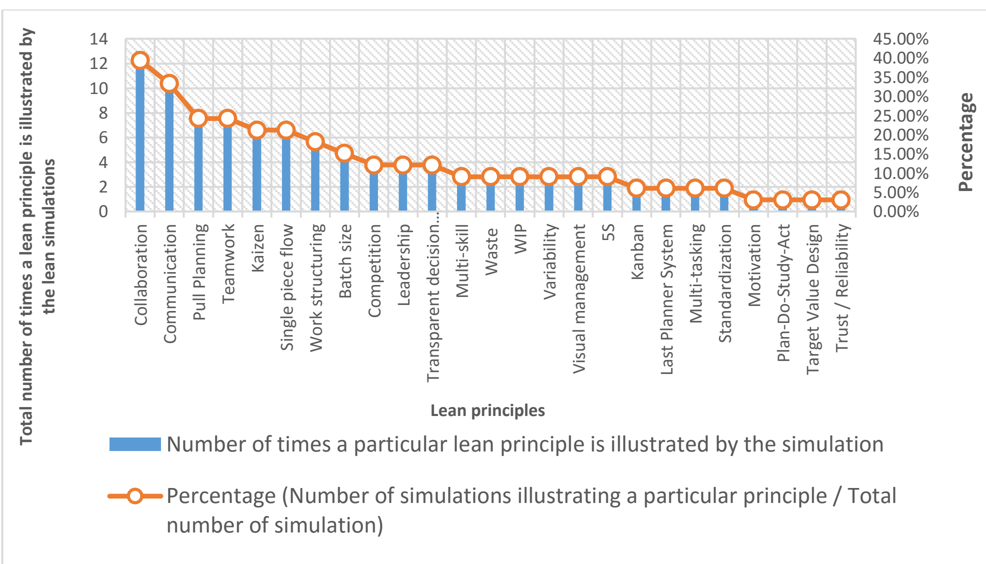


Figure 2: Pareto chart – analyzing the frequency of lean principles illustrated by lean simulations determined in part, by “LCI Simulation Matrix” published at Lean Construction Institute website. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Results from the structured literature study are summarized below:

5.1 Pull planning, small batch sizes and multi-skilled

Table 1: Lean Simulations Section 5.1– LEGO™ "Airplane" Simulation, LEAPCON Simulation and DOT Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
1. Airplane Simulation **2.** LEAPCON Simulation **3.** DOT Simulation	• Waste (the seven wastes) - Defects - Overproduce -Transport - Waiting - Inventory - Motion - Inadequate Processing • Inventory buffers and kanban • Kaizen and work cells •Communication • Pull flow • Small batch size • Multi-skilled workforce	• To clarify the benefits of cellular manufacturing arrangement over a traditional arrangement in construction. • Identifying Work-in-progress as a manageable product. • Load leveling (flexible workforce / distribution of work) • Visualize why high resource utilization might be bad for flow efficiency • Show how people in front of a bottleneck are actually causing problems when adding more work • Understand the impact of - Single-piece flow vs. Batch flow - Pull scheduling vs. Push scheduling - Multi-skilling vs single task specialization	• Arbulu. 2006 • Ballard. 2001 • Bulhões and Picchi. 2008 • Kalsaas et al. 2014 • Modegh. 2013 • Tribelsky and Sacks. 2010 • Tsao et al. 2000 • ***Tsao and Hammons. 2014*** • Valente et al. 2013 • Ward and McElwee. 2007

* Esquenazi and Sacks. 2006, Maturana et al. 2003, Sacks et al. 2005 and Rybkowski et al. 2012 provides a useful insight into the learning objectives achieved through the facilitation of LEAPCON and Airplane simulation.

- Case Study: Learning To See Simplicity within a Complex Project through the Lens of Pull Planning (Tsao and Hammons. 2014).
    - Project Information: Nemours/Alfred I. DuPont Hospital for Children (AIDHC) in Wilmington, Delaware
    - Project Team: Skanska, FKP Architects

This case study analyzed if pull planning can be applied to the 5 story atrium (a complex eight-sided space) to achieve a simpler work-structuring process. The project had a major challenge because of non-uniformity among different faces of the atrium. Therefore, the drywall layout subcontractor had to locate sections in space for layout instead of conveniently drawing a line on the floor (Tsao and Hammons. 2014).

According to Figure 3 and 4 pull planning efforts applied on the atrium project identified that complicated building spaces can be simplified into separate small batches while reducing the seven wastes and enhancing the on-site productivity. Figure 3 illustrates the location of work zones B2, B3, B4, and B5 in the northern part of the atrium and work zones B1, B8, B7, and B6 in the southern part of the atrium.

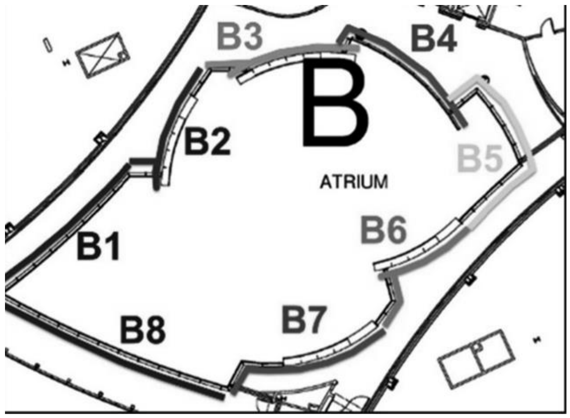


Figure 3: Pull planning handout for Nemours Atrium work zone. Reprinted from Tsao and Hammons (2014, page 756).

Figure 4: Pull plans for atrium work zones B1, B2, B3 and B5. Reprinted from Tsao and Hammons (2014, page 758).

Figure 5 illustrates that the work was started in clockwise direction from zone B2, thereby allowing the drywall crew to finish a whole E-shaped Drywall pop-outs section before proceeding to a subsequent one (Tsao and Hammons. 2014).

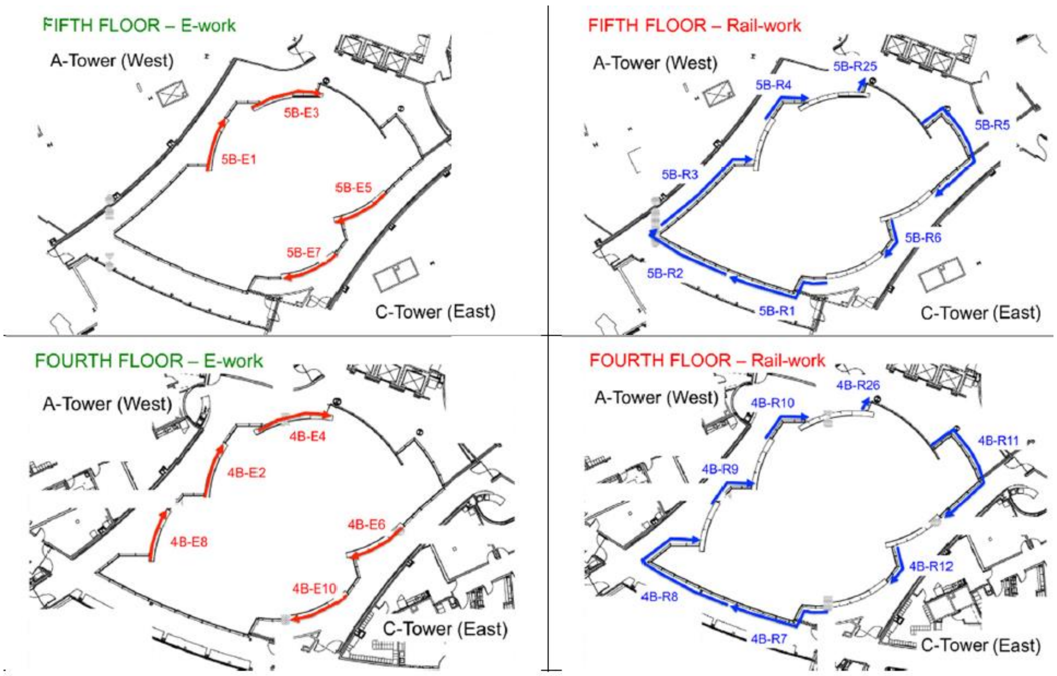


Figure 5: Final sequence for atrium face work on fourth and fifth floors. Reprinted from Tsao and Hammons (2014, page 760).

This project provided a very important learning outcome regarding one-piece flow which is in contrast to traditional thought processes in the construction industry. One-piece flow focuses on simplifying a project into a single repetitive unit while continuously monitoring its progress and identifying any scope for improvement to facilitate a higher efficiency in construction. Table 2 identifies the areas of repetition on each floor in AIHDC's atrium design.

Table 2: Areas of repetition in AIHDC's atrium design. Adapted from Tsao and Hammons (2014, page 757).

Floor	E-shaped Drywall pop-outs	Ferrous metal rail posts	Curtain wall
2nd	B6	B1,B2,B3,B5,B7	B4
3rd	B1,B6,B7	B2,B3,B5,B8	B4
4th	B1,B2,B3,B6.B7	B5.B8	B4
5th	B2,B3,B6,B7	B1,B5,B8	B4

5.2 Supply chain problems

Table 3: Lean Simulations Section 5.2 - BEER (Lean manufacturing) Game Simulation Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
4. BEER (Lean manufacturing) Simulation	• Problems with collaboration in traditional supply chain	• Illustrate the effects of organization structure on individual's behavior • Identify supply chain coordination problems • Experience the pressures of playing a role in a complex system • Minimizing cost for all stakeholders by reducing the inventory as per requirement and successfully completing all orders without delay.	• Arbulu and Tommelein. 2002 • Bjornfot and Stehn. 2005 • Chin et al. 2004 • Kim and Bae. 2009 • Melo and Alves. 2010 • ***Souza and Koskela. 2014*** • Tommelein and Li. 1999 • Vrijhoef and Koskela. 2000

* Maturana et al. 2004 provides a useful insight into the learning objectives.

- Case Study: Interfaces, Flows, and Problems of Construction Supply Chains: A Case Study in Brazil (Souza and Koskela. 2014).
    - Company information: Brazilian Construction Company specialized in infrastructure projects with a database of 4,000 active suppliers and 26 concurrent projects across Brazil.

The presence of a large number of diverse projects, suppliers, workforce and rental equipment significantly fragments the construction supply chain. The objective of this case study research was to determine and authenticate supply chain problems. The first step in this case study was focused on developing a framework according to the flow of information between construction supply chains. Effective management of supply chain problems can facilitate a project to witness substantial improvement in project delivery because of enhanced information, capital flows, and materials. Considerable waste is produced when obstacles located at interfaces restrict continuous flow.

Figure 6 illustrates the first step in this case study that identifies construction supply chain connections between enterprise/organization level, project level, and suppliers. Souza and Koskela (2014) argue there are three interfaces, namely (a) enterprise and project interface, (b) enterprise and supplier interface, and (c) project and supplier interface (Souza and Koskela 2014).

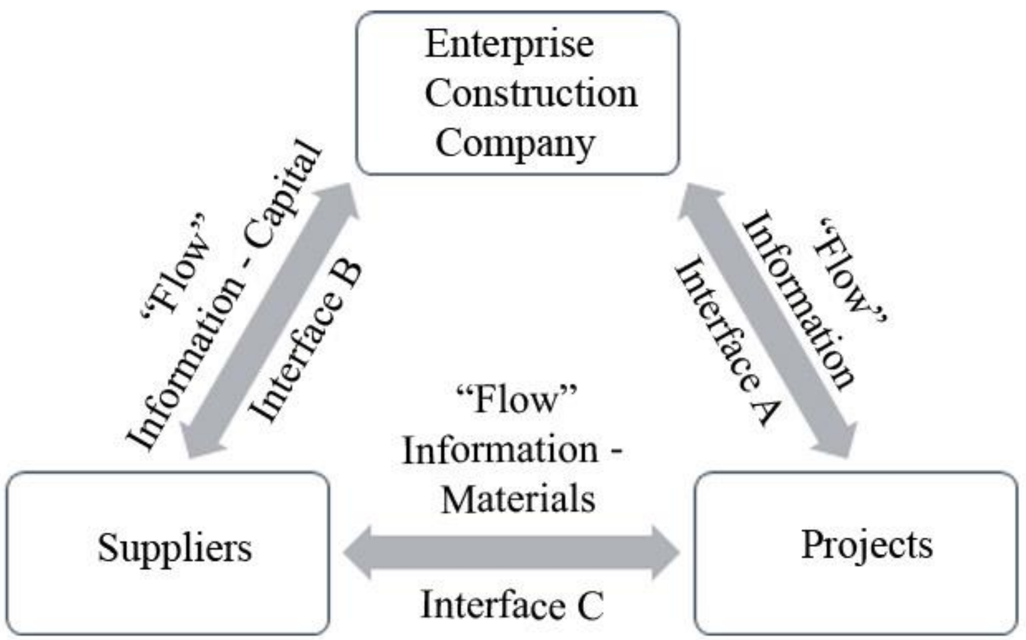


Figure 6: Analysis of construction supply chains to illustrate three interfaces and their specific information flow. Adapted from Souza and Koskela (2014, page 1102).

The second step in this research was focused at implementation of the framework developed from Figure 6 to a construction company. This step involved meetings with company's procurement, quality and cost representatives to ascertain supply chain problems and categorize them according to the three interfaces identified in the first step.

Table 4 illustrates the results of step 2 which identified the construction supply chain problems between the three interfaces for the company. The supply chain problems have been categorized according to the exchange of information, capital and material. These supply chain problems play a critical role in negatively impacting the progress of a construction project.

Table 4: Construction supply chain problems. Adapted from Souza and Koskela (2014, page 1104)

Interface	Information	Capital	Materials
A. Enterprise –Project	• 4000 Request for Proposals (RFPs) on an average per month • Hasty issuance of RFPs that requires rework of RFPs • Lack of comprehensive evaluation of suppliers	N/A	N/A
B. Enterprise –Supplier	• Delayed response of RFPs • Revision of RFPs • Increased number of POs, around 4000 • Hasty issuance of Purchase Orders (POs) that requires rework of around 50% POs • Lack of a reliable Information Technology(IT) system for quantity surveyors and buyers in communicating POs to suppliers • Poor selection of suppliers • Inadequate tracking of POs • Inadequate feedback to suppliers	• Many orders were delayed due to late Purchase Orders (POs) approval process. • POs sent to suppliers before internal authorization • Revisions of invoices • Lack of a reliable Information Technology(IT) system in communicating invoices • Late payment of suppliers	N/A
C. Project – Supplier	• Inadequate data about supplier's performance • Lack of coordination with site schedules	N/A	• Increased cost of transportation damages • Inadequate quality of delivery performance

5.3 Collaboration and communication

Table 5: Lean Simulations Section 5.3 - Magic Stick Simulation, Maroon – White, Win as much as you can Simulation, Silent Squares Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
5. Magic Stick Simulation **6.** Maroon – White Simulation **7.** Win as much as you can Simulation **8.** Silent Squares Simulation	• Collaboration • Leadership • Communication • Competition	• Needs clear leadership • To analyze importance of collaboration in solving problems in AEC industry • To sensitize participants to the importance of working as a team • Evaluate the effect of social dilemmas while choosing between individual versus group benefit. • Illustrates "the concept of "tragedy of commons" • Illustrate the concept of 'Pareto efficiency" which states that to make one choice better it is essential to make another choice worse.	• Alarcón et al. 2011 • Chin et al. 2004 • Elsborg et al. 2004 • Fundli and Drevland. 2014 • Kulkarni et al. 2012 • Parrish et al. 2008 • ***Riley and Horman. 2001*** • Tribelsky and Sacks. 2010

***** Emmitt et al. 2004 and Hill et al. 2007 provides a useful insight into the importance of communication and shared knowledge in construction industry.
* Smith and Rybkowski. 2013 provides a useful insight into benefits achieved through the facilitation of Maroon-White Simulation.

- <u>Case Study:</u> The Effects of Design Coordination on Project Uncertainty (Riley and Horman. 2001)

This study analyzed the effect of increasing design coordination on reducing the uncertainty on the progress of construction project. It further corroborated the need for design coordination through cost savings realized due to reduced change orders and interruptions.

Figure 7 illustrates the four sets of data that were investigated in four projects to ascertain the benefits of coordination realized through cost savings from reduced conflicts in field operations.

Coordination effort	Field conflicts	Conflict costs	Coordination costs
• Effort required to fit systems into buildings without physical interference	• Identifying field conflicts during design coordination	• Average cost of field conflicts that were not identified	• Quantitative cost of the coordination process ?

Figure 7: Datasets investigated in four projects. Adapted from Riley and Horman (2001, page 3)

A two-fold analysis was conducted to firstly to identify the link between design coordination and reduction of conflicts in field operations (Riley and Horman. 2001) and secondly, to explore the interactions between coordination effort and cost savings realized due to reduced field conflicts for different project delivery methods (Riley and Horman. 2001).

To explore the relationship between coordination efforts and field conflicts, a metric was developed which identified a rating of 100% as a situation in which no work was performed before design coordination amongst all contractors. In addition, the field generated change orders generated due to MEP systems interference were identified as the total number of field conflicts. Figure 8 indicates that the number of field conflicts are reduced as the coordination effort increases on the construction projects.

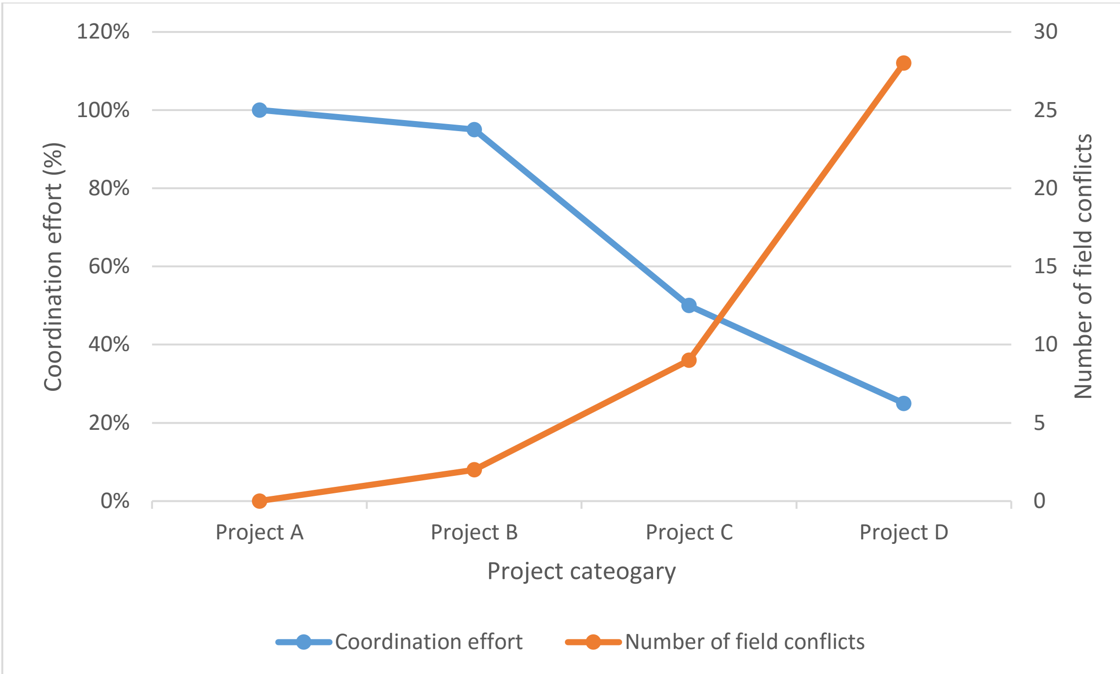


Figure 8: Coordination effort and field conflicts. Adapted from Riley and Horman (2001, page 4)

Analysis of field generated change order cost for fourteen laboratory construction projects of similar size, scope, and cost provided an ideal insight into the range of costs associated with field conflicts. Figure 9 explains the different project delivery methods and their specific coordination strategies that were implemented on construction projects to ascertain the cost of field conflicts.

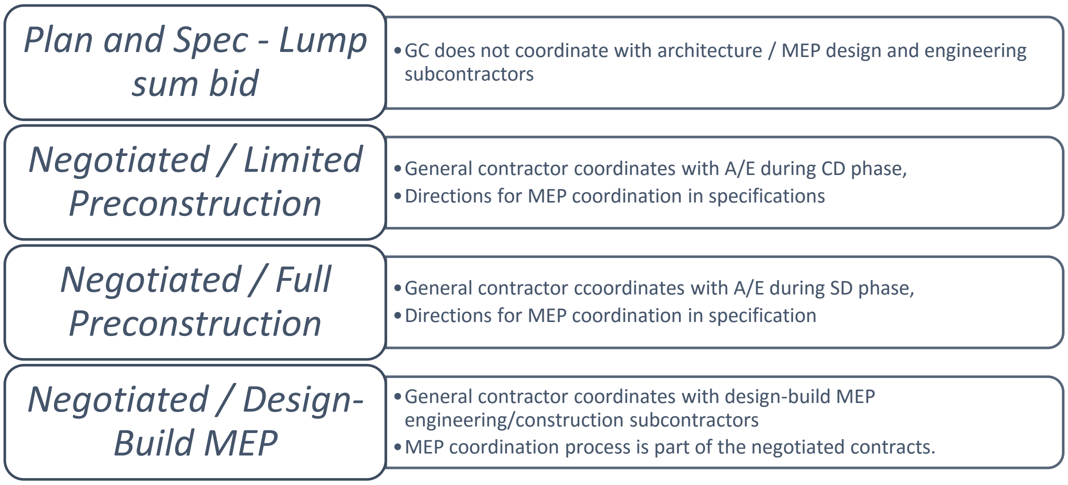


Figure 9: Investigation of different project delivery methods and coordination strategies utilized on construction projects to analyze the cost of conflicts. Adapted from Riley and Horman (2001, page 5)

The investigation clearly illustrates a significant reduction in the cost of field conflicts on projects where all project stakeholders were encouraged to be coordinate from the design phase. Analysis of the total time (hours) taken by MEP project manager (general contractor), CAD operators, foreman and specialty subcontractors for fourteen laboratory construction projects to determine the average costs associated with executing design coordination. Figure 10 illustrates a significant reduction in field conflict costs and field generated change order costs which balanced the initial investments in coordination costs.

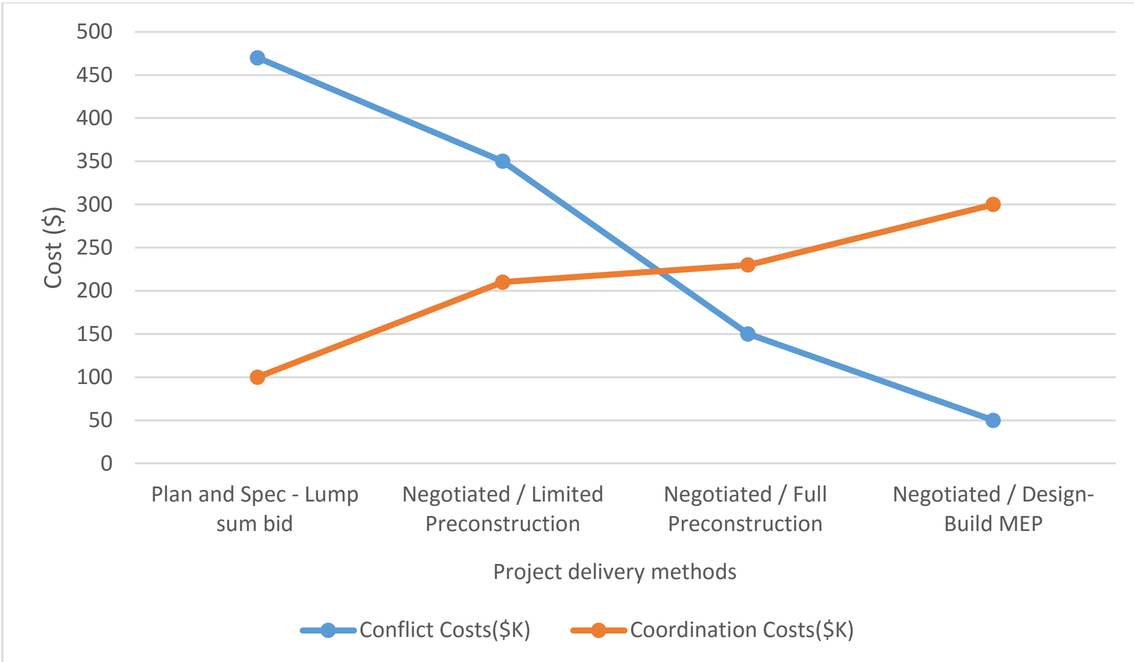


Figure 10: Project delivery methods and overall project field generated conflict costs and coordination costs. Adapted from Riley and Horman (2001, page 5-6).

5.4 Continuous improvement

Table 6: Lean Simulations Section 5.4 - Collective Kaizen and Standardization, Hacky Sack Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
9. Collective Kaizen and Standardization Simulation **10.** Hacky Sack Simulation	• Continuous improvement • Standardization	• Challenges a typical mindset amongst supervisors that external factors (like more intelligent or productive employees) are a significant factor in increasing overall organizational productivity. • Stretch goals to enable change in behavior	• ***Fernandes et al. 2015*** • ***Fosse et al. 2014*** • Gallardo et al.2006 • Hamedi et al. 2009 • Martinez et al. 2015 • Mohamad et al.2014 • Nakagawa. 2005

* Rybkowski and Kahler. 2014 provides a useful insight into the learning objectives achieved through the facilitation of Collective Kaizen and Standardization Simulation
* Aapaoja and Haapasalo. 2014 provides a useful insight into the challenges identified during standardization of products and processes in the construction industry

- Case Study Construction Site Operations Made Leaner and Standardized: A Case Study (Fosse et al. 2014)
    - Project Information: Residential construction

This paper analyzes the improvement on a construction site while reducing waste and optimizing production methods. Some strategies that were implemented on the project were rearranging the work sequence while eliminating non-value adding activities, increasing the number of workers and visualization. This case study analyzed a residential block, six stories high with seven apartments on a single floor having an area between 55 sq.m and 139 sq.m. Inner wall production of a single apartment was analyzed for improvement in construction site operations.

As illustrated by Figure 11, a typical operation of producing inner wall for an apartment area varying between 55 sq.m and 139sq.m was distributed into five different sets of activities. Initially, this whole operation of producing the inner wall was completed by two workers while dividing a typical work day into three “sessions” as a unit of time.

- Session 1: Morning to lunch (7am – 11am)
- Session 2: Lunch to afternoon (11;30am -3:00pm)
- Session 3: Evening session (3:00pm – 7:00pm)

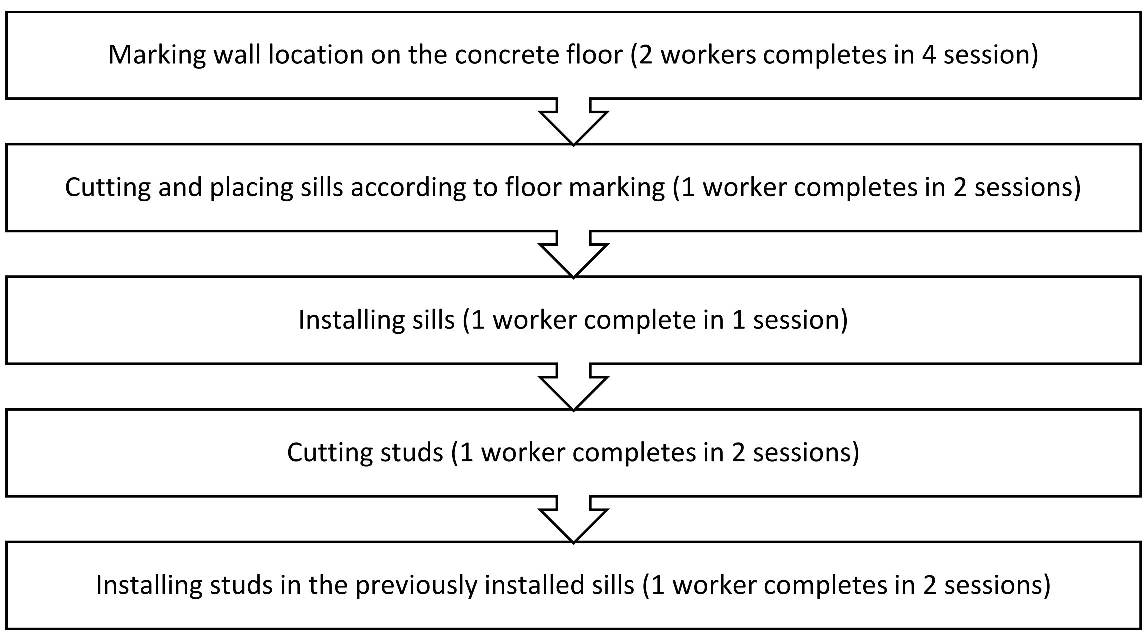


Figure 11: Distribution of the operation of producing inner walls. Adapted from Fosse et al. (2014, page 827)

As illustrated by Figure 12 the total number of workers were increased to three and the work sequence of the tasks was changed as a method to improve the production. The improved approach changed the previous understanding of focusing on a single task at a time to standardizing the workflow so that all the tasks continuously evolve.

Spray paint was utilized to mark the floor to visualize material and equipment flow, was used to improve visualization and prevent conflicts with other trades. As illustrated by Figure 12 the project witnessed significant savings.

- Reduced cycle time from 71.25 work hours (19 sessions) to 37.5 work hours (10 sessions) (savings of 47.4%)
- Reduced man hours from 150 MH to 120 MH (savings of 20%)

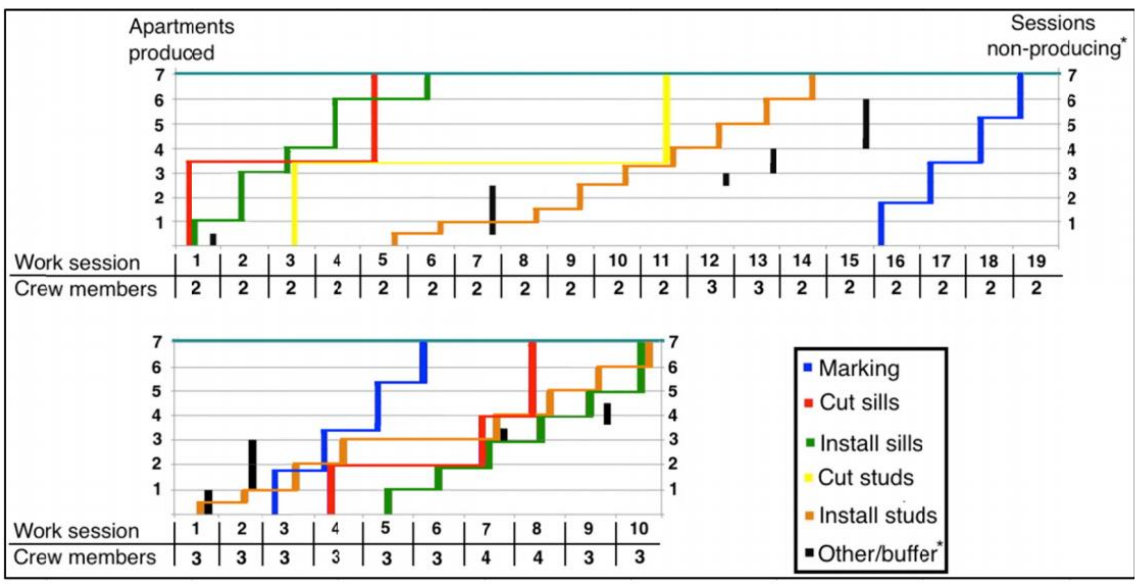


Figure 12: Stairwell diagram showing the progress of work for producing inner walls (top – initial) and (bottom –revised). Reprinted from Fosse et al. (2014, page 830)

- <u>Case Study: </u> The Standardized Work Tool Applied to the Waterproofing Process with Acrylic Membrane (Fernandes et al., 2015)
    - <u>Project Information:</u> Residential building, Fortaleza, Brazil

This paper analyzes the implementation of standardized work procedure for the waterproofing process with the acrylic membrane at a residential construction site in Brazil to improve construction productivity, work conditions and precision in executing tasks. Figure 13 illustrates the five step method that was adopted to improve the existing asphalt mantle waterproofing and change it to acrylic membrane waterproofing.

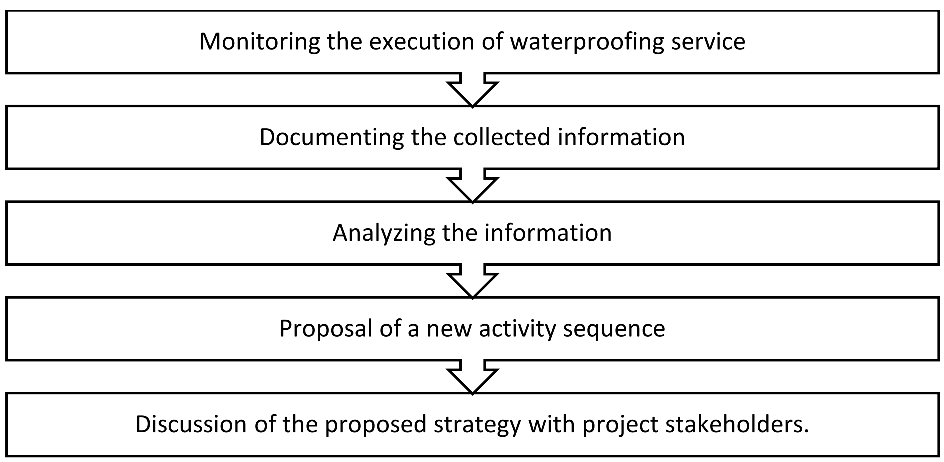


Figure 13: Methodology adopted to improve the existing waterproofing process. Adapted from Fernandes et al. (2015, page 136-137)

Figure 14 illustrates the first step in the five-step method to improve the existing waterproofing of wet areas. Step 1 focused on observing and monitoring the execution of waterproofing services with acrylic membrane. Figure 15 illustrates the sequence of standard activities that were implemented to complete the waterproofing service.

Figure 14: Step 1- A sample illustrating the application of first coat with the acrylic membrane product. Reprinted with permission from Fernandes et al. (2015, page 136)

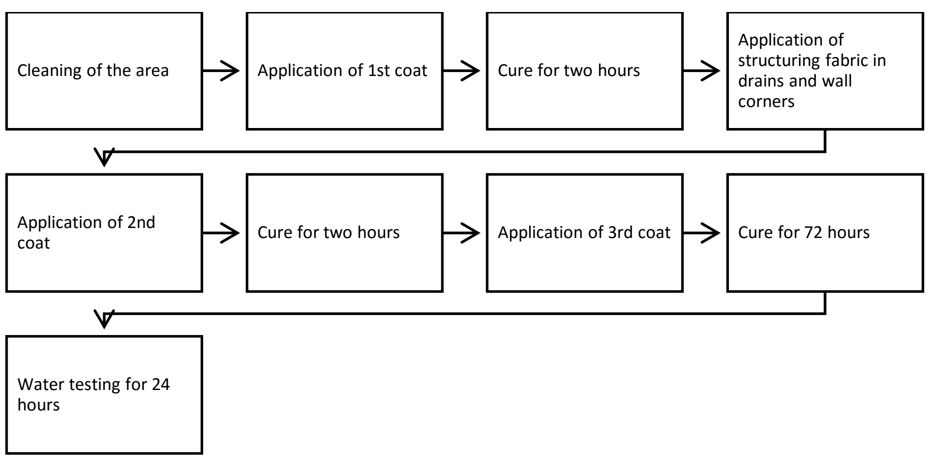


Figure 15: Step 1 - Flowchart explaining waterproofing service methodology used on the project. Adapted from Fernandes et al. (2015, page 138).

Table 7 illustrates the Step 2 in the process which focused on a compilation of qualitative and quantitative information in spreadsheets. The information was obtained during observation and monitoring during Step 1.

Table 7: Step 2 -Tabulation of collected data. Reprinted with permission from Fernandes et al. (2015, page 137).

Period	Time	Interval	Ativities	Comments	Room	Cycle or out of cycle
Morning	07:57:00	00:01:56	Preparation of materials	Polish machine, PPEs, extension cord, etc.	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	07:58:56	00:05:08	Thick cleaning	Removal of ceramics, bags, pallets, etc	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	08:04:04	00:03:21	Preparation of materials	Pick up a light bulb, turn on the extension cord, pick up a brush, pick up a broom.	Hall of the 11th pavement, between appartments 1102 e 1103.	Out of cycle
Morning	08:07:25	00:00:45	Thick cleaning	Sweeping	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	08:08:10	00:01:44	Stop	Identified a leak and called the responsible team.	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle

Figure 16 illustrates the third step in the process which focused on drawing inferences from the analysis of tabulated information in Step 2. The Step 3 analyzed the distribution of critical activities, identified the non-value adding activities and how they can be minimized. It was noticed that non –value adding activities like “stops, thick cleaning, preparation of materials, fine cleaning, displacement and rework” constituted to 60% of employee time and only 40% of the employee time was used in the application of the acrylic membrane “cycle” activity.

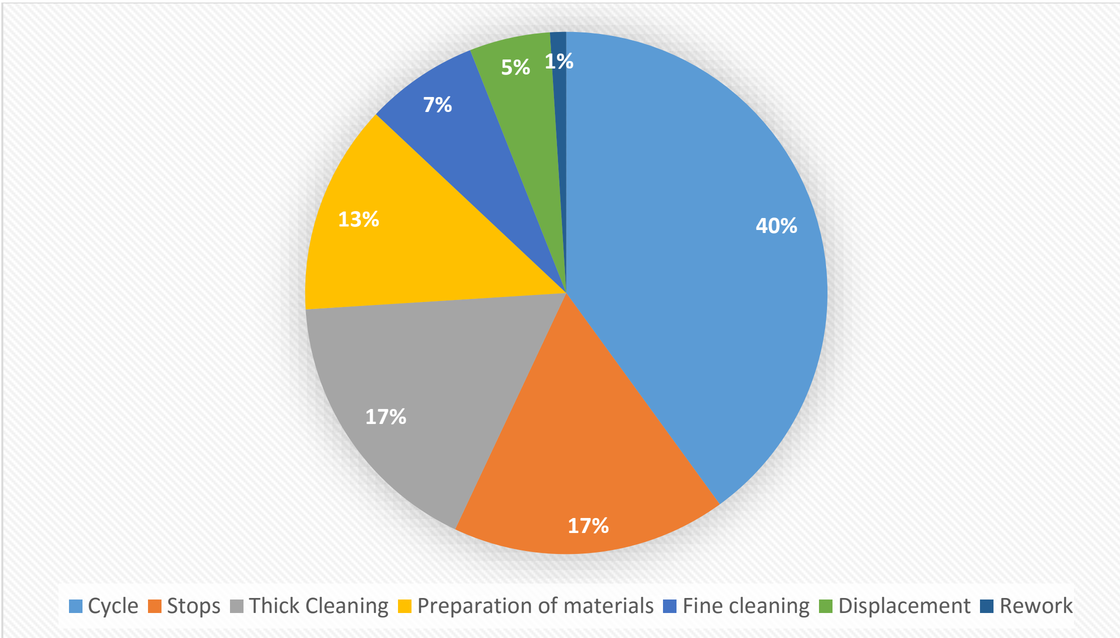
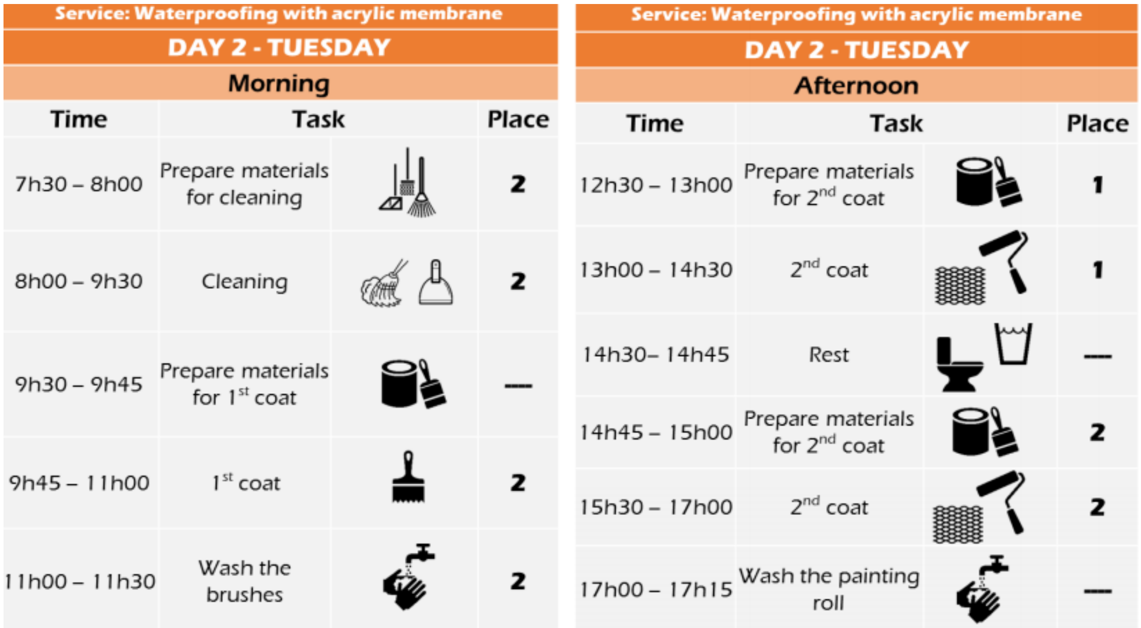


Figure 16: Step 3 – Current operator balance chart analyzing the distribution of value adding and non-value adding activities. Adapted from Fernandes et al. (2015, page 138).

During the fourth step, the waterproofing process was restructured and the activities that did not add value were eliminated. Figure 17 illustrates the fifth step in the process which focused on using flash cards to facilitate an understanding of the new sequence of activities amongst the employees and management.



Service: Waterproofing with acrylic membrane		
DAY 2 - TUESDAY		
Morning		
Time	**Task**	**Place**
7h30 – 8h00	Prepare materials for cleaning	2
8h00 – 9h30	Cleaning	2
9h30 – 9h45	Prepare materials for 1st coat	—
9h45 – 11h00	1st coat	2
11h00 – 11h30	Wash the brushes	2

Service: Waterproofing with acrylic membrane		
DAY 2 - TUESDAY		
Afternoon		
Time	**Task**	**Place**
12h30 – 13h00	Prepare materials for 2nd coat	1
13h00 – 14h30	2nd coat	1
14h30– 14h45	Rest	—
14h45 – 15h00	Prepare materials for 2nd coat	2
15h30 – 17h00	2nd coat	2
17h00 – 17h15	Wash the painting roll	—

Figure 17: Standardized work flashcards for the waterproofing service. Reprinted with permission from Fernandes et al. (2015, page 140)

Implementing a standardized waterproofing service led to an increase in the total number of apartments delivered by the waterproofing crew from 12 apartments per month to 16 apartments per month (33.33% increase in productivity from the initial stage).Some additional qualitative benefits were achieved like improvement in the working conditions due to availability of trunk to store tools and PPE and an ability to control and monitor the production due to availability of flash cards.

5.5 5S (sort, set in order, shine, standardize, sustain)

Table 8: Lean Simulations Section 5.5 - 5S Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
11. 5S Simulation	• Sort • Set in order • Shine • Standardize • Sustain	• Experience the frustration of performing a simple task in a disorganized manner • Personal experience of the incremental increase in ease and speed available in that same workplace as it undergoes the sequential process of the 5S process	• ***Leino et al. 2014*** • Salem et al. 2005 • Ng. 2010

- Case Study: Improving safety performance through 5s program (Leino et al. 2014)
    - Project Information: Finnish Construction Company

This paper analyzes the improvement on a construction site while reducing waste and optimizing production methods. Some strategies that were implemented on the project This paper analyzes the implementation of 5S to realize a reliable workflow, reduced accidents due to slips, trips, and increased productivity. The 5S program consisted of the following steps:

Sort – This step was focused on sorting through work areas to identify the steps necessary to complete the required work.

Set in order – This step was focused on arranging the tools and remaining materials with well-defined site storage locations

Shine – This step was focused on cleaning the work environment through the proper arrangement of waste bins and vacuum cleaners and also ensuring that every worker cleans their workspace after the shift.

Standardize – This step was focused on implementation of simple rules to evaluate a space as correct or incorrect. Each space was evaluated separately, therefore, it was imperative to ensure that no waste is left on the job site after work is complete.It was important to ensure that materials are stored correctly in a single space. Waste should be stored in bins at correct locations. Figure 18 illustrates a shadow board to ensure that tools are stored in the correct place.

Figure 18*:* Shadow board [Online image] Retrieved from Dave Barry http://davebarryplastics.com/wp-content/uploads/2014/08/P1050353.jpg on March 21, 2016.

Figure 19 illustrates the use of spray paints to indicate access ways such as corridors, stairways which should be clear of any obstruction. It was used to improve visualization and prevent conflicts with other trades.

Figure 19: Floor marking to indicate clear access in aisle [Online image] Retrieved from VIBCO http://www.vibco.com/images/continuous-improvement/aisle-clear338551B4FD61.jpg on March 21, 2016

Sustain – This step was focused on ensuring that formal evaluations were conducted for effective implementation of the standard during the current project and also in the future.

Site safety index is a ratio of site safety observations that are accurate to the total number of site safety observations. A 100% Site safety inspection index describes a situation in which all site safety observations comply with the rules with no defaults. Figure 20 illustrates how site safety inspection indices improved after 5S workshop. Month -1 to -4 illustrates 4 months before the workshop was implemented. Month 0 illustrates the workshop month and Month 1-5 illustrates the 5 months after the workshop was implemented. Figure 20 illustrates that the site safety inspection index rose by 3.4% from Month -1 to Month 5.After three months there is a decrease of 1.3 % in Month 3, therefore, it was analyzed that to sustain the benefits, a 5S workshop should be implemented every three months.

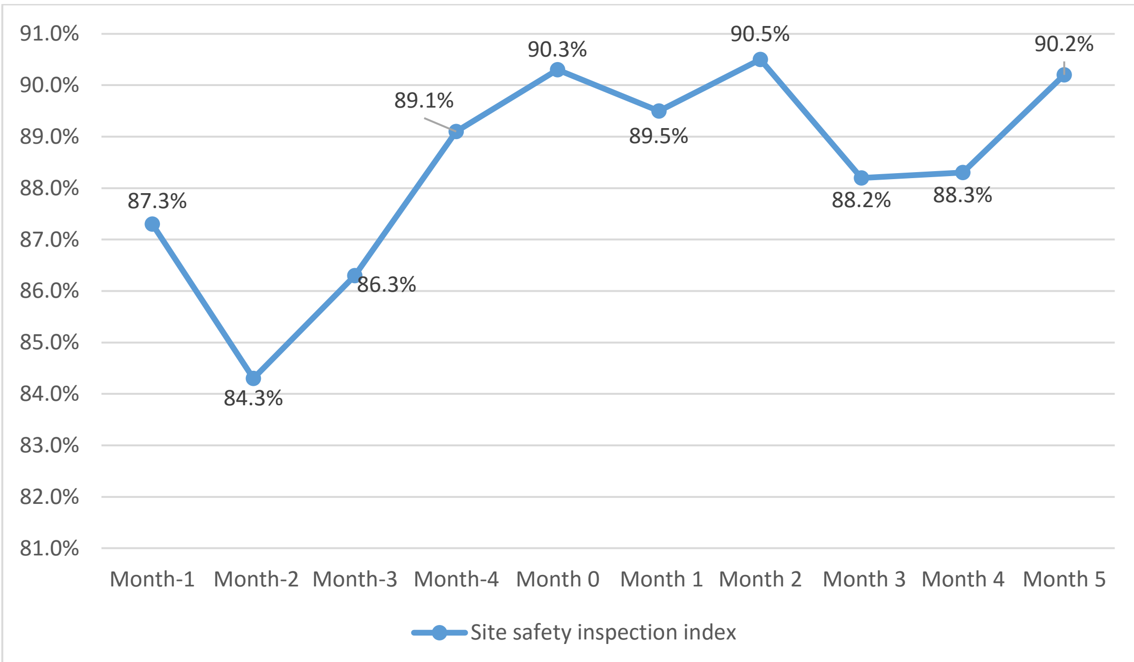


Figure 20: Monthly average site safety index from 20 sites. Adapted from Leino et al. (2014, page 1409).

5.6 Last planner system

Table 9 : Lean Simulations Section 5.6 - Colored Blocks Simulation, Parade of trades Simulation and Villego Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
12. Colored Blocks Simulation **13.** Parade of trades Simulation **14.** Villego Simulation	• Last Planner System • Pull Planning • PPC • Batch size and continuous flow	• Enables players to experience the essence of LPS and understand how the fundamentals of the system work together in a construction project. • The participants will also start to understand the importance of scheduling the handoffs to create a predictable workflow for all. • Identify the effect of pull on a production system • Exhibits the advantages of keeping promises in developing a predictable workflow • Facilitates team development	• ***Ahiakwo et al. 2013*** • ***AlSehaimi et al. 2009*** • Bortolazza et al. 2005 • Fiallo and Revelo. 2002 • Formoso and Moura. 2009 • Fundli and Drevland. 2014 • Junior et al. 1998 • Kalsaas et al. 2009 • Kerosuo et al. 2012 • Kim and Jang. 2005 • Porwal et al. 2012 • Shen and Chua. 2005 • Soares et.al. 2002 • Tommelein and Beeche. 2001 • Valente et al. 2013

* Tommelein et al. 1998 provides a useful insight into the learning objectives achieved through the facilitation of Parade of trades Simulation.
* Warcup and Reeve. 2014 provides a useful insight into the learning objectives achieved through the facilitation of Villego Simulation.

Figure 21 describes the pull planning effort which is a crucial part of Last Planner System. During this phase, each subcontractor provides feedback to develop a sequence of activities for completing the project. Feedback from different trades are then plotted on a weekly or monthly calendar through post-it notes. Figure 22 illustrates the post-it notes plotted on a weekly calendar after taking feedback from all project stakeholders.

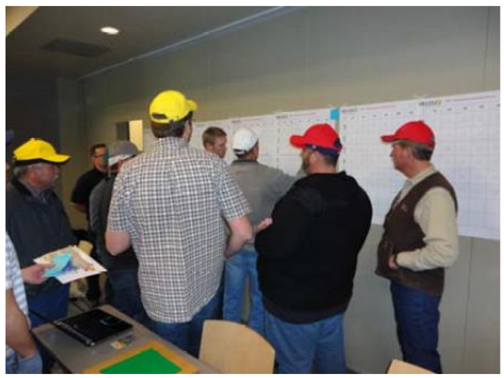


Figure 21: Collaborative pull planning sessions. Reprinted with permission from Warcup and Reeve (2014, page 8).

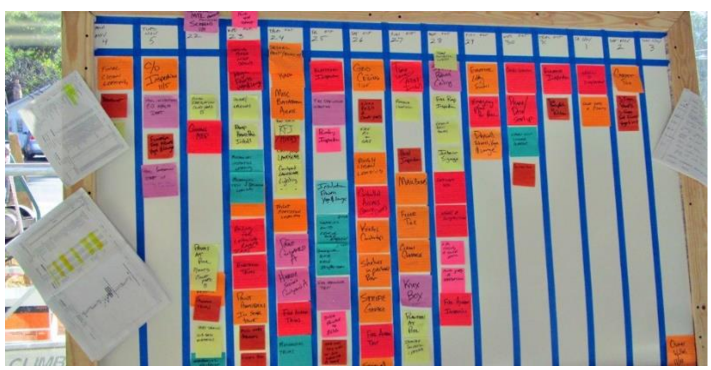


Figure 22: Pull planning wall with colored post-it notes plotted on a weekly calendar [Online image] Retrieved from Balfour Beatty Construction http://buildingwithpurpose.us/clt/wp-content/uploads/2013/07/pullplanning.jpg on March 22, 2016

- Case Study: A Case Study of Last Planner System Implementation in Nigeria (Ahiakwo et al. 2013)
    - Project Information: Federal university in the North Central region of Nigeria

This paper analyzes the benefits achieved in time, cost and PPC (percent planned complete) after the implementation of Last Planner system on a university project in Nigeria. Design Science Research methodology was adopted for this study which focused on producing innovative construction solutions to real-time problems. Figure 23 illustrates the elevation of federal university hostel building that was constructed by each contractor. The contract value for each contract was approximately $ 1,506,000.00.

Figure 23: Elevation of the hostel building being constructed by each contractor. Reprinted from Ahiakwo et al. (2013, page 702).

Table 10 explains the company size (average number of employees), the area of specialization and experience (years) for four different contractors who were engaged in the construction of the prototype hostel buildings.

Table 10: Characteristics of four contractors. Adapted from Ahiakwo et al. (2013, page 702).

Code name for each contractor	Average number of employee	Area of specialization	Years of experience
CRT1	80	Buildings	10
CRT2	120	Infrastructure	20
CRT3	200	Engineering	25
CRT4	85	Buildings	15

The fourth contractor, CRT4 implemented Last Planner System (LPS) on the project and had substantial savings in time and costs. Figure 24 illustrates the Percent planned complete (PPC) achieved during execution of weekly work plans. It was noticed that PPC was low in first few weeks because the project team was reluctant towards LPS implementation but as the project progressed PPC was stabilized to 80%.

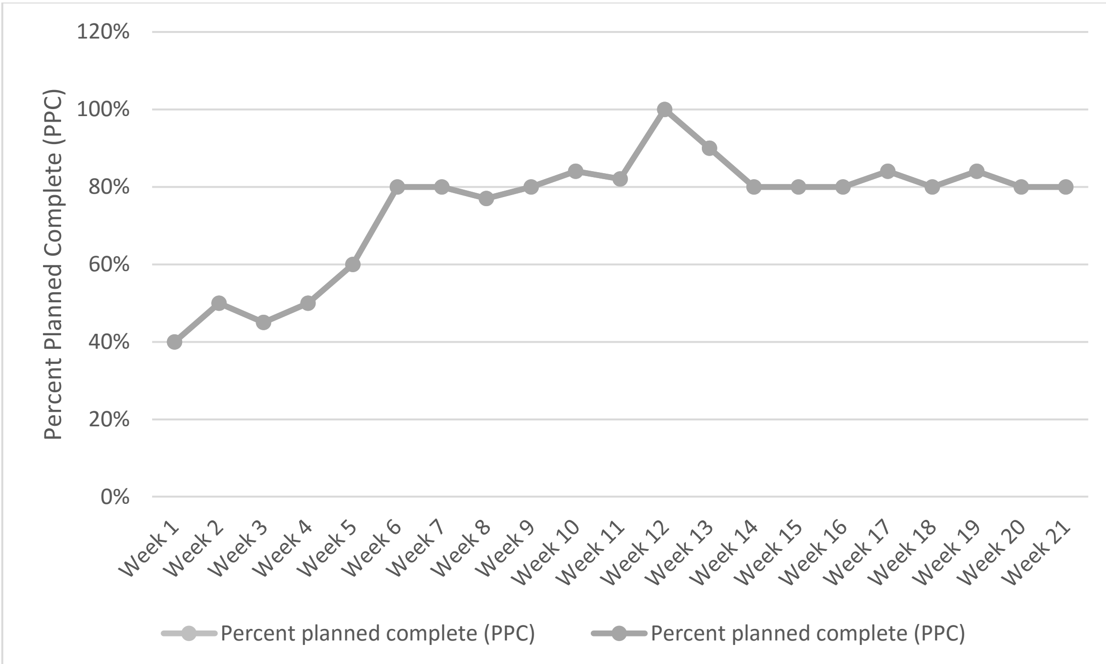


Figure 24: Weekly PPC (percent planned complete) for the complete project. Adapted from Ahiakwo et al. (2013, page 703).

According to Figure 25, the implementation of Last Planner System helped in identifying the valid reasons for non-compliance (incomplete tasks) during the project duration of 21 weeks.

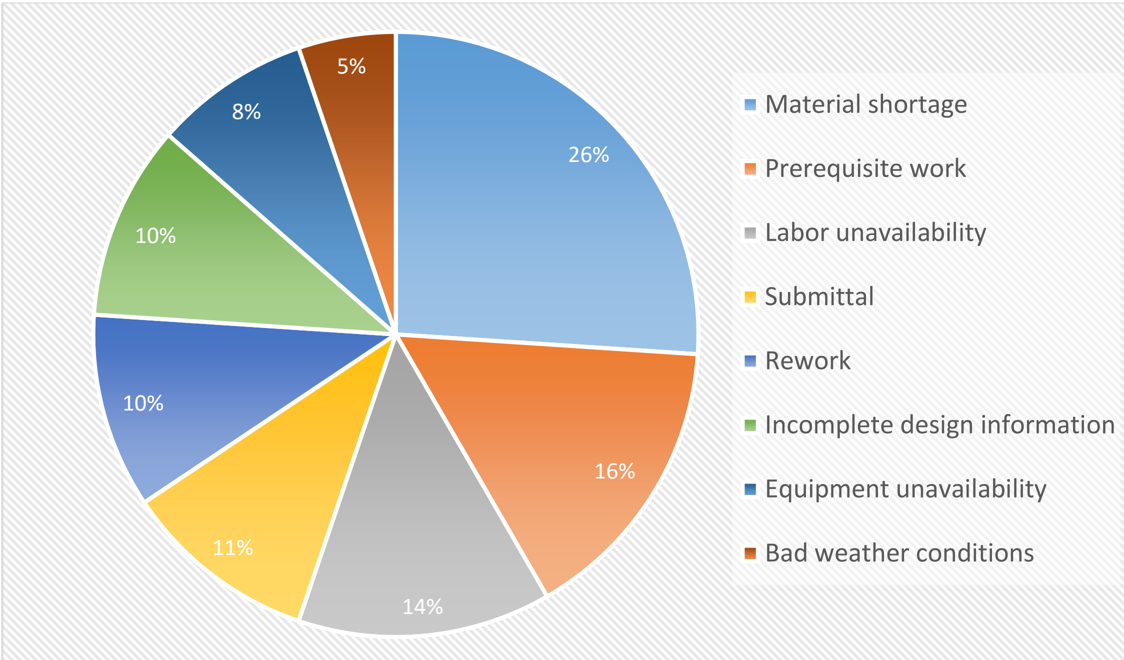


Figure 25: Reasons for incomplete tasks. Adapted from Ahiakwo et al. (2013, page 704).

The project outcomes were analyzed to ascertain the benefits of Last Planner System implementation

- CRT1 completed the project 5 months late
- CRT2 completed the project 6 months late
- CRT3 couldn’t complete the project
- CRT4 that implemented Last Planner System had timely completion of the project with 30% cost savings.

- Case Study: Last planner system: Experiences from pilot implementation in the Middle East (AlSehaimi et al. 2009)

This paper analyzes the benefits achieved in construction planning and site management after implementation of Last Planner System. LPS is also known as collaborative, commitment based planning system. Table 12 describes the two projects which were analyzed for the implementation of Last Planner System.

Table 11: Description of the projects studied for this research. Adapted from (AlSehaimi et al. (2009, page 56)

Project Category	Total contract amount for the project	Total project duration	% of time elapsed after Last Planner System implementation	Subcontractors information
1. Faculty of Business and administrative services	$21 million	1 year 5 months	50%	`Electrical
2. General classrooms and laboratories	$10 million	1 year 5 months	50%	Architectural, Structural, MEP

Figure 26 describes the Last Planner System implementation strategy that was used for the two projects. During the first phase, a workshop was conducted to provide training for implementation of Last Planner System, including the process to calculate PPC and how to identify reasons for incomplete tasks, thereby developing a pull plan with clear handoffs. The second phase was focused on developing make-ready, calculating Percent Planned Complete (PPC) and identifying the reason for non-compliance (incomplete tasks) during five weeks. During the third phase constraint analysis was conducted to develop 4 week Lookahead planning and 6-week Lookahead planning based upon reliable commitments for the project. The fourth phase identified the benefits from LPS implementation through an analysis of PPC and reasons for variance.

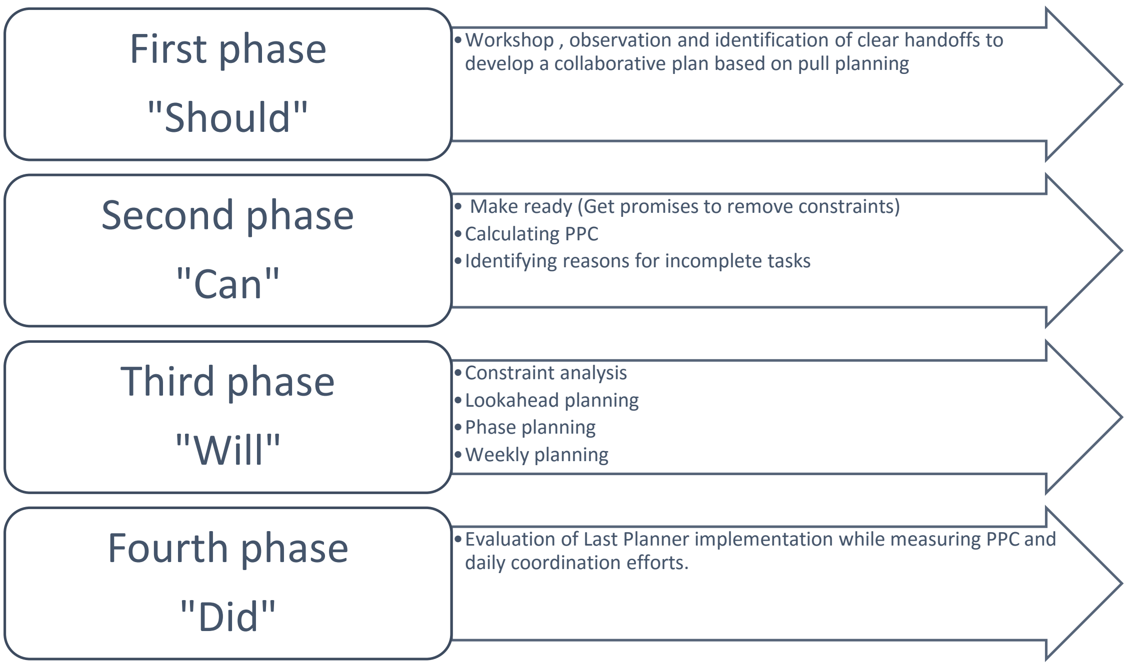


Figure 26: Last Planner System implementation strategy: “Should - Can - Will – Did”. Adapted from AlSehaimi et al. (2009, page 56).

Figure 27 illustrates the Percent Planned Complete (PPC) for both the projects. In the first project, PPC increased for the first week from 69% to finally stabilizing at 86% in the last week. For the second project, PPC increased for the first week from 56% to finally stabilizing at 80% over the last five weeks.

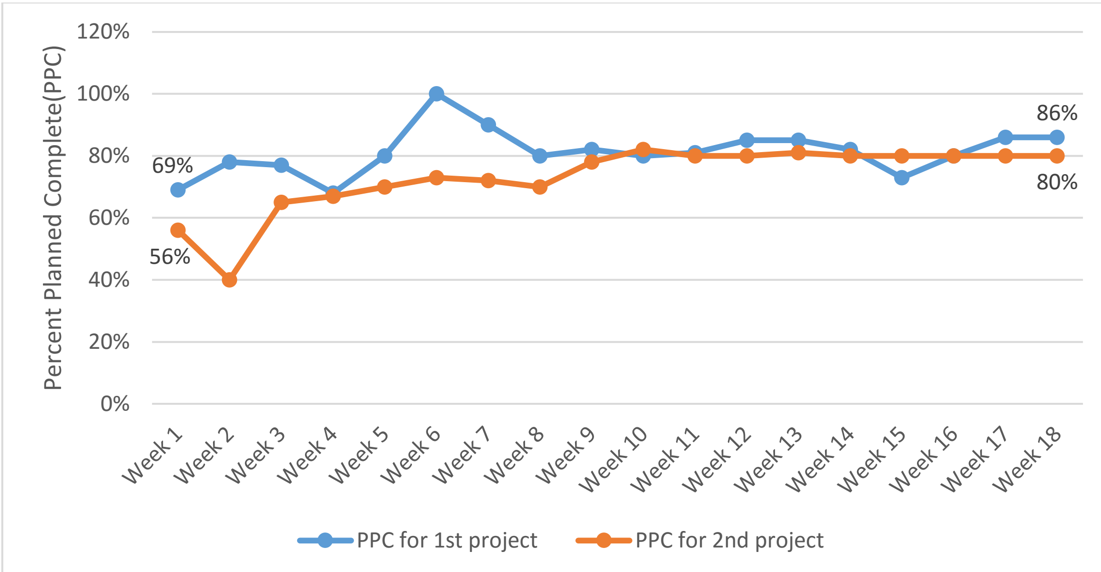


Figure 27: Weekly PPC for the two projects during the complete course of the project. Adapted from AlSehaimi et al. (2009, page 58).

Figure 28 illustrates the various reasons identified for the incomplete assignments. Prerequisite work has been identified as a major reason for incomplete task in this construction phase because most of the activities were dependent on structural subcontractor and their available workforce was inadequate according to the project needs. Inadequate material supplies were the second biggest reason because of the time-consuming approval process by the client and wrong materials being delivered to the job site by suppliers.

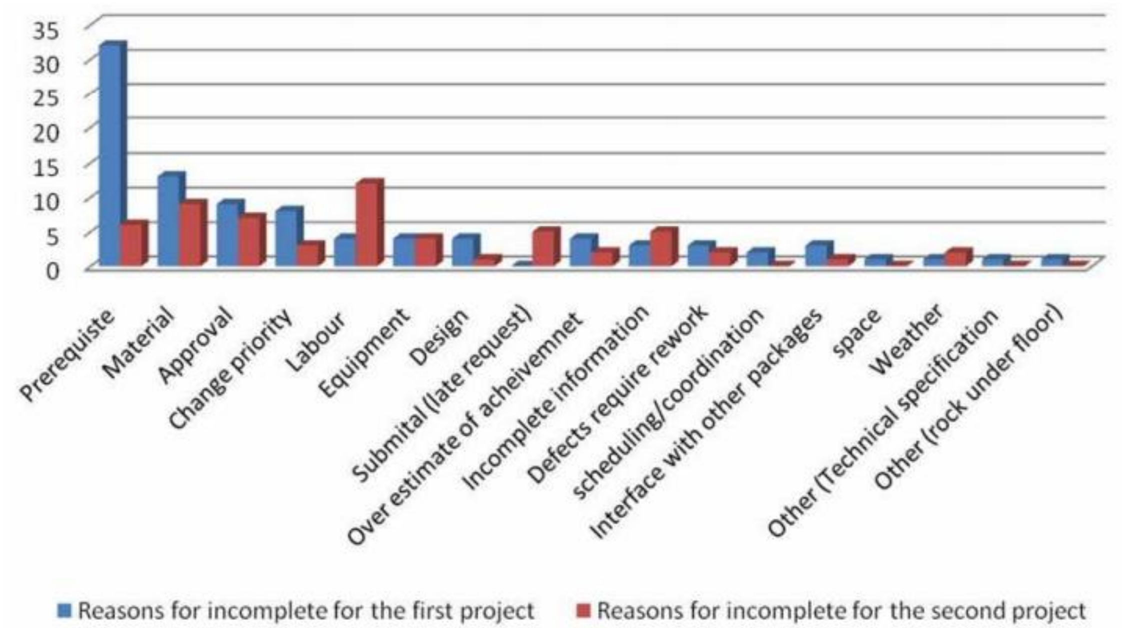


Figure 28: Reasons identified for incomplete assignments on both projects. Reprinted with permission from AlSehaimi et al. (2009, page 59).

Finally, the results of implementation of LPS were compared to some previous researchers such as improvement in PPC over the course of a project (Fiallo and Revelo. 2002; Kim and Jang. 2005; Junior et al. 1998) and identification of prerequisite work as a major reason for incomplete task (Koskenvesa and Koskela. 2003; Ballard, 2000).

5.7 Target value design

Table 12: Lean Simulation 5.7 - Target Value Design Simulation. Adapted from LCI Simulation Matrix, Lean Construction Institute (2015).

Lean Simulation	Lean principles illustrated	Learning objective	Case Study Citations
15. Target Value Design Simulation	• To help participants understand the basic principles of Target Value Design (TVD) within the Integrated Project Delivery (IPD) process	• Stakeholders need to understand importance of pulling design to client's financial resources	• Ballard et al. 2015 • Do et al. 2014 • Kim and Lee. 2010 • Melo et al. 2014 • Oliva and Granja. 2013 • ***Rybkowski. 2009***

* Rybkowski et al. 2011 provides a useful insight into the learning objectives achieved through the facilitation of Target Value Design Simulation.

- Case Study: The application of root cause analysis and target value design to evidence-based design in the capital planning of healthcare facilities (Rybkowski. 2009)
    - Project information: Sutter Fairfield project, a 69,000 SF, a three-story medical office building in Fairfield, CA.

This research explores the results after implementation of Target Value Design principles on the Sutter Fairfield project. Mike Tesmer, Director of Preconstruction Services at Boldt Company stated that the cost estimates for the project would be minimized if all stakeholders were involved early in the design process. Figure 29 illustrates the Tesmer's diagram which explained how the project cost estimates changed over time for the two project delivery methods.

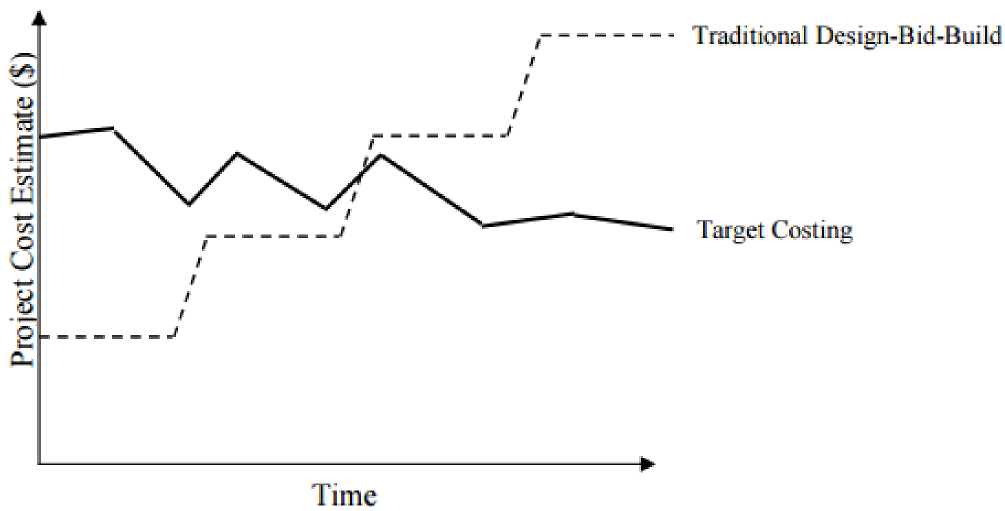


Figure 29: Tesmer's diagram. Reprinted with permission from Rybkowski (2009, page 140).

During the implementation of Target Value Design principles, it was found that it is necessary to "align the project scope, budget and schedule to deliver customer and stakeholder value" (Rybkowski 2009, page 142). The estimated project cost for the Sutter Fairfield project reduced dramatically over the course of collective efforts according to Figure 30.

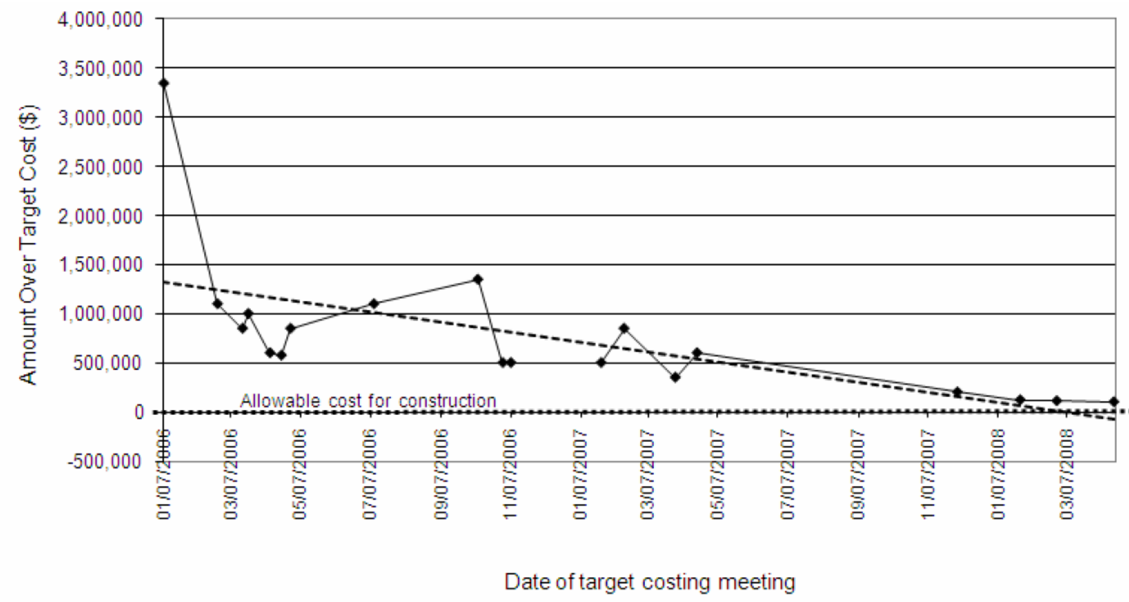


Figure 30: Project estimates over time for the Sutter Fairfield project. Reprinted with permission from Rybkowski (2009, page 141)

The estimated costs evolved over the course of the project. Figure 31 illustrates the relationship between Market cost, Target cost, and Actual cost. The original market cost or benchmark estimate for the project was $22 million and the target cost set by the project team was $ 18.9 million (14% below the original cost).After the project was completed, the actual cost measured was $17.9 million (19% below the original cost)

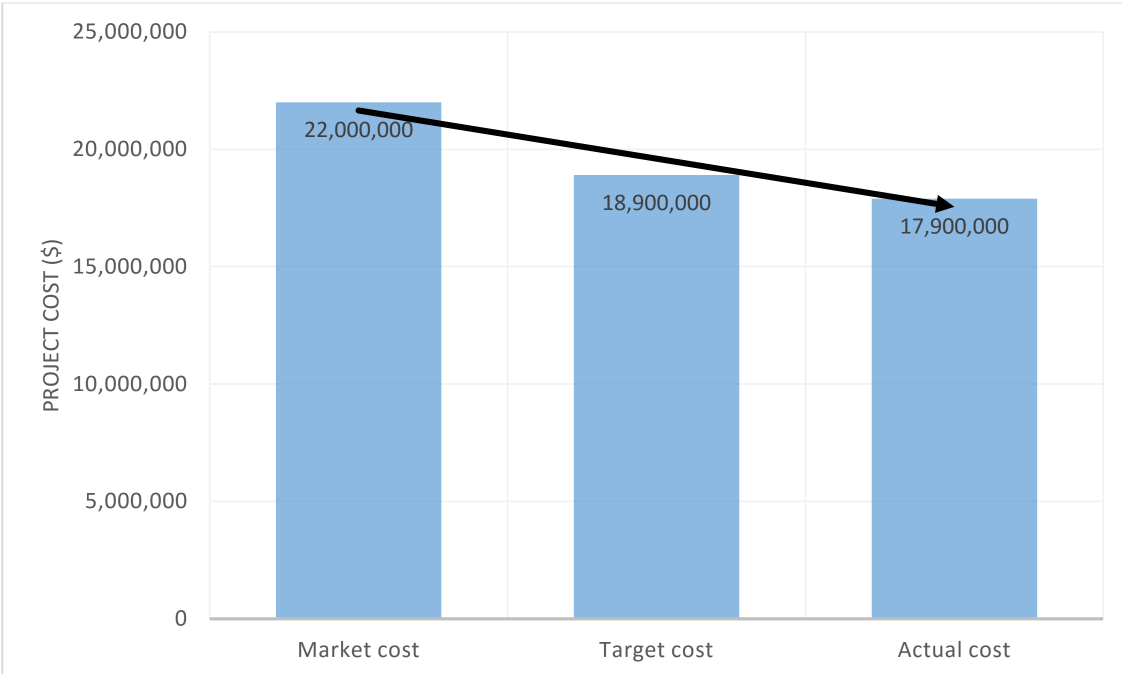


Figure 31: Relationship between market cost, target cost, and actual cost

CHAPTER VI

CONCLUSION

This paper provides a framework with an outline of lean principles and their application to construction sites through an analysis of published case studies. The case studies document impacts on the success of a project where time, cost and quality have been improved.

This framework has the potential to assist novices in making memorable links (simple and clear) between the lean principles and their applications on actual construction projects.

This research explored 15 of the 33 simulations currently documented by “LCI Simulation Matrix” published by Lean Construction Institute. The intent is that the future researchers will expand on this framework and its usefulness in helping construction stakeholders understand and implement lean.

REFERENCES

Aapaoja, A. and Haapasalo, H. (2014). "The Challenges of Standardization of Products and Processes in Construction". *Paper presented at the Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014., 938-993*

AlSehaimi, A. O., Tzortzopoulos, P., and Koskela, L. (2009). “Last planner system: Experiences from pilot implementation in the Middle East”. *Paper presented at the Proceedings of 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009. pp 53-66*

Ahiakwo, O., Oloke, D., Suresh, S., and Khatib, J. (2013). "A Case Study of Last Planner System Implementation in Nigeria". *Paper presented at the Proceedings of 21st Annual Conference of the International Group for Lean Construction, 699-707.*

Alarcón, I., Christian, D., and Tommelein, I. D. (2011). "Collaborating with a permitting agency to deliver a healthcare project: Case study of the Sutter Medical Center Castro Valley (SMCCV)". *Paper presented at the Proceedings of 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 Jul 2011, 402-415.*

Arbulu, R. J., and Tommelein, I. D. (2002). "Value stream analysis of construction supply chains: case study on pipe supports used in power plants". *Paper presented at the Proceedings of International Group for Lean Construction ,Vol. 10, 183-195.*

Arbulu, R. (2006). "Application of pull and CONWIP in construction production systems". *Paper presented at the Proceedings of 14th Annual Conference of the International Group for Lean Construction. Santiago, Chile,215-226.*

Ashwin, A., and Pitts, K. (2007). "Developing learning materials for the unknown online learner :The Challenges of Educating People to Lead in a Challenging World", *273-290*: Springer.

Balfour Beatty Construction. "Pull planning wall with post-it notes on a weekly calendar." *<http://buildingwithpurpose.us/clt/wp content/uploads/2013/07/pullplanning.jpg>(March 22, 2016)*

Ballard, G. (2001). "Cycle Time Reduction in Home Building". *Paper presented at the Proceedings of 9th Annual Conference of the International Group for Lean Construction. Singapore, Singapore, 6-8 Aug 200*1.

Ballard, G. (2000). "The Last Planner System of Production Control". *A Ph.D. Thesis, School of Civil Engineering, University of Birmingham.*

Ballard, G., Dilsworth, B., Do, D., Low, W., Mobley, J., Phillips, P. andWood, N. (2015). "How to Make Shared Risk and Reward Sustainable". *Proceedings of the 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015, 257-266.*

Barry,D. (2014)"Shadow board."<*http://davebarryplastics.com/wp-content/uploads/2014/08/P1050353.jpg> (March 21, 2016)*

Bashir, M. A., Suresh, S., Proverbs, D. G., and Gameson, R. (2010) "Barriers towards the Sustainable Implementation of Lean Construction in the United Kingdom". *ARCOM doctoral workshop, 25 June, University of Wolverhampton.*

Bjornfot, A., and Stehn, L. (2005). "Product design for improved material flow: a multi-storey timber housing project". *Proceedings of the 13th International Group for Lean Construction Conference, 297.*

Bortolazza, R. C., Costa, D. B., and Formoso, C. T. (2005). "A quantitative analysis of the implementation of the Last Planner System in Brazil". *Paper presented at the Proceedings of 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005., 413-420.*

Bulhões, I., and Picchi, F. (2008). "Continuous flow for structural design in prefabricated concrete structures". *Paper presented at the Proceedings of 16th Annual Conference of the International Group for Lean Construction. Manchester, UK, 16-18 Jul 2008.,169-181.*

Caňizares, C. A., and Faur, Z. T. (1997). "Advantages and disadvantages of using various computer tools in electrical engineering courses". *Education, IEEE Transactions on, 40(3), 166-171.*

Chin, S., Yoon, S.W. , Jung, S.0. , Kim, Y.S. , Kim, C.D. , Choi, Y.K. , Chun, J.Y. and Lim, H.C. (2004). "An Analysis of the Life-Cycle Curtain Wall Process Through Supply Chain Management". *Proceedings of 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark, 3-5 Aug 2004.*

Do, D., Chen, C., Ballard, G., and Tommelein, I. (2014). "Target value design as a method for controlling project cost overruns". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014. 171-181.*

Ellington, H. (2001)."Using games, simulations and case studies to develop key skills". *SAGSET (Society for the Advancement of Games and Simulations in Education and Training) keynote address*.

Elsborg, S., Bertelsen, S., and Dam, A. (2004). "BygLOK–A Danish experiment on cooperation in construction". *Paper presented at the Proceedings of 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark, 3-5 Aug 2004.*

Emmitt, S., Sander, D., and Christoffersen, A. K. (2004). "Implementing value through lean design management". *Paper presented at the Proceedings of 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark, 3-5 Aug 2004.*

Esquenazi, A., and Sacks, R. (2006). "Evaluation of lean improvements in residential construction using computer simulation". *Paper presented at the Proceedings of 14th Annual Conference of the International Group for Lean Construction. Santiago, Chile,137-149.*

Fernandes, N. B. L. S., Saggin, A.B. , Valente, C.P. , Brito, F.L. and Mourão, C.A.M.A. (2015). "The Standardized Work Tool Applied to the Waterproofing Process With Acrylic Membrane". *Proceedings of 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015, 133-142*.

Fiallo, M., and Revelo, V. (2002). "Applying the last planner control system to a construction project: a case study in Quito, Ecuador". *Paper presented at the Proceedings of the 10th Annual conference of the International Group for Lean Construction, 6-8 Aug 2002.*

Forbes, L. H., and Ahmed, S. M. (2010). "Modern construction: lean project delivery and integrated practices": *CRC Press.*

Formoso, C. T., and Moura, C. B. (2009). "Evaluation of the impact of the Last Planner System on the performance of construction projects". *Paper presented at the Proceedings of 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009.,153-164.*

Fosse, R., Kalsaas, B. T., and Drevland, F. (2014). "Construction Site Operations Made Leaner and Standardized: A Case Study". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014., 823-834.*

Fundli, I. S., and Drevland, F. (2014). "Collaborative Design Management–A Case Study". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014., 627-638.*

Gallardo, C. A. S., Granja, A. D., Picchi, F., and Folch, A. (2006). "Stabilization and standardization of a precast production process". *Proceedings of 14th Annual Conference of the International Group for Lean Construction. Santiago, Chile, 205-213*.

Hamedi, M. , Sharafi, Z. and Ashraf-Modarres, A. (2009), "Standardization of Fossil-Fuel Power Plant Projects According to Lean Construction Principles" .*Paper presented at the Proceedings of 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009.,31-42*

Heyl, J. V. (2015). "Lean Simulation in Road Construction: Teaching of Basic Lean Principals". *Paper presented at the Proceedings of 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015., 403-412*.

Hill, K., Slivon, C., and Draper, J. (2007). Another approach to transforming project delivery: Creating a shared mind. *Proceedings of 15th Annual Conference of the International Group for Lean Construction. East Lansing, Michigan, USA, 18-20 Jul 2007. pp 417-422*, 417-422.

Hirota, E. H., and Formoso, C. T. (1998). "Some directions for developing construction management training programs on lean construction". *Paper presented at the Proceedings of 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, 13-15 Aug 1998.*

Hopp, W. J., and Spearman, M. L. (2011). "Factory physics": *Waveland Press*.

Izquierdo, J., Cerf, M., and Gomez, S. (2011). "Lean Construction Education: basic management functions workshop". *Proceedings of 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 Jul 2011*.

Junior, J., Scola, A., and Conte, A. (1998). "Last planner as a site operations tool". *Paper presented at the Proceedings of 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, 13-15 Aug 1998.*

Kalsaas, B. T., Gundersen, M., and Berge, T. O. (2014). "To Measure Workflow and Waste. A Concept for Continuous Improvement". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,835-846*.

Kalsaas, B. T., Skaar, J., and Thorstensen, R. T. (2009). "Implementation of Last Planner in a medium-sized construction site". *Paper presented at the 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009.,15-30.*

Kerosuo, H., Mäki, T., Codinhoto, R., Koskela, L., and Miettinen, R. (2012). "In time at last: Adaption of Last Planner tools for the design phase of a building project". *Paper presented at the Proceedings of 20th Annual Conference of the International Group for Lean Construction. San Diego, USA, 18-20 Jul 2012, 1031-1041.*

Kim, Y.-W., and Jang, J.-W. (2005). "Case study: An application of last planner to heavy civil construction in Korea". *Paper presented at the Proceedings of 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005., 405-411.*

Kim, Y., and Bae, J. (2009). "Supply chain costs analysis using activity-based costing: case study in rebar supply". *Paper presented at the Proceedings of 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009.,113-126.*

Kim, Y., and Lee, H. W. (2010). "Analyzing user costs in a hospital: methodological implication of space syntax to support whole-life target value design". *Proceedings of 18th Annual Conference of the International Group for Lean Construction. Haifa, Israel, 14-16 Jul 2010.,93-102.*

Koskenvesa, A. and Koskela, L. (2003). "Introducing Last Planner: Finnish Experiences". *CIB Conference, Helsinki*

Kulkarni, A. S., Rybkowski, Z. K., Fernández-Solís, J., and Shepley, M. (2012). "Cost comparison of collaborative and IPD-like project delivery methods versus competitive non-collaborative project delivery methods", Texas A&M University.

Lean, J., Moizer, J., Towler, M., and Abbey, C. (2006). "Simulations and games Use and barriers in higher education". *Active Learning in Higher Education, 7*(3), 227-242.

Lean Construction Institute (2015). “LCI Simulation Matrix” *<http://www.leanconstruction.org/simulation/>, (March 23,2016)*

Leino, A., Heinonen, R. and Kiurula, M. (2014). "Improving Safety Performance Through 5S Program". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,1401-1412*.

Liker, J. K. (2005). "The Toyota way": *Esensi*.

Martinez, E. H., Alvear, A. M., Tommelein, I. D., and Ballard, G. (2015). "Formwork Standardization and Production Flow- Lessons From an Affordable Housing Project in Ecuador". *Proceedings of 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015.,53-59*.

Maturana, S., Alarcón, L. F., and Deprez, M. (2003). "Modeling the impact of multiskilling and concrete batch size in multi-storey buildings". *Paper presented at the Proceedings of 11th Annual Conference of the International Group for Lean Construction. Virginia, USA,553-566.*

Maturana, S., Alarcon, L. and Vrsalovic, M. (2004). "Achieving Collaboration in the Construction Supply Chain: An Onsite Subcontractors' Evaluation Methodology". *Proceedings of 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark, 3-5 Aug 2004*.

McGrawHill Construction (2013) "Lean Construction: Leveraging collaboration and advanced practices to increase project efficiency". *SmartMarket Report*

Melo, R. S. S. D., and Alves, T. D. C. (2010). "Investigation of the supply chain of prefabricated wooden doors". *Lean Construction Journal, 30-42*.

Melo, R. S. S. D., Kaushik, A., Koskela, L., Granja, A. D., Keraminiyage, K., and Tzortzopoulos, P. (2014). "Target costing in construction: a comparative study". *Paper presented at the Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014., 183-194.*

Modegh, S. G. (2013). "An Evaluation of Waste in Steel Pipe Rack Installation". *Proceedings of 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013.,729-738*.

Mohamad, A. , Gehbauer, F. and Haghsheno, S. (2014), "Improving the Implementation of Modularization and Standardization of MEP Systems in Design"'. *Paper presented at the Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,509-518*

Nakagawa, Y. (2005). "Importance of standard operating procedure documents and visualization to implement lean construction". *Paper presented at the Proceedings of 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005.,207-215.*

Ng, K., Laurlund, A. , Howell, G., and Lancos, G. (2010). "An Experiment With Leading Indicators for Safety". *Proceedings of 18th Annual Conference of the International Group for Lean Construction. Haifa, Israel, 14-16 Jul 2010., 253-259.*

Nofera, W., Abdelhamid, T. S., and Lahouti, A. (2015). "Teaching Lean Construction for University Student (S)". *Proceedings of 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015., 424-433*.

Ohno, T. (1988). "Toyota production system: beyond large-scale production": *CRC Press.*

Oliva, C. A., and Granja, A. D. (2013). "An Investigation Into Collaborative Practices in Social Housing Projects as a Precondition for Target Value Design Adoption". *Paper presented at the Proceedings of 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013., 429-437.*

Parrish, K., Wong, J. M., Tommelein, I. D., and Stojadinovic, B. (2008). "Set-based design: case study on innovative hospital design". *Paper presented at the Proceedings of* 16*th Annual Conference of the International Group for Lean Construction (IGLC 16), Manchester, UK.*

Porwal, V., Dave, B., Fernandez-Solis, J., Koskela, L. J., and Mehta, H. S. (2012). "State of production plan reliability–a case study from India". *Paper presented at the Proceedings of* 20th Annual Conference *International Group for Lean Construction. San Diego, USA, 18-20 Jul 2012.*

Riley, D., and Horman, M. (2001). "Effects of design coordination on project uncertainty". *Paper presented at the Proceedings of 9th Annual Conference of the International Group for Lean Construction. Singapore, Singapore, 6-8 Aug 2001*.

Rolfe, J. (1991) "SAGSET 1990 – The Proof of the Pudding"*: The Effectiveness of Games and Simulations', Simulations/Games for Learning 21(2): 99–117.*

Rybkowski, Z. K., Wong, J. M., Ballard, G., and Tommelein, I. D. (2008). "Using controlled experiments to calibrate computer models: the Airplane Game as a lean simulation exercise". *Proceedings of 16th Annual Conference of the International Group for Lean Construction., 309-319.*

Rybkowski, Z. K. (2009). The application of root cause analysis and target value design to evidence-based design in the capital planning of healthcare facilities, *Doctoral dissertation, University of California, Berkeley.*

Rybkowski, Z. K., Munankami, M., Gottipati, U., Fernández-Solis, J., and Lavy, S. (2011). "Toward an Understanding of Cost and Aesthetics: Impact of Cost Constraints on Aesthetic Ranking Following Target Value Design Exercises". *Proceedings of 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 Jul 2011*.

Rybkowski, Z. K., Zhou, X., Lavy, S., and Fernández-Solís, J. (2012)."Investigation into the nature of productivity gains observed during the Airplane Game lean simulation". *Lean Construction Journal 2012, 78*-90.

Rybkowski, Z. K., and Kahler, D. L. (2014). "Collective Kaizen and Standardization: The Development and Testing of a New Lean Simulation". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,1257-1268*.

Sacks, R., Derin, Z., and Goldin, M. (2005). "Pull-driven construction of high-rise apartment buildings". *Paper presented at the Proceedings of 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005., 217-226.*

Salem, O., Solomon, J., Genaidy, A., and Luegring, M. (2005). "Site implementation and assessment of lean construction techniques". *Lean Construction Journal, 2(2), 1-21*.

Sarhan, S., & Fox, A. (2013). "Barriers to implementing lean construction in the UK construction industry". *The Built & Human Environment Review, 6(1).*

Shen, L., and Chua, D. (2005). "Impact of variability on construction schedules". *Proceedings of 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005.,375-383*.

Smith, J. P., and Rybkowski, Z. K. (2013). "The Maroon and White Game: A simulation of trust and long-term gains and losses". *Paper presented at the Proceedings of 21st Annual Conference of the International Group for Lean Construction,Fortaleza, Brazil, July 2013., 987-996.*

Soares, A.C. , Bernardes, M.M. and Formoso, C.T. (2002). "Improving the Production Planning and Control System in a Building Company - Contributions After Stabilization". *Paper presented at the Proceedings of 10th Annual Conference of the International Group for Lean Construction. Gramado, Brazil, 6-8 Aug 2002.*

Souza, D. V. S. D., and Koskela, L. (2014)." Interfaces, Flows, and Problems of Construction Supply Chains – A Case Study in Brazil". *Paper presented at the Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,1095-1106*.

Tommelein, I. D., Riley, D. R., and Howell, G. A. (1998). "Parade game: Impact of workflow variability on trade performance". *Proceedings of 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, 13-15 Aug 1998*.

Tommelein, I. D., and Li, A. (1999). "Just-in-time concrete delivery: mapping alternatives for vertical supply chain integration". *Paper presented at the Proceedings of 7th Annual Conference of the International Group for Lean Construction. Berkeley, USA, 26-28 Jul 1999.,97-108.*

Tommelein, I. D., and Beeche, G. (2001). "De-Coupling Cladding Installation From Other High-Rise Building Trades: A Case Study". *Paper presented at the Proceedings of 9th Annual Conference of the International Group for Lean Construction. Singapore, Singapore, 6-8 Aug 2001.*

Tribelsky, E., and Sacks, R. (2010). "The relationship between information flow and project success in multi-disciplinary civil engineering design". *Paper presented at the Proceedings of 18th Annual Conference of the International Group for Lean Construction. Haifa, Israel, 14-16 Jul 2010.,140-150.*

Tsao, C. C., Tommelein, I. D., Swanlund, E., and Howell, G. A. (2000). "Case study for work structuring: Installation of metal door frames". *Paper presented at the Proceedings of 8th Annual Conference of the International Group for Lean Construction. Brigthon, UK, 17-19 Jul 2000.*

Tsao, C., Alves, T., and Mitropoulos, P. (2012). "Different perspectives on teaching lean construction". *Paper presented at the Proceedings of 20th Annual Conference of the International Group for Lean Construction. San Diego, USA, 18-20 Jul 2012.*

Tsao, C., Azambuja, M., Hamzeh, F. R., Menches, C., and Rybkowski, Z. K. (2013). "Teaching lean construction—Perspectives on theory and practice". *Paper presented at the Proceedings of 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013.,977-986*.

Tsao, C., and Hammons, G. J. (2014). "Learning to See Simplicity within a Complex Project Through the Lens of Pull Planning". *Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,751-762*.

Valente, C. P., Montenegro, G. A., Brito, F. L., Biotto, C. N., Mota, B. P., and Schramm, F. K. (2013)."Benefits of Batch Size Reduction: A Case Study in a Residential Project". *Proceedings of 21th Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil, 31-2 Aug 2013.,1029-1038*.

Vibco. "Floor marking to indicate clear access in aisle" *<http://www.vibco.com/images/continuous-improvement/aisle-clear338551B4FD61.jpg>(March 21, 2016)*

Vrijhoef, R., and Koskela, L. (2000). "Roles of supply chain management in construction". *Proceedings of 7th Annual Conference of the International Group for Lean Construction. Berkeley, USA, 26-28 Jul 1999*.

Warcup, R., and Reeve, E. (2014). "Using the Villego® Simulation to Teach the Last Planner® System". *Lean Construction Journal, January 1.,*

Walters, B. A., Coalter, T. M., and Rasheed, A. M. (1997). "Simulation games in business policy courses: Is there value for students?" *Journal of Education for Business, 72*(3), 170-174.

Ward, S., and McElwee, A. (2007). "Application of the principle of batch size reduction in construction". *Paper presented at the Proceedings of 15th Annual Conference of the International Group for Lean Construction. East Lansing, Michigan, USA, 18-20 Jul 2007., 539-548.*

Wildman, S., and Reeves, M. (1997). "The value of simulations in the management education of nurses: students' perceptions". *Journal of Nursing Management, 5*(4), 207-215.

APPENDIX A SECTION 5.1: LEAN SIMULATION FACILITATION GUIDELINES

LEGO^{TM} "Airplane" simulation

LEGO "AIRPLANE" Game

Courtesy: Visionary Products
(http://www.visionaryproducts.biz/Home/Products/LZPM/tabid/61/Default.aspx)

Lean Principles Illustrated

To illustrate the importance of small batch size, pull planning and multi-skilled workforce

Learning Objective

- The benefits of cellular manufacturing over traditional plant layouts
- The effects of rapid throughput with traditional manufacturing
- Work-in-progress as a manageable asset
- Inventory risks
- Independent cross training
- Flexible workforce (load leveling)
- One-piece workflow with a pull system

Target Audience

Anyone in the construction industry

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 2
- Facilitator : 4

Number of players per facilitation

1 facilitator per round, 5 players per team

Duration per facilitation

- 3 rounds of six minutes each. Duration of (Setup+Play+debrief) :
  Minimum : 1.5 hours
  Ideal: 2 hours

Materials required per facilitation

- 20-page instruction manual (Visionary products)
- Flip Charts
- Stopwatch
- Feeler gauge
- Markers
- More than 1000 plastic interlocking parts for constructing airplanes

Facilitation Guidelines

- Get the participants in groups of 5 per team around a workstation with materials distributed to each workstation as per illustration in Figure 1

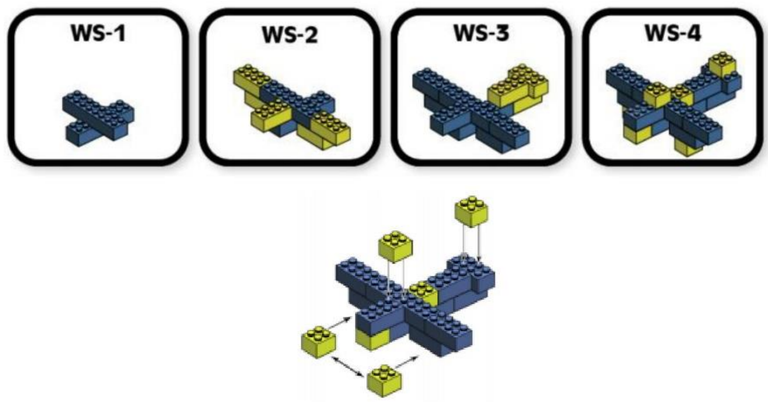


Figure 1: First four workstations of LEGO "Airplane" Game

- Each workstation assembles the plane according to the instructions given in the manual and the completed plane is inspected by the participant acting as the quality control manager. The airplane that passes the quality inspection is stored in the accepted pile and if it fails the quality inspection is stored in the rejected pile.
- The game is played in four rounds:
  - Phase 1: Push system (push system, unleveled work load")
  - Phase 2: Cellular layout (batch size of 5, push system, unleveled work load; e.g. "5 Push")
  - Phase 3: One-piece flow (batch size of 1, pull system, unleveled work load; □ e.g. "1 Pull")
  - Phase 4: Load-leveling (batch size of 1, pull system, leveled work load; e.g. "1 Even")
- The facilitator recorded the time to first batch, Total number of successful planes and total work in process (WIP)

Discussion

Table 1: Typical results during facilitation of LEGO "Airplane" Game

	Time to 1st Batch	# of planes	WIP 1	WIP 2	WIP 3	WIP 4	Total WIP
5 Push	206	10	88	5	5	4	102
1 Push	46	18	69	1	1	1	72
1 Pull	46	18	1	1	1	1	4
1 Even	46	29	1	1	1	1	4

- Transitioning to smaller batch sizes is reduced time to first batch (206 to 46)
- Moving from a push to a pull system is reduced WIP (72 to 4)
- Load-leveling increases quantity of final product (18 to 29).
- How can these principles be applied to real time construction activities?

References

Lean Construction Institute (2015). "LCI Simulation Matrix." <http://www.leanconstruction.org/simulation/> (March 23, 2016)

Rybkowski, Z. K., Zhou, X., Lavy, S., and Fernández-Solís, J. (2012)."Investigation into the nature of productivity gains observed during the Airplane Game lean simulation". *Lean Construction Journal 2012, 78*-90.

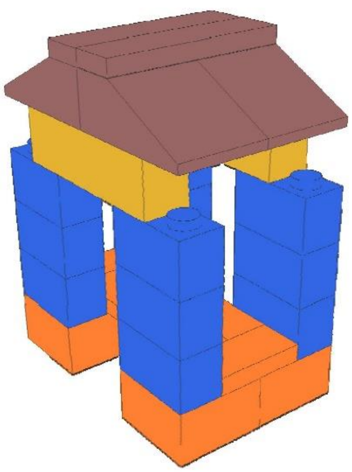
Rybkowski, Z. K., Wong, J. M., Ballard, G., and Tommelein, I. D. (2008). "Using controlled experiments to calibrate computer models: the Airplane Game as a lean simulation exercise". *Proceedings of 16th Annual Conference of the International Group for Lean Construction., 309-319.*

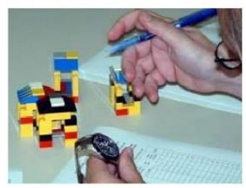
LEAPCON simulation

Technion LEAPCON™ (Lean Apartment Construction) Game

Technion LEAPCON Game

Technion Lean Apartment Construction Game





2nd Edition, January, 2007

Dear Facilitator,

Welcome to the 'Technion Lean Apartment Construction' simulation game. The game demonstrates the impacts of pull flow scheduling, single-unit batching and work restructuring in multi-tasking teams by simulating the finishing works of high-rise apartment construction, which is traditionally subject to high degrees of variation and uncertainty.

This kit contains all of the materials you will need to play the game, with the exception of the LEGO® bricks, a clock or watch that shows seconds, pencils, markers, etc. An overhead projector is useful for showing the blank result chart, but you can equally copy it onto a whiteboard or a large blank page. A list of the LEGO® bricks needed is provided with the facilitator's instructions.

If you use the game, we ask that you do two things:

1) ***Please cite its' use in any of your own work by referring to one of the publications listed in the publications section of the kit.***
2) ***Please send the results of each play, together with your comments and some notes on the nature of the group playing, by e-mail, to cvsacks@technion.ac.il***

Sincerely,

Dr. Rafael Sacks

Technion LEAPCON™ (Lean Apartment Construction) Game

Copyright

Disclaimer

The LEAPCON game is available as a PDF file containing a complete set of instructions, all of the playing cards, role definitions, building layout cards, tables of results, and a detailed list of the LEGO parts that you will need. The LEGO parts can be ordered quite easily at the LEGO online store http://shop.lego.com - there is a detailed list of the parts you need in the instructions. The file is 4.5MB, 60 pages

The game cannot be included in this thesis because of copyright issues, but it can be accessed for academic purposes through a confirmation from Dr. Rafael Sacks (email - cvsacks@tx.technion.ac.il)

DOT simulation

The Dot Game

Based on Lean Manufacturing Cup Game:
http://lean.vel.pl/index2.php?option=com_content&task=view&id=85&Itemid=111&pop=1&page=0

Then modified to not use cups.

Purpose

Concepts to be understood:

- How people doing work in front of a bottleneck that adds to the queue of the bottleneck are actually causing problems. The more of this they do the more problems they are causing
- Having too much work in progress adds to the waste of the system and makes it harder to detect and fix problems

Other concepts:

- If there is no productive work you can do, then it is better to do something outside of this value stream that you can complete on your own – this can include any of the things people always want to get to but never have time – however, it cannot create new work in progress that will create delays in another value stream.

Materials Required (see figure 1 – except forget the cups!):

- 3x3 yellow post-its (enough packs for 300 stickies)
- 3/4 inch round assorted color dots: (3 Packs)

Figure 1: the materials needed for the software factory game.

Instructions

We used to play this game with multiple groups. An alternative is to have one game going on and everyone else observing. This takes 8 participants, and the rest are observers. If you have more than 25 people or so, you can have a group of 8 for every 25 participants as it gets difficult to observe if there are more people than that. However, I have successfully run this game with 30 observers. If you want to run as many games as possible it is useful to have a few observers spread amongst the teams.

This game is significantly simpler than the original cup game.

The game is played in 3 rounds, each lasting about 20 minutes – 5 minutes prep, 5 minutes running the game, 10 minutes group discussion (where the real learning takes place).

The purpose of the game is to complete software features, which are defined to be 1 yellow post-its in it that has 6 colored stickers in the following pattern/order:

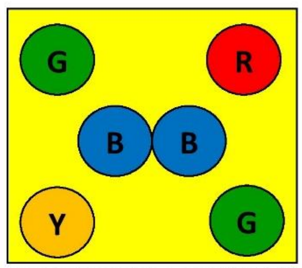


Figure 2: Each "done" post-it represents contain a completed "feature"—3x3 yellow post-it with dot stickers placed in the correct location.

There are very many ways to run this game and they all tend to work. My favorite is to make an example of the desired stickie on a white board and tell them this is what you want. Draw it imperfectly (the outer dots touching the edge, for example). Then, when they do the game, they certainly won't get it right. You can then discuss acceptance criteria during the discussion. However, people typically don't get it right even if you give them an exact example.

The last two pages of this document are the student instructions. Print 7 copies, single sided of these pages to give to each participant so they can orient the second page with the way the sit. Everyone gets a copy but the customer.

Players:

1. Business Analyst
2. Technical Analyst (Can combine BA and TA if needed)
3. Designer
4. UI Developer
5. Developer
6. Tester

7. Project manager (must have a watch with a second hand).
8. Customer

The rules change each round.

Round 1

Push. Strict hand-off, big batches (6), testing last.

Round 1 Details: Have all the materials on each table, and have each of the “roles”, other than the customer, arranged around the table in a U order (see figure 3).

Designer		UI Developer
Technical Analyst		Developer
Business Analyst	IN AREA (materials)	Tester OUT AREA

Figure 3: Roles around the table

Instructions to give participants

Each role has an “in” area and an “out” area. None of the roles are allowed to talk to each other about quality. If stickers are falling off, it is up to the tester to “discover” the defects and place them in the defective pile. NOTE: This was the original rule but I have been finding that not stating this rule has people not talk about quality in any event. The fact that they are not instructed to not talk about quality and they still don’t is pretty illuminating.

In round one, the work proceeds as follows:

1) BA picks 6 post-its and passes them to the tech analyst
2) Tech analyst puts on the yellow dot
3) Designer puts on red dot
4) UI Developer puts on green dots
5) Developer puts on blue dots
6) Tester tests – puts in defect area if things don’t look like figure 2.

7) Project manager times:
   a. Time it takes for first batch to be completed
   b. Warns team when there is one minute left
   c. Tells team when time is out (after 5 minutes)

You can have some fun if you act like a manager telling people to focus on their work and not worry about other people. That if each role works hard and does the best it can that has to result in the best costs. If each station has the lowest cost then the overall cost will be lowest.

Basically, everyone is to work as fast as they can and not worry if they are being kept up with. They are being measured on how *they* are doing, not the total throughput.

To start things off, tell the customers to come to you and tell the team to get going. While the teams are working, tell the customers that they will not accept anything where the blue dots are overlapping or not touching. Also, if the dots in the corner are not fairly evenly spaced from the two sides, they can reject those as well. Tell the customer to respond to people when asked but not to volunteer information.

NOTE: Be sure to tell observers that they can only observe. They should not communicate to the participants. If they talk amongst themselves they have to do so in a way that no participants hear them.

At end of round 1

After 5 minutes, have the customers say how many of the features are accepted. Have the PM total the following:

1) # of completed post-its
2) # of accepted post-its
3) # of post-its that are in progress (WIP)

A normal team will get about 3 batches of 6 "done" in 5 minutes. Depending on how mean the tester is they might pass none or all, but the "customer" will probably accept 0.

Stop here and discuss how long it took for each team to get any completed work (i.e. the first batch done). It should be around 2.5-3 minutes, so notice "cycle time" that was first measured was 3 minutes. HOWEVER, this is a great time to revisit CT = WIP/TP. Here, TP would be 18 (ignoring pass/fail). If they are like most teams, bottlenecks begin to occur during the 5 minutes, and the might have 60 postits on the table. So in this case:

WIP: 60
TP: 18/5 minutes = 3.6 postits per minute
CT = WIP/TP = 60/3.6 = 16.7 MINUTES (not 3 like we measured for the first batch)!!

This is an important point of emphasis, that the first batch was done in 3 minutes, but our bottlenecks are making it rise as more and more WIP gets opened!!!!!!

Round 2:
I recommend some discussion before revisiting and doing round 2. Talk about minimizing WIP, pull, and smooth flow, and how it helps productivity AND quality at the same time. Emphasize that in round 2 we are going to "slow down to speed up"!!!!!!!

Set it up again, but let them do one-piece flow. Still need to have each person do their own role.

OPTIONAL: Can change the requirement but don't need to. They will likely validate things quickly now so even with this delay results will be better. But don't need to do this. Make it sound like the requirements are the same, but go ahead and establish for the whole group that quality matters, and the blue dots have to be perfectly touching in the middle make the requirements be the corner dots have to touch the ends of the post-it as shown in figure 4.

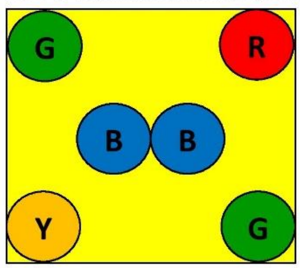


Figure 4.

In a three segment offering, round two should just do 1-piece flow. Don't allow smoothing. See what happens. Then, in round three allow for smoothing. If this is the last round, then let them do what they want.

Suggest that they smooth the flow by balancing out the number of dots, and if anyone "frees up" from reorganizing, they can help "test". Discuss "in-place" testing, and how there should be little or no opportunities for failing final testing. People will almost certainly ask the customer this time (tell them it is ok to answer questions).

Do same timing and recording.

This round, the first post-it should come through in about 20 seconds!

Since we are doing 1 piece flow, and emphasizing "finish before you start", WIP should be 2-4 at most!

Teams can usually get at least 24 done, even with slowing down to get the dots right.

The first postit will come through about 20-25 seconds. Note that without bottlenecks, it should actually start to decrease, so have the PM measure several post-its end-to-end during the 5 minutes.

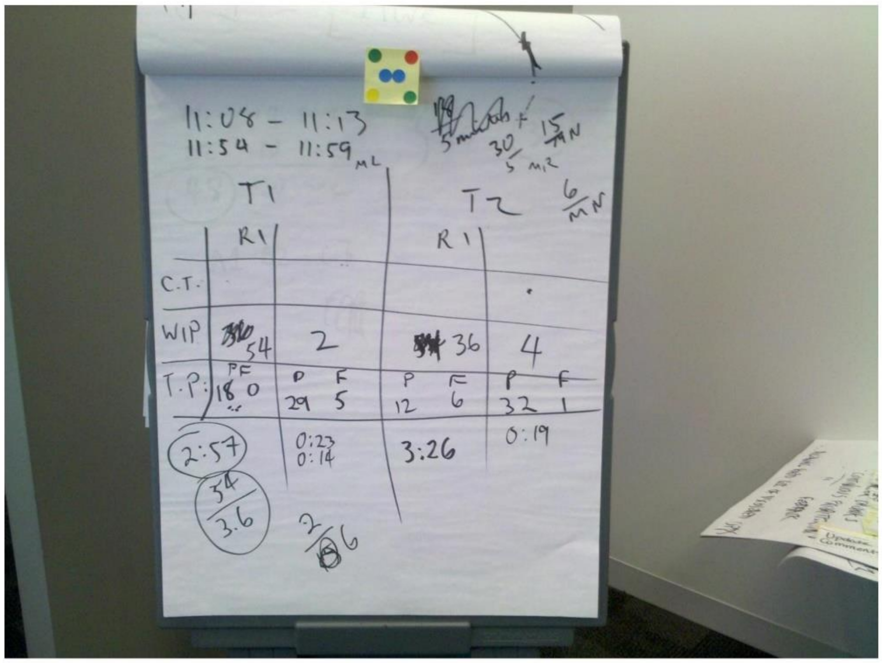
Now revisit the calculation!!!!!

WIP = 2

TP = 24 postits/5 minutes = 4.8 postits per minute

CT = WIP/TP= 2/4.8 = 0.4 minutes = 24 seconds!!!!!!

Emphasize that without bottlenecks, smooth flow made the cycle time stable and predictable!!!!!!!!



Round 3:

In this game, let them figure out how they can maximize throughput. They can load-balance if they like. But don't let anyone be able to do anything equally well. That is not realistic. You could say that those who do the first three roles can help in the roles doing two dots but can only do it at half speed. Before the game starts have a conversation about how the game and roles are like their software development. Ad lib so the game would mirror a real life load-balancing conversation.

I've often spent 10-15 minutes before they play discussing what they can do to help those who are stuck. This discussion often mirrors their real-world work – which is great.

The Dot Game – Handout to Participants

Based on Lean Manufacturing Cup Game:
http://lean.vel.pl/index2.php?option=com_content&task=view&id=85&Itemid=111&pop=1&page=0

Players:

1. Business Analyst
2. Technical Analyst (Can combine BA and TA if needed)
3. Designer
4. UI Developer
5. Developer
6. Tester
7. Project manager (must have a watch with a second hand).
8. Customer

Round 1:

Push. Strict hand-off, big batches (6), can only do your own work, test last.

Details: Have all the materials on each table, and have each of the "roles", other than the customer, arranged around the table in a U order (see figure 3).

Figure 3: Roles around the table

Each role's table has an "in" area and an "out" area. A person can only do work defined by their role, they cannot do the work of another role.

Each role should work as fast as they can. Don't worry if the person next to you isn't keeping up.

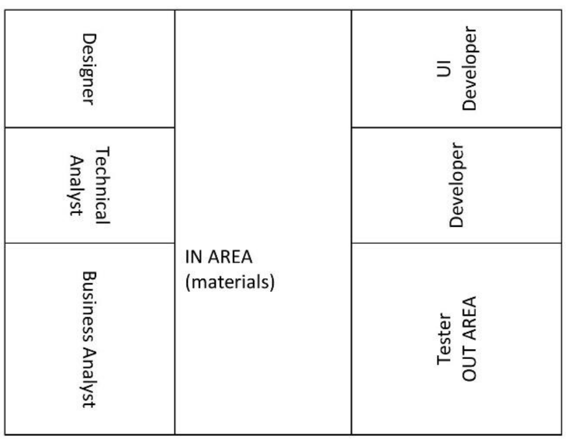
Also, remember you are working in batches – do 6 at a time and hand off all 6 at the same time.

In round one, the work proceeds as follows:

1) BA picks 6 post-its and passes them to the tech analyst
2) Tech analyst puts on the yellow dot
3) Designer puts on red dot
4) UI Developer puts on green dots
5) Developer puts on blue dots
6) Tester tests – puts in defect area if things don't look like figure 2.
7) Project manager times:
    a. Time it takes for first batch to be completed (when gets to customer)
    b. Warns team when there is one minute left
    c. Tells team when time is out (after 5 minutes)
    d. Make sure you don't stop your watch – most important is timing 5 minutes

After 5 minutes, have the customers say how many of the features are accepted. Have the PM total the following:

1) # of completed post-its
2) # of accepted post-its
3) # of post-its that are in progress (WIP)



Round 2 and Round 3 have no handouts.

Net Objectives

The Dot Game – Handout to Participants

(intentional duplicate)

Based on Lean Manufacturing Cup Game:
http://lean.vel.pl/index2.php?option=com_content&task=view&id=85&Itemid=111&pop=1&page=0

Players:

1. Business Analyst
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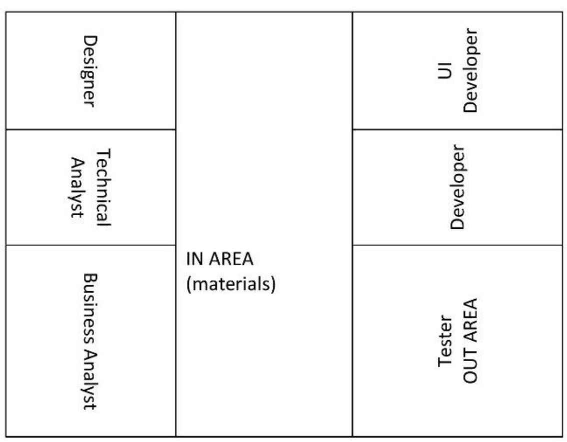

Round 2 and Round 3 have no handouts.

APPENDIX B SECTION 5.2: LEAN SIMULATION FACILITATION GUIDELINES

BEER “Lean Manufacturing” simulation

1

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University at Albany - State University of New York
Albany, NY 12222
Phone (518) 442-3865 Fax (518) 442-3398 E-mail: office@systemdynamics.org
http://www.systemdynamics.org

Instructions for Running the Production-Distribution Game

“The Beer Game”

Adapted from Instructions written by John Sterman;
Revised by System Dynamics Society, May 1998

The Production Distribution Game was developed by the System Dynamics Group at the MIT Sloan School of Management.

This document outlines the protocol for the Production-Distribution Game (The Beer Game), developed to introduce people to concepts of system dynamics. The game can be played by as few as four and as many as 60 people (assistance is required for larger groups). The only prerequisite, besides basic math skills, is that none of the participants have played the game before, or else agree not to reveal the "trick" of the game.

1. Purpose

   a. Introduce people to the key principle "structure produces behavior"
   b. Experience the pressures of playing a role in a complex system

2. Overview of production-distribution system

   a. Identify the four positions on the board: retailer, wholesaler, distributor, and factory. Each board will have one or two players at each position. Each board comprises one team.

   b. Each position is identical (except for the factory). Each position has an inventory of beer. Each position receives orders from and ships beer to the sector downstream. Each position orders beer from the sector upstream. Beer is received after a shipping delay. (In the case of the factory, beer is received after a production delay.) Orders are received after a mailing delay (orders placed to incoming orders).

3. Basic rules

   a. Have each team pick a name for their brewery (e.g. the name of a real beer).* Distribute one Record Sheet to each position and have them label their Record Sheet with the name of their brewery and their position, e.g. retailer, wholesaler, etc.

   b. Have each person ante up $1.00, or an appropriate amount, which will go to the winning team, winner takes all.

*Note: The product represented by the chips does not have to be beer. Any product appropriate to the group may be chosen by the facilitators.

c. The object of the game is to minimize total costs for your team. The team with the lowest total costs wins. Costs are computed in the following way: The carrying costs of inventory are $.50 per case per week. Out-of-stock costs, or backlog costs, are $1.00 per case per week. The costs of each stage (retailer, wholesaler, distributor, factory) for each week, added up for the total length of the game, determine the total cost.

d. No communication between positions. Retailers should not talk to anyone else, same for wholesalers, distributors, and factories. The reason for this is that in real life there may be five factories, several dozen distributors, thousands of wholesalers, and tens of thousands of retailers, and each one cannot find out what the total activity of all the others is. The only communication between sectors should be through the passing of orders and the receiving of beer.

e. Retailers are the only ones who know what the customers actually order. They should not reveal this information to anyone else.

4. Steps of the Game (see attached sheet). The game leader should call out the steps as the game progresses. The first few times when the system is still in equilibrium the leader should go through the steps very slowly to make sure people have the mechanics down. Notice that of the five steps of the game, only the last, placing orders, involves a decision. The first four steps only involve moving inventory of beer or order slips, and are purely mechanical. For the first few weeks the leader should tell everyone to order four units to keep the system in equilibrium.

5. Initialization of the boards

a. There should be twelve chips (or coins) representing twelve cases of beer in each inventory. Each chip or coin represents one case. There should be four chips in each shipping box and production delay. There should be order slips with "4" written on them, face down in each order box (orders placed, incoming orders, and production requests). A supply of blank order slips should be available at each position (see Initializing The Board sheet). A supply of chips should be placed at the factory for production of new cases of beer.

b. Place the customer order cards in the "order cards" box, with the order numbers face down, and the week number showing. Weeks 1 through 50 should be in order. The customer order cards with the customer demand should not be revealed in advance. The pattern of customer demand that is most effective for first-time players is a pattern of four cases per week until week five, and then eight per week from week five on. Each order deck should have fifty weeks' worth of cards, and the players should be told that the game will be fifty weeks long. Typically it is only necessary to run the game thirty-five weeks or so in order to see the pattern of fluctuation, but telling the players it will be fifty weeks prevents horizon effects, where they run their inventories down because they feel the end of the game is coming.

6. Tips

a. It is very helpful if the game leader makes sure that each team stays in step so that he/she can quickly glance around the room and see that everyone is at the right place.

b. The game leader should write the current week on the blackboard or flip chart as the steps for that week are called out.

c. In about the eighth or ninth week the retailer will run out of inventory and have a backlog for the first time. People do not understand the meaning of backlogs, or the cumulative nature of the backlog. It is necessary to stop the game at this point, ask everyone to pay attention, and explain how backlog accounting works. Explain that the backlog represents orders you have received, but have not yet filled, and which you must fill in the future. Explain that the backlog is cumulative. "Next week you have to fill the incoming orders that you receive, plus whatever is in your backlog, if possible. If not possible, then the amount left over is added to the existing backlog and must be filled in later weeks." Emphasize at this point that backlog costs twice as much as inventory. You may need to do this one or two more times, and should be careful to check and be sure that they do in fact fill their backlog. It is helpful to write the following equation on the blackboard to help with backlog accounting:

Orders to fill = New orders + Backlog
this week this week last week
(Please see "Orders to Fill" sheet)

d. The game can be played in as little as one and a half hours if the leader maintains a very brisk pace. The debriefing usually requires at least 40 minutes and can be expanded substantially.

The attached quotation from Tolstoy's War and Peace illustrates well the idea "structure produces behavior."

7. End of game

a. Halt the game after about 36 weeks (but play the game up to that point as if it is going on to 50 weeks, to avoid unusual end-of-game moves).

b. Ask each position on each team to calculate their total cost :

Cost = Total Inventory X $0.50 + Total Backlog X $1
and to mark the total cost on the Record Sheet for the position.

c. Pass out Orders graph sheets - one to each position. Ask each position to graph **their own** orders, week by week. Clarify to Factory that they will graph their Production Requests.

d. Pass out Effective Inventory graph sheets - one to each position. Ask each position to graph the inventory week by week, showing any backlog as negative inventory.

e. Team name and position must be indicated on all sheets. Once the graph is complete, have the players connect the dots with a bold magic marker (color coded - black, blue, green and red - to the board) for ease of viewing by the group.

f. Pass out the Customer Order graph sheets to everyone except Retailers. Ask each person to sketch what he or she thinks the customer order rate looked like over time. Ask each to indicate a simple scale or maximum value.

Ask Retailers not to discuss anything about customer orders until after the debrief of the game.

g. Collect all the sheets, and send players off for a break.

h. During break:

a) Calculate team costs to determine the winner, and compute the average team cost.

b) Tape sheets together (as shown below) and hang up team graphs.

Effective Inventory	**Orders/Production Requests**
Retailer	Retailer
Wholesaler	Wholesaler
Distributor	Distributor
Factory	Factory

Tolstoy on the "Laws of History"
War and Peace

Part 11, I:

"The first fifteen years of the nineteenth century present the spectacle of an extraordinary movement of millions of men. Men leave their habitual pursuits; rush from one side of Europe to the other; plunder, slaughter one another, triumph and despair; and the whole current of life is transformed and presents a quickened activity, first moving at a growing speed, and then slowly slackening again. What was the cause of that activity, or from what laws did it arise? asked the human intellect.

The historians, in reply to that inquiry, lay before us the sayings and doings or some dozens of men in one of the buildings of the city of Paris, summing up those doings and sayings by one word--revolution. Then they give us a detailed biography of Napoleon, and of certain persons favorably or hostilely disposed to him; talk of the influence of some of these persons upon others; and then say that this it is to which that activity is due, and these are its laws.

But the human intellect not only refuses to believe in that explanation, but flatly declares that the method of explanation is not a correct one, because in this explanation a smaller phenomenon is taken as the cause of a greater phenomenon. The sum of men's individual wills produced both the revolution and Napoleon; and only the sum of those wills endured them and then destroyed them.

‘But whenever there have been wars, there have been great military leaders; whenever there have been revolutions in states, there have been great men,' says history. 'Whenever there have been great military leaders there have, indeed, been wars,' replies the human reason; 'but that does not prove that the generals were the cause of the wars, and that the factors leading to warfare can be found in the personal activity of one man.'

...

For the investigation of the laws of history, we must completely change the subject of observations, must let kings and ministers and generals alone, and study the homogeneous, infinitesimal elements by which masses are led. No one can say how far it has been given to man to advance in that direction in understanding of the laws of history. But it is obvious that only in that direction lies any possibility of discovering historical laws; and that the human intellect has hitherto not devoted to that method of research one millionth part of the energy that historians have put into the description of the doings of various kings, ministers, and generals...."

OUTLINE FOR POST-GAME DISCUSSION

1. Get all the graph sheets of results (Orders, Effective Inventory) taped up for display.

2. Find out which team won (lowest total cost) and distribute the winnings.

3. Although they played the game to minimize cost, that is not the real purpose of the game.

The game is designed to:

1) give them an experience of playing a role in a system

2) show them how "structure produces behavior"

4. Ask participants what their experience of playing the game was. Some good leading questions are:

   1) Did you feel yourself "at the mercy" of forces in the system from time to time? Did you feel the effects of the forces in the system from time to time? (i.e., relatively helpless in the face of huge incoming orders or excess inventories)

   2) Did you find yourself "blaming" the person next to you for your problems?

5. After a few minutes (about 10) of discussion, look at the graphs of the results. Ask them, "What commonalities do you see in the graphs for the different teams?" Participants should see common pattern of overshoot and **oscillation**. This should be most evident in the effective inventory graph.

   - Get them to really **see** for themselves that different people in the same structure produce qualitatively similar results. Even though they acted very differently as individuals in ordering inventory, **still** the overall patterns of behavior are similar.

   Differences in individual ordering patterns (free will) result in the quantitative differences in game results. But the qualitative patterns are the same.

   - This is a very important point--take as long as necessary to have them see it for themselves.

   You might reflect at this point on what happens in the real world when such order-rate and inventory oscillations are generated. The typical organizational response is to find the "person responsible" (the guy placing the orders or the inventory manager) and blame him. The game clearly demonstrates how inappropriate this response is--different people following different decision rules for ordering **all** generated oscillations.

6. After having had them all see the extent to which different people produce similar results in a common structure, you then need to move on to what is usually the most powerful point made by the game: that internal structure, **not** external events, cause system behavior. The way to make this point is to ask the following question:

   "All of you who were not retailers, or who otherwise have not found out what the pattern of customer orders was, what do you think the customers were doing?"

   Most people usually believe that customer demand was fluctuating because they believe that the system fluctuations must have been externally driven. Get each of them (<u>other than retailers</u>) to see that they assumed fluctuating customer orders.

   - Show the Customer Order charts that were filled out at the end of the game (Sketch a few on an single overhead transparency. Then go to one team's graphs and carefully draw in the customer order rate on the Factory's Order (Production Requests) graph. The small step from from 4 to 8 orders should make a strong **visual impression** in contrast to the order rate fluctuations which often have an amplitude of 20 to 40 orders per week. Moreover, the sustained oscillations generated by the system contrast sharply to the absolutely flat customer order rate after the step at week 5.

   This simple exercise of getting them to see how, contrary to their expectations, the internal system structure is completely capable of generating fluctuating behavior is the most profound lesson they can learn from the game.

   - It is important that they see this for themselves, as a demonstration or an experimental result which **they did**, not as an idea of which you are trying to convince them. In fact, the game is an experiment in very true sense. The result of oscillating behavior was not predetermined.

7. The assumption that the system's problems are caused by the customer stems from the external orientation most of us adopt in dealing with most problems. In a sense, this is just an extension of the viewpoint that attributes your problems to the person(s) playing next to you in the game: "he/she did it to me" is a special case of "they (the customers) did it to me". In system dynamics we take an alternative viewpoint--that the internal structure of a system is more important than external events in generating qualitative patterns of behavior. **This can be illustrated by this diagram:**

events
(such as inventory stock-outs
and extreme order surges)

↑

behavior/process (oscillation)

↑

structure

Most people try to explain reality by showing how one set of events causes another or, if they have studied a problem in more depth, by showing how a particular set of events are part of a longer-term historical process.

- Have the participants illustrate this for themselves by looking at their own "explanations" for events during the game. Take a particular incident in the game, for example a large surge in production requests at the factory, and ask the people responsible why they did that. Their answer will invariably relate their decision to some prior decision of the people they supply or who supply them. Then turn to those people and ask them why they did that. Continue this until people see that one can continue to relate one event to earlier events **indefinitely**.

The basic problem with the "events cause events" orientation is that it gives you very little **power** to alter the course of events. The focus on internal structure greatly enhances the possibilities of influencing the course of events because you are dealing with the **underlying source** of the process, not just trying to manipulate events.

The slinky demonstration on the training video is a good way to emphasize the focus on internal structure -- the slinky oscillates not just because the hand was withdrawn but mainly because there is something about the structure of a spring that wants to oscillate. (Please note: This training video is currently in production and not yet available.)

8. If time permits, have students think of examples of problems which can be viewed as internally or externally caused.

   e.g. illness
   famine

9. This leaves you at the point of dealing with the problem:

   "How do we deal more effectively with underlying structure?"

   - This is the purpose of system dynamics. So you are in an excellent position to begin introducing system dynamics tools for understanding underlying structure.

STEPS OF THE GAME

----

1. Receive inventory and advance the shipping delays.

   Factory advance the production delay.

2. Look at incoming orders and fill orders. (Retailer looks at customer order cards. Factory looks at incoming orders, not the production request.)

   All incoming orders **plus** orders in backlog must be filled.

   If your inventory is insufficient to fill incoming orders plus backlog, fill as many orders as you can and add the remaining orders to your backlog.

3. Record your inventory or backlog.

4. Advance the order slips; and the brewery brews. That is, the factory converts the production request from last week into cases of beer and put the cases (chips) in the first production delay.

5. Place and record your orders. Factory places and records its production requests.

Beer Game Checklist

Project/Company: ____________________________________ Date: ______________

Per Team (or board)
- Game board (1)
- Single chips (500-600)
- Ten chips (30) (optional, can replace some single chips)
- Customer order cards (1)
- Order slips (200)
- Graphs
  - Effective Inventory (4)
  - Orders (4)
  - Customer Orders (3)
- Record sheets (4)
- Pencils (4)
- Markers in four colors (1 each)
  - Green - Blue
  - Red - Black
- Calculators (2)

Per Session
- Masking tape
- Outline for post-game discussion
- Orders to Fill sheet
- Flip charts (optional)
- Slinky (optional)
- Previous game graphs (if available)

What you receive with one complete set:

- Game board (1) - Video (1)
- Customer order cards (1) - Single chips (600)
- Printed instructions including record sheet, graphs, etc. to be duplicated
- Articles relating to the Beer Game

What you need to purchase/obtain to provide for game:

- Markers in four colors - Masking tape
- Pencils - Flip chart (if needed)
- Calculators - Slinky (optional)

What you need to duplicate/make for distribution:

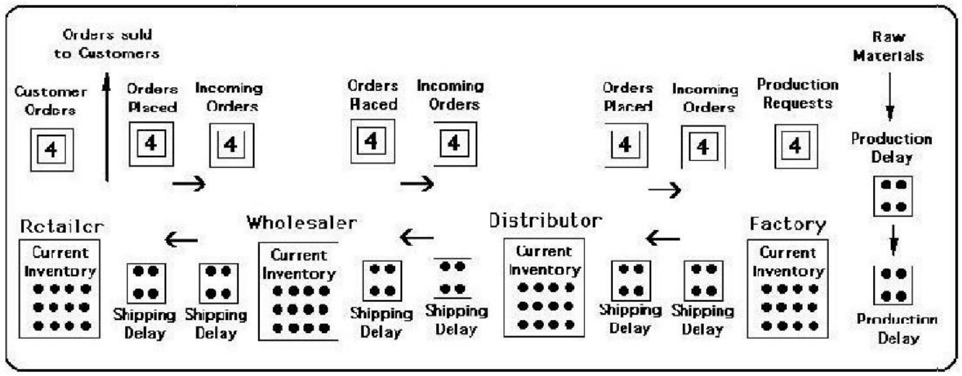
Graphs: Copy:

1. Record Sheet (4 per team) - One per position
2. Effective Inventory graph (4 per team) - One per position
3. Orders graph (4 per team) - One per position
4. Customer Orders graph (3 per team) - One for wholesaler, distributor and factory only, not retailer.

Blank Order Slips

- 50 placed at each position
  - You may use small "Post-it" notes, or cut paper into small rectangles measuring approximately 1.5" x 2"
- Make seven order slips per game board with "4" on each one, and place them **face down** in each of the "orders" boxes to initialize the game board.

Initializing The Board



Note: Order slips showing "4" are placed face down on the game board.
Customer order cards are placed in "Customer Orders" box.

Orders to Fill

1. **Orders to fill = Backlog + Current Orders**

2. a) If you have enough inventory, <u>ship</u> all the orders to ship and <u>record</u> your new inventory.

2. b) If you do not have enough inventory, <u>ship</u> all the inventory you have and <u>record</u> the remaining unfilled orders to fill as your new backlog.

Record Sheet

Please check-off your position:

Team Name: ___________________ **☐ Retailer ☐ Wholesaler ☐ Distributor ☐Factory**

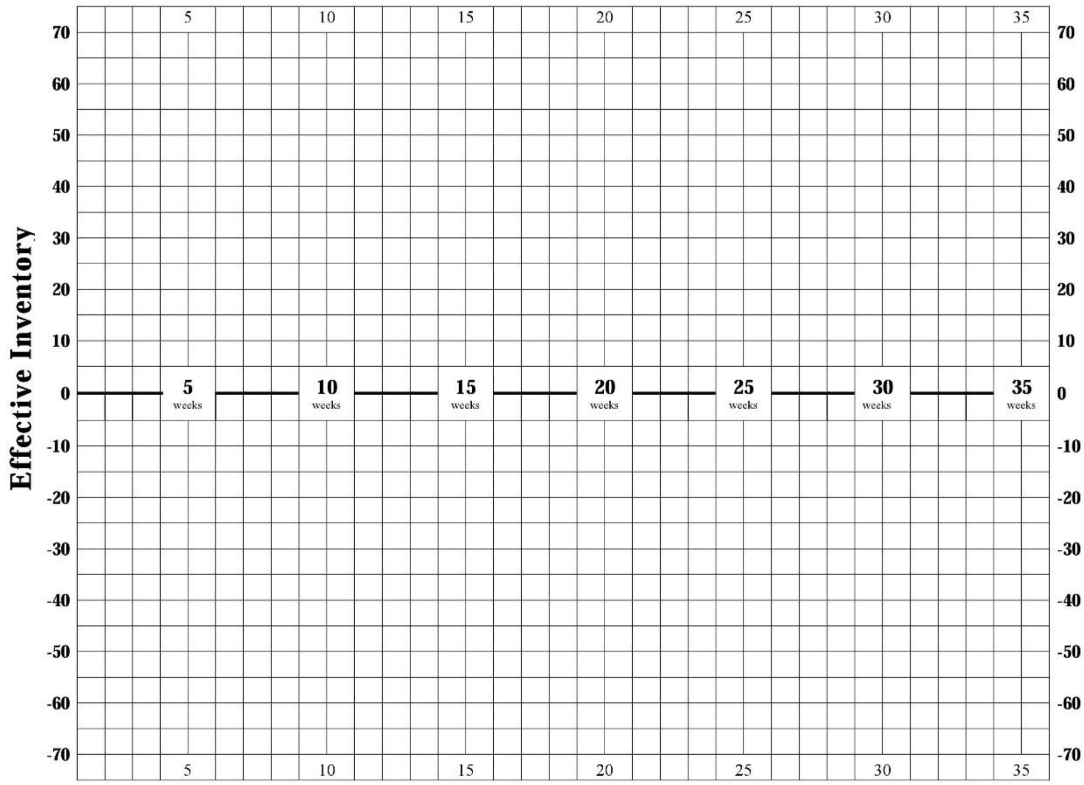
Week	Inventory	Backlog	Your Orders Placed		Week	Inventory	Backlog	Your Orders Placed
1					26			
2					27			
3					28			
4					29			
5					30			
6					31			
7					32			
8					33			
9					34			
10					35			
11					36			
12					37			
13					38			
14					39			
15					40			
16					41			
17					42			
18					43			
19					44			
20					45			
21					46			
22					47			
23					48			
24					49			
25					50			

Total: ☐ INV 1 ☐ BL 1 ☐ INV 2 ☐ BL 2

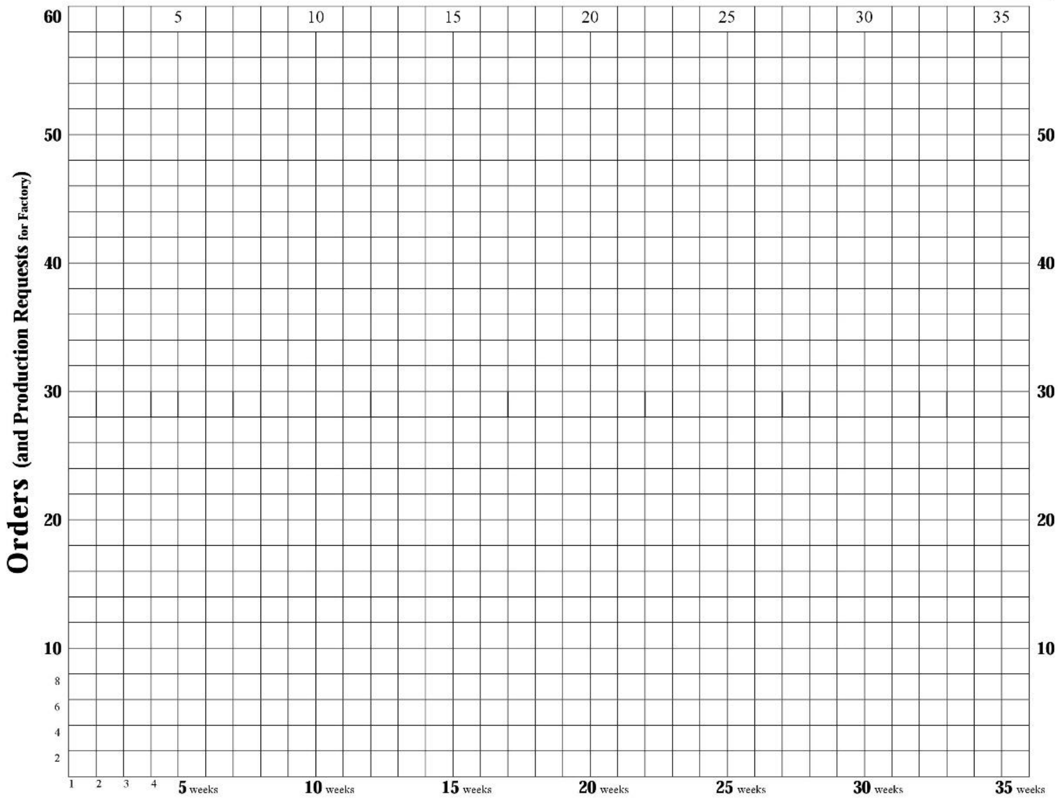
(INV1 + INV2) X .50
+ (BL1 + BL2) X 1.00

= Total Cost

Team Name ______________________ ☑Please check off your position: ☐Retailer ☐Wholesaler ☐Distributor ☐Factory



Team Name ______________________________ ☑Please check off your position: ☐Retailer ☐Wholesaler ☐Distributor ☐Factory



Customer Orders

(Sketch here what you think customer orders were)

Team:

Position:
□ Wholesaler
□ Distributor
□ Factory

(Retailers do not fill this in)

5 10 15 20 25 30 35

Week

The Beer Distribution Game

An Annotated Bibliography
Covering its History and Use in Education and Research

Prepared by

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April 1992; revised July 1992

The Beer Distribution Game dates to the earliest days of system dynamics. The game has been used for three decades as an introduction to systems thinking, dynamics, computer simulation, and management. It has been played by thousands of people, all over the world, from high-school students to CEOs of major corporations. The references below provide useful information for those who want to follow up the experience of the game. These works describe the history of the game, the equations for simulating the game on a computer, the success of organizational change efforts based on the original model embodied in the game, the psychological processes people use when playing, and even how these processes can produce chaos.*

Forrester, J.W. (1958) Industrial Dynamics: A Major Breakthrough for Decision Makers. *Harvard Business Review*, 36(4), July/August, 37-66.

The first article in the field of system dynamics. Presents the production-distribution system as an example of dynamic analysis of a business problem. Reprinted in Roberts (1978).

Forrester, J.W. (1961) *Industrial Dynamics*. Cambridge MA: Productivity Press.

Contains the material in Forrester 1958 expanded to include additional discussion of policies to improve performance in the production-distriubtion system. Also includes complete equations for a computer model of the system from which the Beer Game was derived. Describes the results of many policy experiments. Industrial Dynamics is the classic work in the field and remains an extremely useful reference and text thirty years after publication.

Jarmain, W. E. (ed.) 1963. *Problems in Industrial Dynamics*. Cambridge, MA: MIT Press.

Contains a description of an early version of the Beer Distribution Game

MacNeil-Lehrer Report, (1989) *Risky Business - Business Cycles*, Video, Public Broadcasting System, aired 23 October 1989.

Videotape showing students in John Sterman's Systems Dynamics course at MIT playing and discussing the Beer Game. Relates the game to boom and bust cycles in the real world. Excellent in debriefing the game, and helpful to those seeking to learn how to run the game. Copies available from System Dynamics Group, E60-388, MIT, Cambridge MA 02139.

Mosekilde, E., E. R. Larsen & J. D. Sterman (1991). Coping with complexity: Deterministic Chaos in human decision making behavior. In J.L. Casti & A. Karlqvist (Eds.), *Beyond Belief: Randomness, Prediction, and Explanation in Science*, 199-229. Boston: CRC Press

Shows how simple and reasonable decision rules for playing the Beer Game may produce strange nonlinear phenomena, including deterministic chaos.

Radzicki, M. (1991). Computer-based beer game boards. Worcester Polytechnic Institute, Dept. of Soc Sci and Policy Studies, Worcester, MA 01609-2280

Beer game boards in PICT format for Macintosh computers available on disk for $5.00; all proceeds go to the System Dynamics Society.

Thomsen, J.S., E. Mosekilde, & J.D. Sterman (1992). Hyperchaotic Phenomena in Dynamic Decision Making. *Systems Analysis and Modelling Simulation*, forthcoming.

Extends earlier papers by Moskilde, Sterman, et al. to examine hyperchaotic modes in which the behavior of the beer distribution system may switch chaotically among several different chaotic attractors (for aficionados, "hyperchaos" exists when a dynamical system contains multiple positive Lyapunov exponents).

Roberts, E.B., ed. (1978) *Managerial Applications of System Dynamics*. Cambridge, MA: Productivity Press.

Excellent anthology of early applied system dynamics work in organizations, including analysis of efforts to implement the results of the model which led to the Beer Game.

Roberts, E.B. (1978) Equations for the Production-Distribution System, in Roberts, E.B.(ed.) *Managerial Applications of System Dynamics*. Cambridge, MA: Productivity Press.

Presents documented equation listing for the production-distribution system based on Forrester (1961), in the DYNAMO computer simulation language.

Senge, P. (1990) *The Fifth Discipline*. New York: Doubleday.

Excellent non-technical discussion of the Beer Game, and systems thinking principles generally.

Sterman, J.D. (1984). Instructions for Running the Beer Distribution Game. D-3679, System Dynamics Group, MIT, E60-388, Cambridge, MA 02139.

Explains how to run and debrief the Beer Game, including layout of boards, set up, play, and discussion. Incorporates debriefing notes by Peter Senge. Some people have found this document, in conjunction with the MacNeil/Lehrer video and plenty of practice, is sufficient to enable them to lead the game successfully.

Sterman, J.D. (1988) Deterministic Chaos in Models of Human Behavior: Methodological Issues and Experimental Results. *System Dynamics Review*, 4, 148-178.

The decision rules people use when playing the Beer game can lead to deterministic chaos.

Sterman, J.D. (1989). Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment. *Management Science*, 35(3), 321-339.

Detailed analysis of Beer Game results. Examines why people do so poorly in the Beer Game. Proposes and tests a model of the decision making processes people use when playing the game and shows why they do so badly.

Additional information on systems dynamics, including publications, simulation games, management flight simulators, journals, etc. is available from John Sterman at the address above.

*If you know of additional publications which discuss aspects of the game not included in this bibliography please send a copy to John Sterman at the address above so they can be incorporated in future revisions.

APPENDIX C SECTION 5.3: LEAN SIMULATION FACILITATION GUIDELINES

Magic Stick simulation

MAGIC STICK Game

Courtesy: Alan Mossman

Lean Principles Illustrated

To illustrate the importance of Collaboration, leadership and communication

Learning Objective

- Illustrate:
    - Best efforts are not enough
    - Losses mount up and gains are lost
    - More people (resources) makes it worse
    - Collaboration – people have to work together
    - Needs clear leadership

Target Audience

Anyone in the construction industry

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 2
- Facilitator : 3

Number of players per facilitation

From 8 upwards
If group is larger split them into 2 or more groups – this brings more out of the game
The minimum size of each group is 6, maximum size depends on the length of the stick, but is about 10

Duration per facilitation

- Introduction : 5-10 minutes
- Gameplay : 20 minutes
- Debrief and Discussion : 10 minutes

Materials required per facilitation

- 1 x 2.5m (8') bamboo cane (~200 grams) for per 8-12 participants
- Flip chart if desired for review
- Flat for area of at least 12' square per group

Facilitation Guidelines

- Get the participants in groups of 8-12
- Arrange each group so that one half are facing the other half about an arms length apart
- Ask each group in turn to raise their forearms to the horizontal with both index fingers pointing to the person opposite so that all the index finger are in a line
- As you lay a bamboo on the extended index fingers explain that the objective of the task is to lower the stick to the ground while observing the following condition:
  - The stick must rest ***on*** both index fingers of each participant at all times; only index fingers may touch the stick.
  - [note: thumbs are not permitted on top of the stick]
- You may need to start the process again at this point as the stick will almost always begin to rise as soon as you explain this rule – then leave them to it.
  - You may remind the group of the rule at any point – this will often cause the stick to rise
- Allow the groups to continue until they have completed the task – watch for rule violations
- Review on completion. If more than one group, explore their different strategies. Flip chart issues if desired. Explore similarities and differences with what happens on projects. You could use this review to demonstrate a simple AAR process on a flipchart:

Objectives and intentions	**What happened**
Key issues	**Key learning**

Options

- Start a group with planning – explain the task to them without giving them the stick and have them plan for 5 minutes then go to step 2.
- After the review allow the groups to have another go and see if they learnt from their experience – note what additional learning they gained – possible link to First Run Studies.

Discussion

- What enabled you to make progress as a team?
- What roles emerged during the simulation?
- Who was the leader?
- What did s/he do?

Collaborative working:

- What was the initial reaction of the group?
- How well did the group cope with this challenge?
- What skills did it take to be successful as a group?
- What creative solutions were suggested and how were they received?
- What would an outside observer have seen as the strengths and weaknesses of the group?
- What did each group member learn about him/her self as an individual?
- What other situations (e.g., at school, home or work) are like the cane?

Losses mount up and gains are lost:

- What happened when you went wrong?
- And then if you went wrong again?
- What happened if you made progress, but then went wrong?
- How did you prevent this happening?
- What other situations (e.g., at school, home or work) are like the cane?
- How can you apply this learning to those situations
-

Don't rush in too fast – take stock and plan first

References

Alan Mossman (1982). "Management training for real". IPM National Conference, Section Meeting 43

Alan Mossman (1982). "Making choices about the use of the outdoors in manager and management development". Management Education and Development, Vol 14, Pt.13, 1983, pp 182-196

Lean Construction Institute (2015). "LCI Simulation Matrix" *<http://www.leanconstruction.org/simulation/>(March 23,2016)*

Maroon – White simulation

MAROON –WHITE

Courtesy: Dr. James Smith and Dr. Zofia Rybkowski, Texas A&M University

Lean Principles Illustrated

To illustrate the importance of collaboration and trust

Learning Objective

- Needs clear leadership
- To analyze importance of collaboration in solving problems in AEC industry
- To sensitize participants to the importance of working as a team
- Evaluate the effect of social dilemmas while choosing between individual versus group benefit.

Target Audience

Anyone in the industry

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 1
- Facilitator : 2

Number of players per facilitation

- Three teams of 3-5 players per team

Duration per facilitation

- minutes

Materials required per facilitation

- Flipchart or chalk boards
- Chalk or Markers
- Stopwatch

Room Logistics per facilitation

A large room which can be divided into three separate sections to give private space for deliberation to both the teams.

Facilitation Guidelines

- Before proceeding with the game, write the following point distribution on flipchart or a chalk board.

Table 1: point distribution for Maroon-White game

Color chosen	Team 1 points	Team 2 points	Team 3 points
M-M-M	50	50	50
W-M-M	100	0	0
W-W-W	0	0	0

- In the first round, inform everyone that the objective of this game is to score maximum points. Teams are requested to choose a color " Maroon" or "White "and the points are distributed based on the point distribution scale mentioned in table 1.
- The game is played in 4-7 rounds and the points are calculated based on the color choosen.

Discussion

- How can everyone score maximum points?
- What can we learn from this game?
- Once a team chooses white, how is the game affected?
    - Distrust and betrayal, other teams seek opportunities to return the negative outcome from previous round
- How might these lessons be applied to construction industry?

References

Lean Construction Institute (2015). "LCI Simulation Matrix." <http://www.leanconstruction.org/simulation/> (March 23, 2016)

Smith, J. P., and Rybkowski, Z. K. (2013). "The Maroon and White Game: A simulation of trust and long-term gains and losses". *Paper presented at the Proceedings of 21st Annual Conference of the International Group for Lean Construction,Fortaleza, Brazil, July 2013., 987-996.*

Win As Much As You Can simulation

Win as much as you can

Courtesy: W.Gellerman and Wiley Publisher

Lean Concept Illustrated

Competition and Collaboration in both intragroup and intergroup relations.

Learning Objective

- Examine aspects of social dilemmas, situations where one must choose between supporting individual versus group benefit.
- It incorporates aspects of the "tragedy of the commons," Pareto efficiency (no one can be better off without making someone else worse off), and collective action.

Target Audience

Senior staff, team members, and anyone else who will be involved in building and construction industry.

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 1
- Facilitator : 1

Number of players per facilitation

This activity is designed for two teams of eight members each. Teams of more than eight members can be accommodated easily by having the participants play the game in trios instead of pairs and/or assigning some participants to be process observers. If either team has fewer than eight members, single participants may work by themselves (instead of in pairs) or the facilitator may alter the game on which the activity is based.

Duration per facilitation

- Introduction : 10 minutes
- Gameplay : 25 minutes
- Debrief and Discussion : 15 minutes

Materials required per facilitation

- A copy of the Win as Much as You Can Score Sheet for each pair.
- A pencil for each pair.
- Flip chart

Room Logistics per facilitation

A large room with movable chairs for all members of both teams. The teams are seated well apart from each other. Each team is divided into four pairs; the pairs are seated far enough away from one another so that they can discuss strategy privately, yet close enough so that all team members can interact when asked to do so. Figure 1 is a suggested configuration for one team.

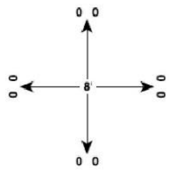


Figure 1: Suggested Seating Configuration

Facilitation Guidelines

- There are three key rules:
    - You are not to confer with other groups unless you are given specific permission to do so. This prohibition applies to nonverbal as well as verbal communication.
    - Each group must agree upon a single choice for each round.
    - You are to ensure that the other groups do not know your group's choice until you are instructed to reveal it.
- There are ten rounds to this activity. During each round you and your partner will have one minute to mark your choice for the round. Remember the rules. You may now take one minute to mark your choice for round one. *[The facilitator pauses for one minute.]*

ROUND ONE
You may now take one minute to mark your choice for round one.

- *Allow a minute to lapse.* Has everyone reached a decision?
- Have each group share and mark their decision on the score-board.

ROUND 2, 3, AND 4
Similar to round one.

ROUND FIVE – bonus round
Let the groups know that all amounts won or lost on this round will be *multiplied by three.*

- Before your group marks your choice for this round, you are allowed to send one representative outside of this room to confer with a representative from each of the other groups.
- Your representatives will have *three minutes for this discussion.*

Once back in the room, you now have one minute to confer within your group.

- *Allow a minute to lapse.* Has everyone reached a decision?
- Have each group share and *mark their decision* on the score-board.

After the group discussion, you and your partner will have one minute to discuss your decision.

ROUND 6 and 7
Similar to round one.
ROUND 8 – bonus round
Let the groups know that all amounts won or lost on this round will be *multiplied by five.*

- Before your group marks your choice for this round, you are allowed to send one representative outside of this room to confer with a representative from each of the other groups.

- Your representatives will have *three minutes for this discussion.*

Once back in the room, you now have one minute to confer within your group.

- Allow a minute to lapse. Has everyone reached a decision?
- Have each group share and mark their decision on the score-board.

ROUND 9
Similar to round one.

ROUND 10 – bonus round
Let the groups know that all amounts won or lost on this round will be *multiplied by ten.*

- Before your group marks your choice for this round, you are allowed to send one representative outside of this room to confer with a representative from each of the other groups.
- Your representatives will have three minutes for this discussion.

Once back in the room, you now have one minute to confer within your group.

- Ask: what do you predict the other groups will do?
- Allow a minute to lapse. Has everyone reached a decision?
- Have each group share and mark their decision on the score-board.

Have the groups and facilitator tally the scores. Including the total score for all of the groups together.

Discussion

1. Does the "You" in "Win as Much as You Can" mean you as in each of your groups or the whole room?
    a. The effects of competition and collaboration should be considered
2. What strategies did your pair employ towards the rest of the group?
3. Was anyone completely altruistic? (Y every time)
4. Who won? Did the group win? Show the optimal group outcome on the board (+$100 net gain)
5. Where is this cooperation applicable in real life? (ex: public services – schools, hospitals, parks.) Individuals are better off when we use these without contributing to their upkeep (paying taxes). If everyone did this, the resources would not be provided and everyone would be worse off.
6. Groups with negative net $$: Tragedy of the Commons. Each pair worked for individual interest, resulting in a depletion of the resource (denoted at $$ in this exercise), even when it was clear this was not in anyone's interest for it to happen.

Additional Information

Scoring Guidelines

4 X's:	Lose $1.00 each
3X's: 1 Y:	Win $1.00 each Lose $3.00
2 X's: 2 Y's:	Win $2.00 each

	Lose $2.00 each
1 X: 3 Y's:	Win $3.00 Lose $1.00 each
4 Y's:	Win $1.00 each

Score Sheet

	Scores										
	1	2	3	4	5	6	7	8	9	10	Total
Grp1											
Grp2											
Grp3											
Grp4											
Grp5											

Some possible outcomes

	Tragedy of commons	Zero – Sum game	Optimal Individual outcome	Optimal group outcome
Cluster Choices	4 X's each round	Mix of X's and Y's	1X, 3Y's per round	4 Y's each round
Individual outcomes	-$25	Some +/- $$	+$75 3x -$25	+$25
Cluster outcome	-$100 net	+$0.00 net	+$0.00 net	+$100 net

References

"Pfeiffer's Classic Activities: Managing Conflict at Work". *Copyright © 2003 by John Wiley & Sons, Inc.*

Chen, C. and Roth, H. (2005). "The Big Book of Six Sigma Training Games". *McGraw-Hill, New York, pp 91-94*

"Win as much as you can". *University of California Santa Barbara, <http://geog.ucsb.edu/~hartman/WinAsMuchAsYouCan.pdf > (March 23, 2016)*

"Win as much as you can". *Wiley, <http://media.wiley.com/assets/manual/sample_download.pdf > (March 23, 2016)*

Silent Squares a.k.a Broken Squares simulation

Building Dynamic Groups

THE OHIO STATE UNIVERSITY EXTENSION

Broken Squares

Introduction: Through the "Broken Squares" activity and discussion, participants learn the importance of effective interpersonal skills and discover ways they can develop their own interpersonal abilities. As a result of the activity, participants should be able to identify at least one reason why interpersonal skills are important and at least one way that they can improve their own interpersonal abilities.

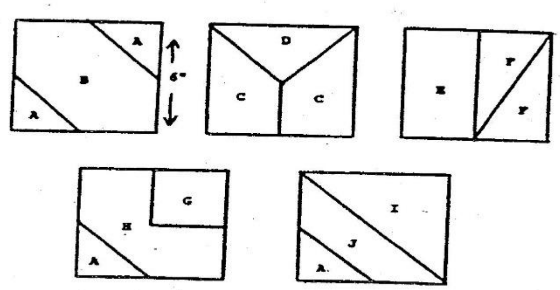
Material:

-Enough sets of "broken square" pieces for each participant to make a square.
-Enough floor space for participants to sit in circles of five participants each with room to make the squares in the center of the circle.

<u>Directions for Making a Set of Squares</u>

A set consists of five envelopes containing pieces of cardboard which have been cut into different patterns and which, when properly arranged, will form five squares of equal size. One set should be provided for each group of five persons.

To prepare a set, cut out five cardboard squares of equal size, approximately six-by-six inches. Place the squares in a row and mark them as below, penciling the letters, a, b, c, etc., lightly so that they can be erased later.



The lines should be so drawn that when cut out, all pieces marked "a" will be of exactly the same size, all pieces marked "c" of the same size, etc. By using multiples of three inches, several combinations will be possible that will enable participants to form one or two squares, but only one combination is possible that will form five squares six-by-six inches.

After drawing the lines on the six-by-six inch squares and labeling them with lower case letters, cut each square as marked into smaller pieces to make the parts of the puzzle.

Mark the five envelopes A, B, C, D, and E. Distribute the cardboard pieces in the five envelopes as follows:

Envelope A. has pieces	i,h,e
B	a, a, a, c
C	a, j
D	d, f
E	g, b, f, c

Erase the penciled letter from each piece and write, instead the appropriate envelope letter. This will make it easy to return the pieces to the proper envelope for subsequent use when a group has completed the task.

Time Required: 30 minutes

Procedure: Divide participants into groups of five by "numbering off" or playing a creative grouping game to separate "best friends" into different groups to encourage "mixing" and interpersonal relationships with additional people.

Depending on the maturity level of the group, "extra participants" left after the groups of five are formed can 1) be observers for the group (give them a copy of the observer instructions), 2) form a smaller group of three or four (you will have to remove the pieces from their packets for the unneeded squares), or 3) divide among the other groups to make a few groups of six (you will have to give those groups pieces for additional squares and have them mix up and re-allocate 3 pieces per person).

Direct the group not to begin until after you have finished reading the instructions.

Read the following instructions to the group...
"In this packet there are five envelopes, each of which contains the pieces of cardboard for forming squares. When the facilitator gives the signal to begin, the task of your group is to form five squares of equal size. The task will not be completed until each individual has before him or her, a perfect square of the same size as that held by others.

Specific limitations are imposed upon your group during this exercise:

- No talking, pointing, or any other kind of communicating among the five people in your group.
- Participants may give pieces to other participants but may not take pieces from other members.
- Participants may not simply throw their pieces into the center for others to take; they have to give the pieces directly to one individual.
- It is permissible for a member to give away all the pieces to his puzzle, even if he has already formed a square.

Are the instructions clear?" (Questions are answered)

Give the signal to "begin working."

With the help of any observers make sure that the rules are observed throughout the activity. As groups complete the task they may applaud to signal that they are finished, but should then sit quietly and observe other groups who are still working until everyone has finished.

When everyone has completed the task, ask the following questions to summarize what happened. If observers were present, direct the questions first to them and then get additional ideas from the rest of the group.

- Who was willing to give away pieces of the puzzle?
- Did anyone finish his/her puzzle then somewhat divorce himself/herself from the struggles of the rest of the group?
- Was there anyone who continually struggled with his or her pieces, but yet was unwilling to give any or all of them away?
- How many people were actively engaged in mentally putting the pieces together?
- Did anyone seem especially frustrated?
- Was there any critical turning point at which time the group began to cooperate?
- Did anyone try to violate the rules by talking or pointing as a means of helping fellow members solve their puzzle?

Processing:

For this activity to be meaningful to participants in developing interpersonal skills, it's important for them to think about what really happened in the group, what they learned from the experience, and how they can apply it in other interpersonal situations. This can be accomplished by having each participant write on a sheet of paper his or her own answers to these questions.

Read the questions to the group and ask participants to jot down their responses as you go. After this has been done, discuss the questions one-by--one with the total group. Make sure that each participant takes part in the discussion, and do not allow anyone to completely dominate the discussion. Encourage participants to make additional notes on their written answers as the discussion proceeds.

1. What part of the experience did you find most enjoyable?
2. What part of the experience did you find most frustrating?
3. What kinds of things could other members in your group have done differently to make the experience more satisfying and successful?
4. What kinds of things could you personally have done to make the experience more satisfying and successful?
5. What did you learn from this experience that could be helpful when you work with other people in other situations?
6. What do you wish other people would do differently or better when they're with you?
7. What would you most like to improve about yourself in relating to other people?

Closing:

-Summarize the purposes of the "Broken Squares" activity.
-Review major points brought out from the processing questions.
-Challenge participants to strengthen their interpersonal skills in everyday life by acting on their personal written answers and notes related to the processing questions.

Instructions to the Observer/Judge

Your job is part observer and part judge. Make sure each participant observes the rules:

1. No talking, pointing, or any other kind of communicating among the five people in your group.
2. Participants may give pieces to other participants but may not take pieces from other members.
3. Participants may not simply throw their pieces into the center for others to take; they have to give the pieces directly to one individual.
4. It is permissible for a member to give away all the pieces to his puzzle, even if he has already formed a square.

Do your best to strictly enforce the rules.

As an observer, you may want to look for some of the following:

1. Who was willing to give away pieces of the puzzle?
2. Did anyone finish his/her puzzle then somewhat divorce himself/herself from the struggles of the rest of the group?
3. Was there anyone who continually struggled with his or her pieces, but yet was unwilling to give any or all of them away?
4. How many people were actively engaged in mentally putting the pieces together?
5. Did anyone seem especially frustrated?
6. Was there any critical turning point at which time the group began to cooperate?
7. Did anyone try to violate the rules by talking or pointing as a means of helping fellow members solve their puzzle?

Reference: Martin, R.R.; Weber, P.L.; Henderson, W. E.; Lafontaine, K. R.; Sachs, R. E.; Roth, J.; Cox, K. J.; Schaffner, D. (1987). Broken squares (Section 5 p.3). Laser d.i.s.k. Columbus, OH: Ohio State University Extension.

APPENDIX D SECTION 5.4: LEAN SIMULATION FACILITATION GUIDELINES

Collective Kaizen and Standardization simulation

COLLECTIVE KAIZEN AND STANDARDIZATION

Courtesy: Dr. Zofia Rybkowski, Texas A&M University

Lean Concept Illustrated

To illustrate the importance of continuous improvement and standardization

Learning Objective

- Challenges a typical mindset amongst supervisors that external factors (like more intelligent or productive employees) is a significant factor in increasing overall organizational productivity.

Target Audience

Anyone in the industry

Scale of Difficulty

- Easier for those with creative skills
- Difficult for those without the necessary creative skills

Number of players per facilitation

- 4 Workers
- 1 Quality Assurance Worker
- 1 Timer Worker (person that times in seconds)

Duration per facilitation

- The duration of the song Survivor's "Eye of the Tiger."

Materials required per facilitation

- Desk tops with 9 per table for participants to fold paper airplanes on
- Photocopies of a 7" ruler (a few per table) so participants can measure out 7-inches per plane.
- Masking tape to mark the starting line on floor for throwing planes.
- 8 ½" x 11" pieces of scrap paper (at least two per participant; one for each round)
- Tape measure to measure distance planes travel.
- "Eye of the tiger" DVD by rock group Survivor or access to YouTube video of the song
- Stopwatch

Facilitation Guidelines

- In the first round (pre-round), all the participants are instructed to make a 7" paper airplane in three minutes to the tune of "Eye of the tiger" song. The facilitator uses a stopwatch to monitor the time.
- At the end of three minutes all the participants are requested to line up at the starting point and test-fly their planes.

- The plane that travels farthest in a straight line is declared the winner and the participant who designed this plane is requested to fly the plane again to confirm the results.
- In the second round (post-round), the winner is requested to share his plane-folding strategy and supervises everyone to make the plane according to the standardized process to the tune of "Eye of the tiger" song within three minutes. At the completion of three minutes, all the participants are again requested to line up at the starting point and test-fly their paper airplanes.
- The facilitator measures the distance travelled by all the planes for the two rounds and compares them to analyze any improvement.

Results

- A typical result for this exercise at Texas A&M University shows improvement in the distance travelled by the airplanes after following a standardized process that improved their design.

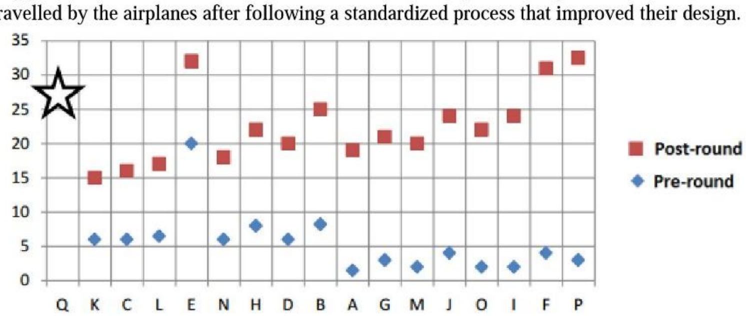


Figure 1: Pre-round and post-round flight performance of paper airplanes arranged by increasing levels of performance improvement. Pre-round- and Post-round flight distance by participant Q—the "first-rate performer"—is indicated by a star.

Discussion

- What "light bulb moments" did you have after playing the game?
- How might these lessons be applied to what you do every day in the design office?

References

Rybkowski, Z. (2013). "Advancing with the employees you have now: Strategically coupling collective kaizen & standardization in IPD". Texas A&M University, Department of Construction Science, College Station, TX, Novemeber 8, 2013

Rybkowski, Z. K., and Kahler, D. L. (2014). "Collective Kaizen and Standardization: The Development and Testing of a New Lean Simulation". Proceedings of 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014.,1257-1268.

Hacky Sack simulation

HACKY SACK

Courtesy: Brent Nikolin, Turner Construction Company

Lean Concept Illustrated

To illustrate the importance of continuous improvement.

Learning Objective

- Challenges a typical mindset amongst supervisors that external factors (like more intelligent or productive employees) is a significant factor in increasing overall organizational productivity.
- Stretching goals to enable change in behavior.

Target Audience

Anyone in the industry

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 2
- Facilitator : 2

Number of players per facilitation

- 1 Facilitator per 3 groups
- Group of 5 or more people

Duration per facilitation

- Setup: 0 minutes
- Play: 10 minutes
- Debrief: 5 minutes

Materials required per facilitation

- A room where people can stand and have enough space to pass the ball
- Ball
- Stopwatch

Facilitation Guidelines

- The objective is to create a process to move the ball through the hands of every person in the group within a set time
- Ball cannot be passed to someone next to you
- The ball must return to the person who it started with
- The ball must travel through the air
- The ball cannot be rolled across any surface e.g. floors, walls, tables, etc.

- This process is aimed at creating a product and one product is equal to 8 rounds of passing the ball in the correct sequence
- If you go out of sequence or drop the ball you must start over

Discussion

- This exercise provides a real-time scenario of improvements in results after everyone was familiar with rules and when they developed a standardized approach to achieve the results.
- What "light bulb moments" did you have after playing the game?
- How might these lessons be applied to what you do every day in the construction industry?

References

Lean Construction Institute (2015). "LCI Simulation Matrix." <http://www.leanconstruction.org/simulation/> (March 23, 2016)

APPENDIX E SECTION 5.5: LEAN SIMULATION FACILITATION GUIDELINES

5S simulation

The 5S Numbers Game.

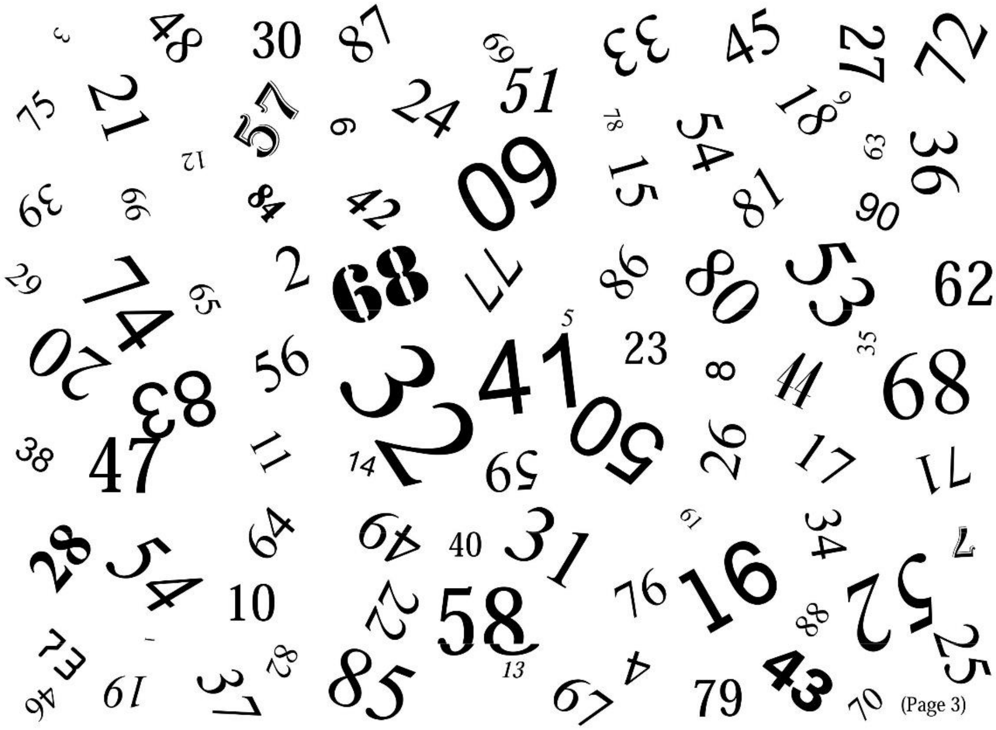
Sort ▪ Set in Order ▪ Shine ▪ Standardize ▪ Sustain

This exercise is adapted from a version I found on the web created by Kirt Tassmer, Stanley Fastening Systems. The original game was developed byRWD Technologies Ltd.

The Worksheet on the following page represents the Current State of our Work Place. *[no peeking !]*

- Your Job is to use a pen or pencil to Strike Out the numbers 1 to 49 in Correct Sequence. **Example:** ~~1~~ ~~2~~ ~~3~~
- You will have 30 seconds to complete this task.

- The designated time keeper will tell you when to start and announce the end of your task at the 30 second mark.
- When time has been called, ask each person to call out the highest number they crossed out and record these individual scores on an easel chart.
- Circle the Lowest Score – this is the Team's Official Score for this round. *[You will have more chances! … Soon]*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"How do you feel about your score ?"

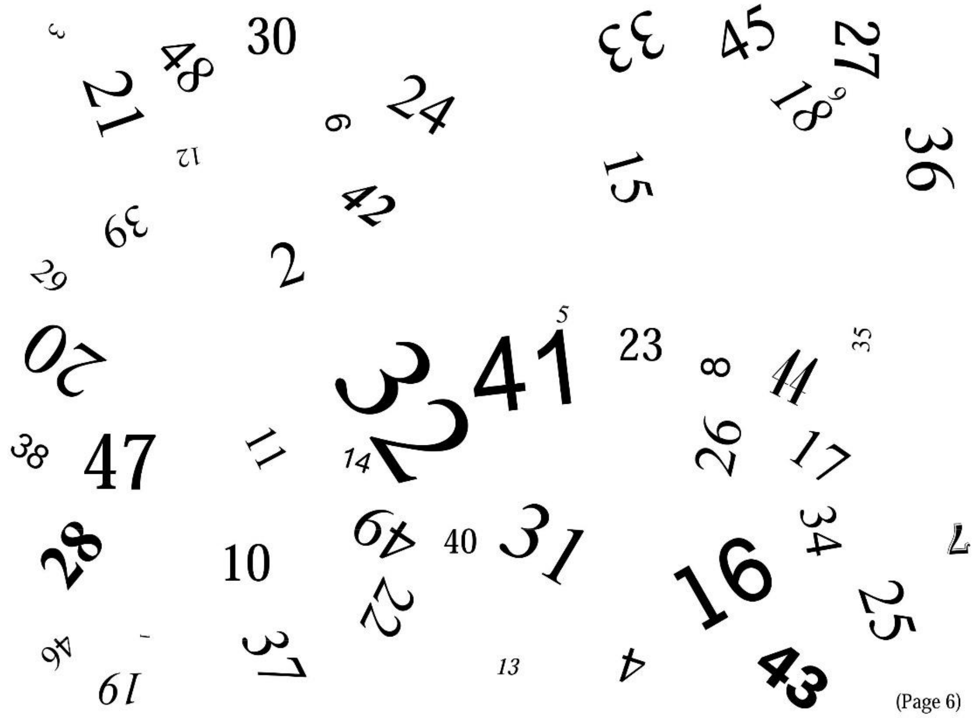
"What appeared to get in the way of achieving a higher score ?"

5S Step #1:

SORT

We are going to implement 5S in this work area.
The first step is **"Sort"**

- Our Initial Analysis shows numbers 50 to 90 are not essential to our daily tasks … they have been removed from the work area
- In a moment, you will repeat the "Strike Out" task in the Sorted Work Place on the following page.
- <u>Same rules apply</u>: Use a pen to strike out numbers 1 to 49 in sequence during a 30 second shift
- Record your individual scores and circle the lowest as your Official Team Score for the round



(Page 6)

"How do you feel about your score this time ?"

"What appeared to get in the way of achieving a higher score ?"

5S Step #2:

SET IN ORDER*

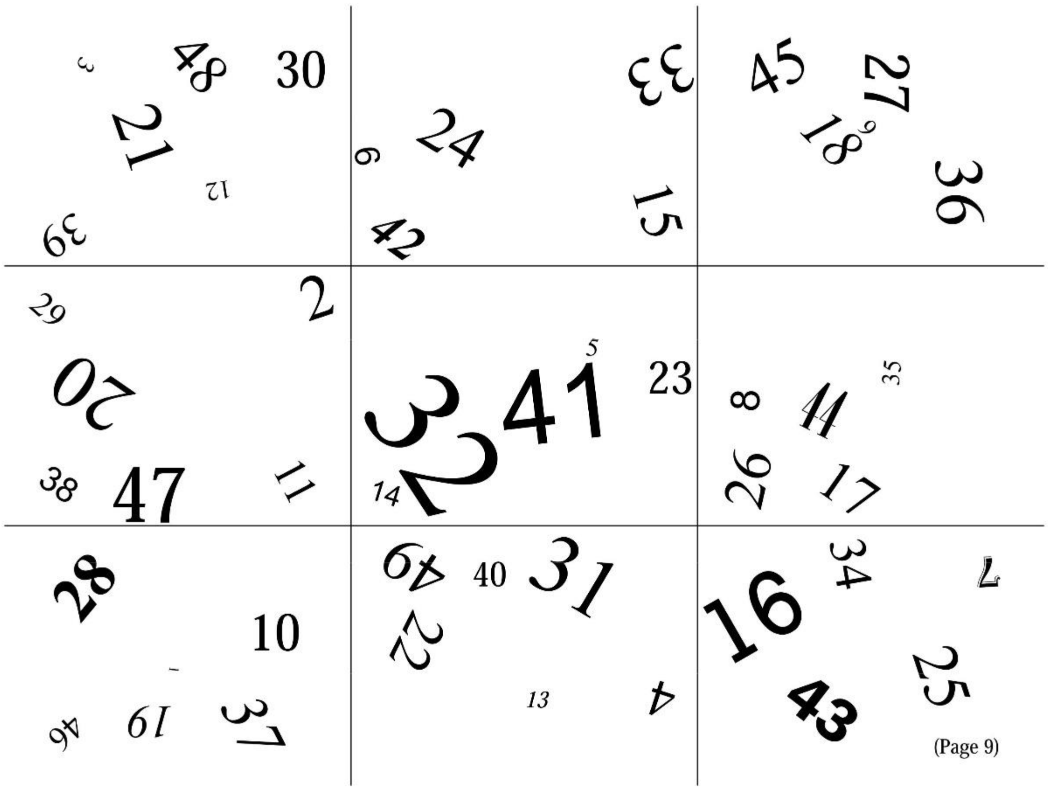
* Also referred to as "Straighten"

Having achieved some improvement, we will now move to the next 5S step **"Set In Order"**

- We have installed some racking on the job site using a 3 X 3 grid.
- We have organized the numbers so that Number 1 is located in the bottom left hand corner and the numbers are sequenced from bottom to top and left to right

  <u>Example</u>: #1 in the bottom left, 2 in the middle left, and 3 in the top left, then 4 in bottom middle, 5 in middle middle … and so on
- <u>Same rules apply</u>: Strike out numbers 1 to 49 in sequence during a 30 second shift. Lowest individual score is your Official Team Score.

Page 8


(Page 9)

"How do you feel about your score this time ?"

"What appeared to get in the way of achieving a higher score ?"

5S Step #4:

STANDARDIZE

[NOTE: We will skip the third "S" - "Shine" in this game]

Next is the fourth "S" - **"Standardize"**

- After in-depth Work Flow Analysis, we have installed the more detailed racking system on the next page.

  [NO peeking !]
- This allows us to re-organize the numbers in a standard fashion which will ease the completion of your task.
- <u>Same rules apply</u>: When you turn the page, strike out numbers 1 to 49 in sequence during a 30 second shift. , lowest individual score equals Official Team Score.

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	

"How do you feel about your score this time ?"

"What appeared to get in the way of achieving a higher score ?"

The 5S Quality Dividend

What benefits can you expect from
application of 5S to this workplace ? Let's See.
[Note: technically, we have only worked with 3 of the "S's" to this point]

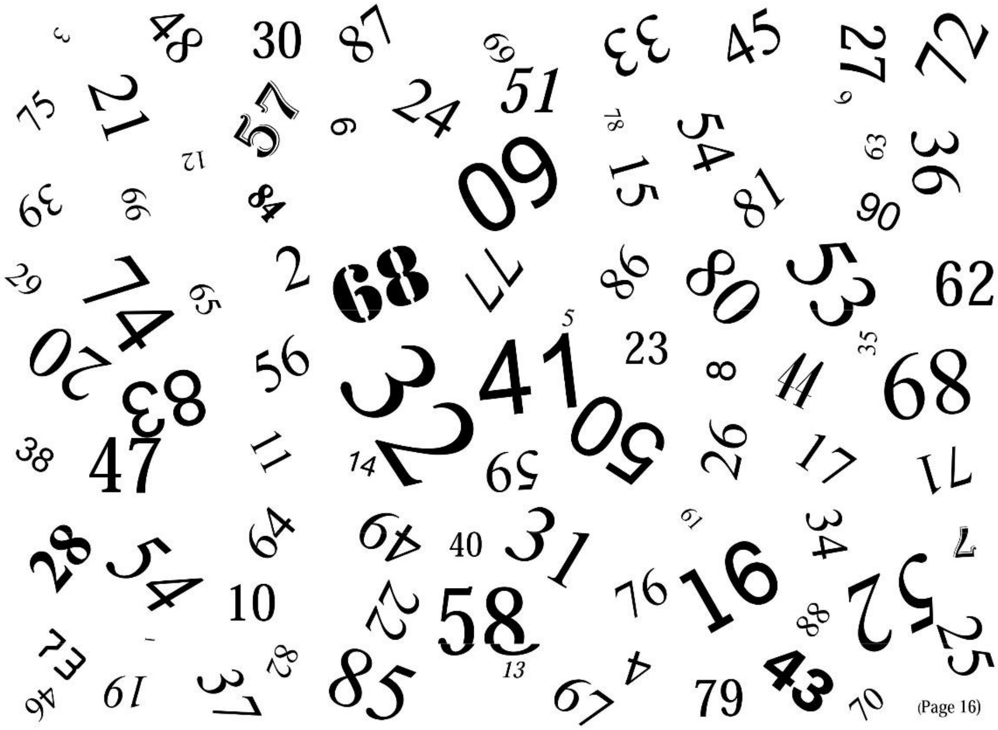
Quality Audit Alert:

- We have recently discovered two numbers are missing! We cannot finish our job without these numbers - so first we have to find them.
- Your Team Task: Identify the two missing numbers as quickly as possible.

The 5S Quality Dividend

In a moment you will ….

- Start the timer
- Flip to the next page
- Find the two missing numbers as a team– call them out as you identify them
- Every 30 seconds is a “Shift” of work.
- Timer, please announce the number of shifts out loud as the Team works to find the missing numbers.
- Stop the timer when the numbers are found and announce the total shifts required to complete the task.


(Page 16)

"How do you feel about your score ?"

"What appeared to get in the way of achieving a lower score ?"

The 5S Quality Dividend

Let's try that again in the Workplace
that has experienced your **"Sort", "Set in Order"**
and **"Standardize "** Steps of 5S

In a moment you will …

- Turn the page
- Start the timer
- Find the two missing numbers
- Count the number of 30 second shifts the task requires this time

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17		19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41		43	44	45	46	47	48	49	

"How do you feel about your score this time ?"

"What appeared to get in the way of achieving a lower score ?"

Payoff Questions

- What did you learn in this 5S Numbers Game?
- What else?
- How might you incorporate the 5S process into your current workplace?
- What difference would you expect it to make?

<u>The Fifth "S" is "SUSTAIN"</u>

Imagine you have applied the 5S process to your current workplace and seen improvements as you did in this exercise.

What would you have to do
– or have to stop doing –
to <u>SUSTAIN</u> these changes ?

APPENDIX F SECTION 5.6: LEAN SIMULATION FACILITATION GUIDELINES

Colored Blocks LPS simulation

This is an older version of the Colored Blocks LPS Simulation. For the most recent version, please contact Mr. George Zettel, Regional Lean Manager, Turner Construction Company (email - gzettel@tcco.com)

Coaches Tips – Where to Get Materials B

COACHES SHEET

Per request - I strongly encourage you to get several kits set up. History: DPR developed the simulation sharing it with the DPR / Turner joint venture at UHS Temecula Hospital ~ 1/2010. It was used for monthly "on-boarding" training of all new supervisors over the entire project. DPR sells these kits on their external web-store. We have made the kits ourselves with simple on-line orders to Toys R Us and Office Depot. Get 6 complete kits per computer carrying case or duffle bag. We utilized this at UHS Temecula and Amgen to greatly improve the quality of a new team's pull plan. Frequently, there is a majority of "first timers"… and if they say they have done it, other GC's or owners may do pull planning a little differently, so it is still worth taking the time to run the simulation. It takes about 35 to 45 minutes for 4 to 6 groups with 2 or 3 trained facilitators. It also quickly trains GC Px, PM, Engineers, Supt. for basic skills for pull planning.

This link is for Toy R Us on-line order(not in the store) the brand is important – Standardize… also, you get more "painted usable blocks" from the on-line kit - "Mellissa and Dougs" brand blocks. You get 4 kits from the 100 pcs set. Simulation is 4 people per team per kit – so I carry a bag with 6 kits, able to coach a team of 24 folks. If a team is > 24, use one or more 5 people teams: 4 trades, +1 GC

http://www.toysrus.com/product/index.jsp?productId=2807727&cp=&parentPage=search
only $19 each and if you buy 4 shipping is free.

Powerpoint follows– there are 10 pages that I get laminated back to back to end up with 4 laminated cards – one hole punched and a key chain or split ring holds the 5 cards. There are 4 "instructor only" cards. I suggest you print out the "speakers notes" pages of the ppt and keep for reference for new trainers. Use when having first pull plan meeting with a team and there is no full boot camp planned.

This simulation DOES NOT teach "why we use pull and not push" , Use Lego airplane game or lego crossbeam game…or paper airplanes.
This simulation does NOT teach "why we use small batches / single piece flow" vs. large batches. Use Lego airplane /cross beam game.
Please send suggestions for plan do study adjust or PDSA. Accelerate the full use of Last Planner System using the Villego simulation.

George Zettel | Manager, Lean Construction – Southwest USA; **Turner Construction,** 1900 South State College Blvd., Suite 200 | Anaheim, CA 92806-6136 mobile 714.290.8331 | gzettel@tcco.com

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Pull Plan Coaching - Wood Block Tower

Summary: Help a team that is new to Last Planner System and to pull planning learn how to make a high quality pull plan by practicing to make a pull plan to build a wood block tower!.

C

COACHES SHEET

Learning Objectives:

1. Pull planning is one of 5 key steps of the full last planner system.
2. Every hand-off of work between parties, there is a customer, and a supplier.
3. Work can be planned when the "customer" makes a clear request to the supplier – the customer pulls what they need from the supplier.
4. Supplier becomes a customer in order to meet the END CUSTOMER's request
5. Work is planned starting from the milestone activity working right to left.
6. As you get closer to date the task will be performed, you may need to adjust plan to improve process and that adjustment to the plan is OK, & is expected.

Materials:

1. Laminated plans / drawings of the tower & have a projector or smart board
2. Wood Block Kit (1 per 4 person team) & 4 fine-point sharpie markers per team
3. 4 x 4 "extra sticky" post-its of 4 colors for each color of blocks. (6 tags / color)
4. Milestone stickers w/ "Owner Move into VIP Suite - red triangle w/ point down"
5. Example "post-it" tag with sections filled in.

Turner

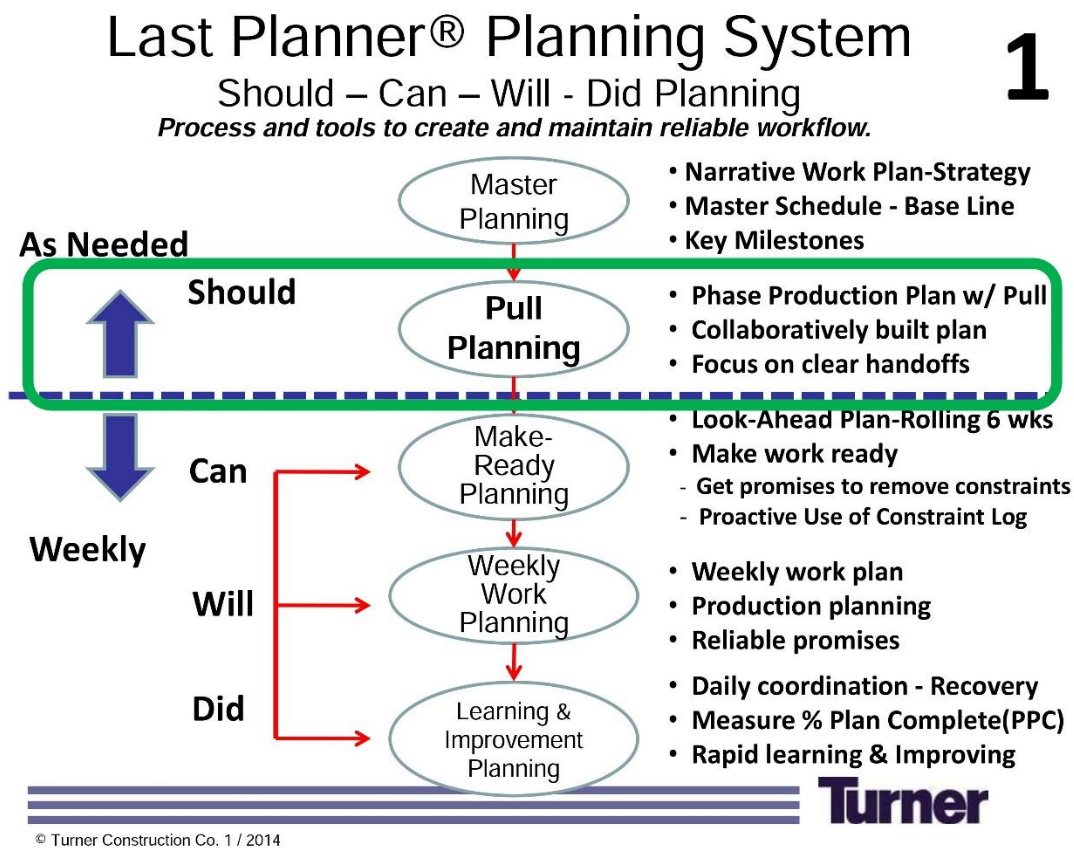
4

Our Challenges With Planning **D**

COACHES SHEET

- IF this is an average USA construction project:
- IF this group promised to finish 10 tasks on specific days next week, how many tasks actually finish on the day promised?
- Raise your hand if you think… *# Votes*
  - 10 tasks are done on day promised ____
  - 8 tasks … ____
  - 6 tasks … ____
  - 4 tasks … ____
  - 2 tasks … ____

SPEAKER NOTES: Why is it so challenging to plan and schedule the work in our projects? Lets hear a few reasons? What do you think? [jot on flip chart] "lets look at this question –*see bullets above* – raise your hand … tally votes: THEN "Per LCI research We only finish 54% of tasks on average. What do we do for the 46% missed promises / tasks? We need to be more reliable and to do that we use the Last Planner Planning System.


Last Planner® Planning System
Should – Can – Will - Did Planning
Process and tools to create and maintain reliable workflow.
1
Master Planning
• Narrative Work Plan-Strategy
• Master Schedule - Base Line
• Key Milestones
As Needed
Should
Pull Planning
• Phase Production Plan w/ Pull
• Collaboratively built plan
• Focus on clear handoffs
Can
Make-Ready Planning
• Look-Ahead Plan-Rolling 6 wks
• Make work ready
- Get promises to remove constraints
- Proactive Use of Constraint Log
Weekly
Will
Weekly Work Planning
• Weekly work plan
• Production planning
• Reliable promises
Did
Learning & Improvement Planning
• Daily coordination - Recovery
• Measure % Plan Complete(PPC)
• Rapid learning & Improving
Turner
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What Is The Question This Team Is Trying To Answer ? **2**

"How will we do our work to reach this milestone?"

Injury Free, Quality, Efficiently, Reliably, On Time

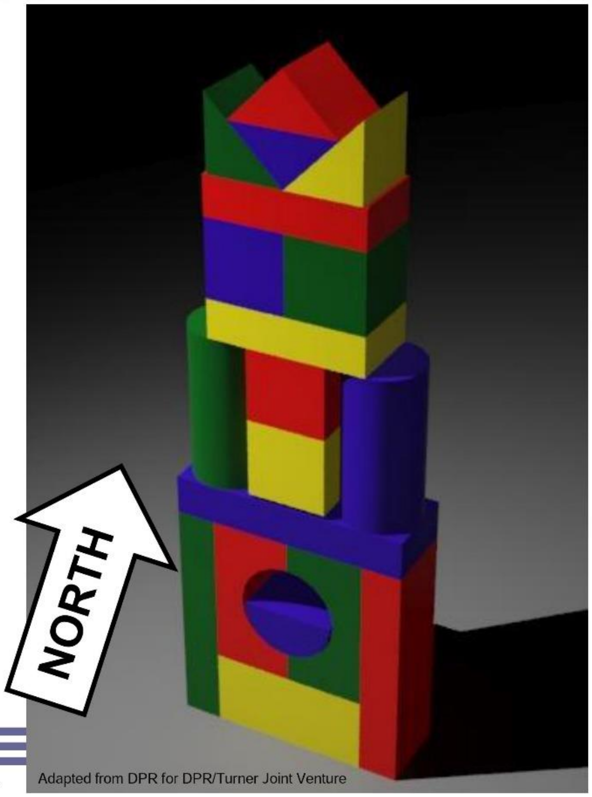
Turner

Make a Pull Plan To Build This Tower 3

1. Make a pull plan.

2. Build tower per your plan WITHOUT the picture / drawings.

3. Check for quality.

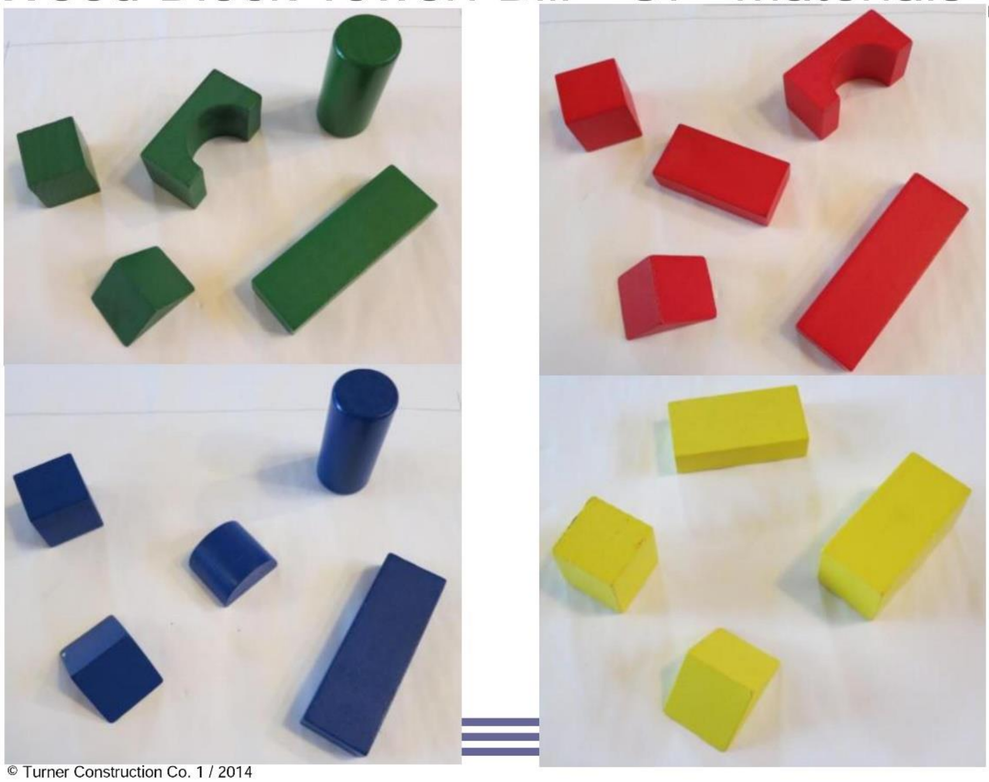


Block Color Legend

R = Red
B = Blue
G = Green
Y = Yellow

Turner

Wood Block Tower: Bill - Of - Materials 4



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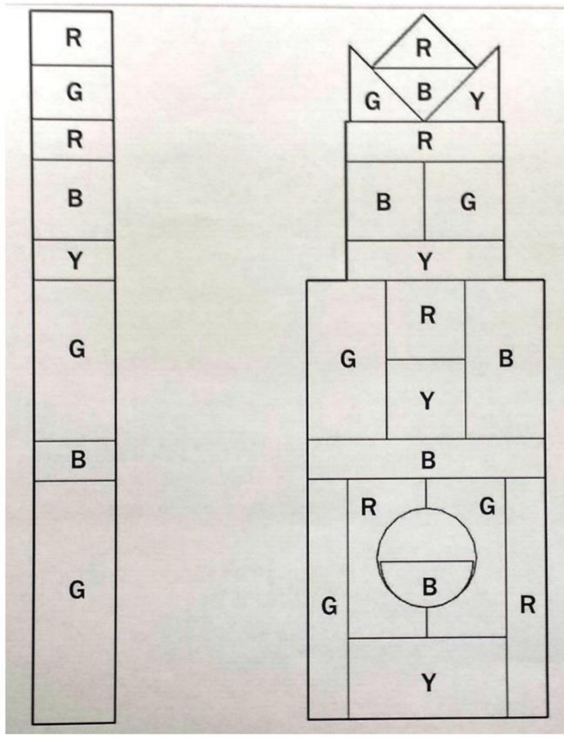


Block Color Legend

R = Red
B = Blue
G = Green
Y = Yellow

2 West Elevation

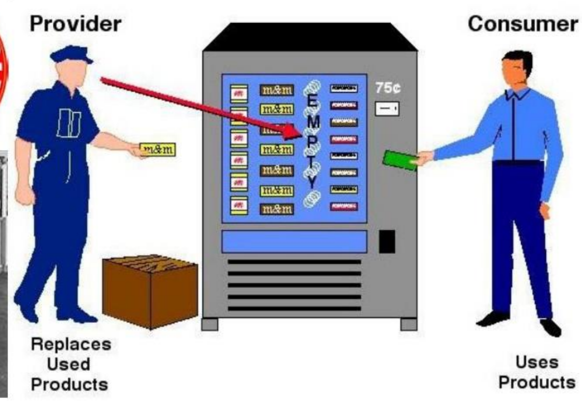
1 South Elevation

Turner

Adapted from DPR for DPR/Turner Joint Venture

Ready To Plan? Use **Pull** *Not Push* 6

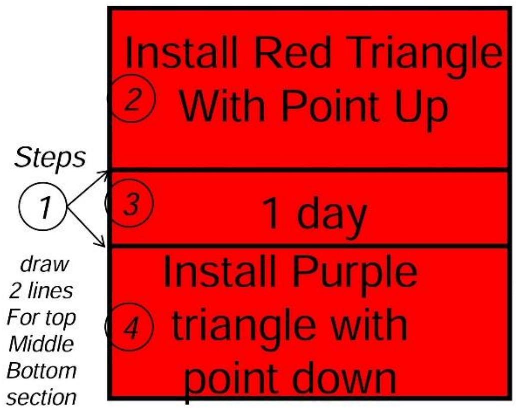
- Pull ensures you do not make something or deliver a service until your customer really needs it.
- Reduces the waste of making something before needed:
  - Storing it somewhere - Looking for it
  - Counting & Reporting - Damaged
  - Design is changed



Format / Layout To Add Info To Tags **7**

EXAMPLE TAG

Each task gets one tag
A task MIGHT have more than one task by other needed



2 **Describe:** ***The Task I Will Will Do - be specific***

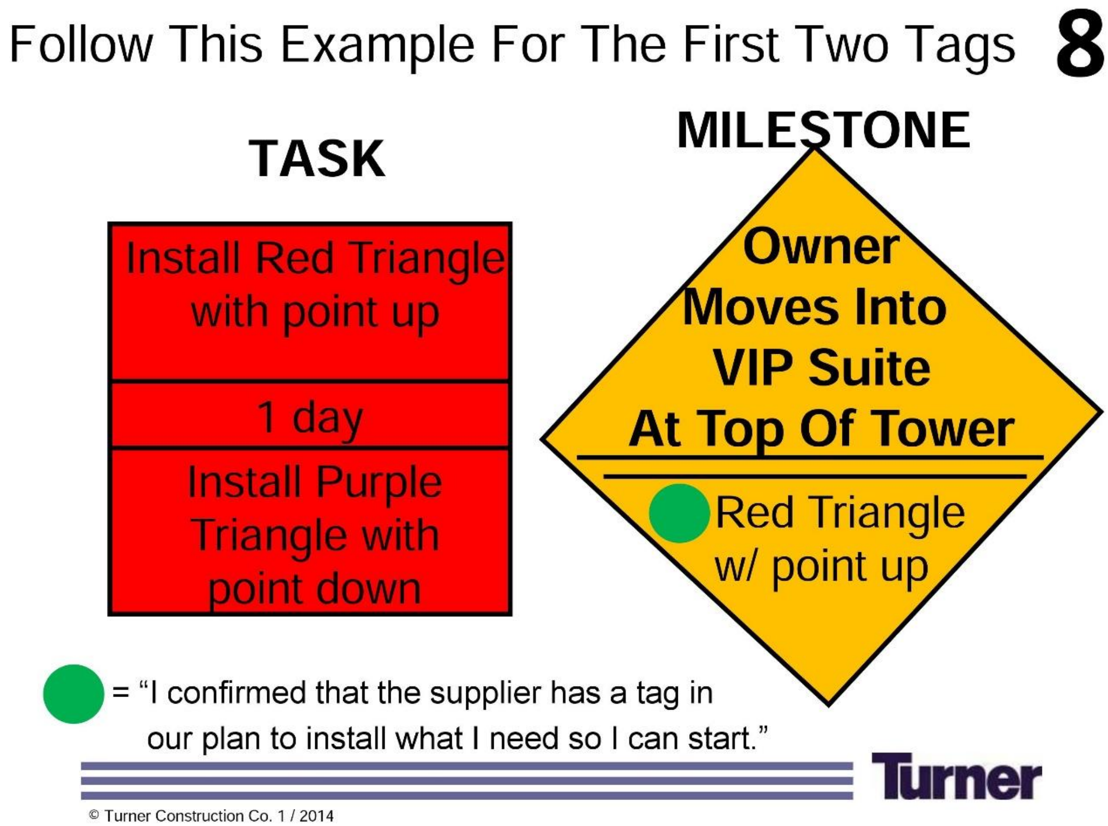
3 **duration:** ***# Days***

4 **Describe:** ***I need __?___ by others to start my task***

Be Specific & Clear –
"My Conditions Of Satisfaction are…_________."

A task MIGHT have more than one "I need"

Turner


Follow This Example For The First Two Tags 8
TASK
MILESTONE
Install Red Triangle with point up
1 day
Install Purple Triangle with point down
Owner Moves Into VIP Suite At Top Of Tower
Red Triangle w/ point up
= “I confirmed that the supplier has a tag in our plan to install what I need so I can start.”
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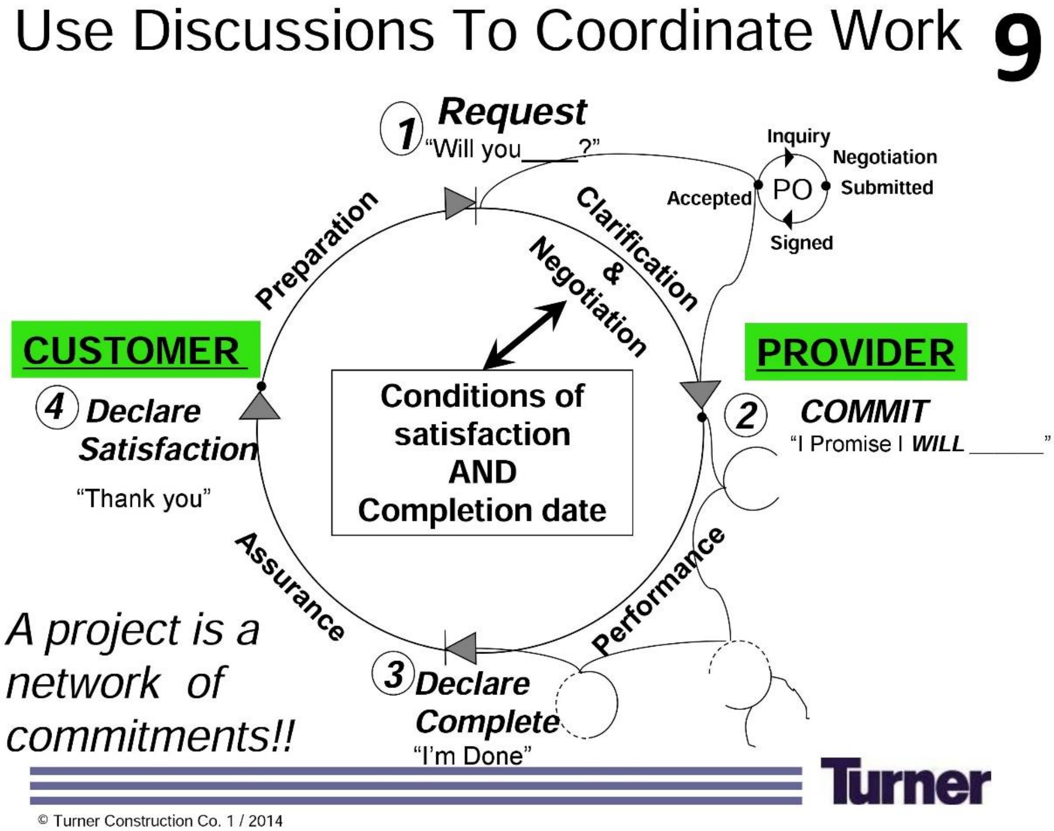
© Turner Construction Co. 1 / 2014


Use Discussions To Coordinate Work
9
1 Request
"Will you____?"
Inquiry
Negotiation
Accepted
PO
Submitted
Signed
Preparation
Clarification
&
Negotiation
CUSTOMER
PROVIDER
Conditions of satisfaction AND Completion date
4 Declare Satisfaction
"Thank you"
2 COMMIT
"I Promise I WILL ______"
Assurance
Performance
A project is a network of commitments!!
3 Declare Complete
"I'm Done"
Turner
© Turner Construction Co. 1 / 2014

Pull Planning Meeting Tips, Details **10**

- Start with "**target milestone activity**" on the far right end.
- Add tags to left when requested by your "**customer**"
  - Scheduler *
  - Superintendent**
  - *Trades/Designers are just to the left of this picture*

© Turner Construction Co. 1 / 2014

- One by one, add tasks to left, work from right to left – using "**pull mechanism**". "**To start this** task, I must have XYZ task **done.**" **Ask, what** one task really allows me to start ?

Turner

Parade of Trades simulation

PARADE OF TRADES

Courtesy: Greg Howell

Lean Principles Illustrated

To illustrate the importance of batch size, continuous flow and PPC

Learning Objective

- Understanding the impact of dependence and variation on project workflow is critical for the performance of construction trades and their successors
- Explain the benefits of variation reduction on construction operations
- Identify the effect of batching on production systems
- Identify the effect of pull on a production system

Target Audience

Anyone in the construction industry

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 2
- Facilitator : 3

Number of players per facilitation

1 Facilitator per round with 7 players.

Duration per facilitation

- 90 minutes

Materials required per facilitation

- 35 chips (representing the work)
- Blue, red, green, or black dice
- Summary Score sheet
- Room with tables set for 7/table where participants have sufficient space to easily play the game

Facilitation Guidelines

- Each trade is arranged around the table as shown in Figure 1. The trades work in sequence, with each following trade able to work only on what was produced in the previous week by the prior trade.
- The simulation is started with all 35 chips on the left of concrete. Establish queue spaces (buffers for inventory) between each trade.

- Work is done by rolling a die and passing the number of units rolled, x, up to the number of units the trade has available to process. In the real world, this is the same as your trade completing x number of units of work per week.
- The number rolled also represents the number of workers brought to the site that week by the trade rolling the die. Each worker is able to process one unit of work per week.
- The trades come onto the project a week apart. Work is completed and available to the next trade once a week. A die has an average production rate of 3.5 units per roll (per week).
- The project is complete when 35 units of work (chips) have been processed by each of seven trades.
- What duration would you propose for the project? (Hint: 35 units per project, 3.5 units per week, 7 trades. One complete roll through all trades at a table represents 1 week).

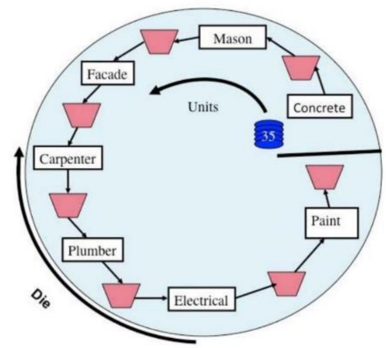


Figure 1: Arrangement of trades around a table

Key-takeaways

- Reducing workflow variability
  - Concurrently improves total system performance: cost, schedule, quality, safety
  - Makes project outcomes more predictable
  - Simplifies coordination
  - Reveals new opportunities for improvement
- Point speed and productivity of a single operation doesn't matter – throughput / workflow does.
- Strategy: Reduce variation then, and only then, go for speed to increase throughput: "Go Slow to Go Fast."

Discussion

- What are the consequences of unpredictable workflow?
- Which project will have fewer change orders?
- Which project will have fewer legal issues?

- Which one would you want to manage?
- Which one would you want to estimate for?
- Which would you rather have:
    - A die that was faster, or a die that was more reliable/predictable?
- Which one do we choose on our projects every day?

References

Tommelein, I. D., Riley, D. R., and Howell, G. A. (1998). "Parade game: Impact of work flow variability on trade performance". *Proceedings of 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, 13-15 Aug 1998.*

Lean Construction Institute (2010). "Parade of trades™". *Joint FCURT/LCI Meeting, 12 August 2010*

Bolivar, A. (2011). "Enhancing the Construction Parade of Trades Game". *Proceedings of 47th ASC Annual International Conference*

Villego simulation

VILLEGO

Courtesy : Villego.com

Lean Principles Illustrated

To illustrate the importance of Last Planner System

Learning Objective

- Shows the differences between the old way and the new, lean way
- Enables participants to experience the essence of Last Planner
- Demonstrates the benefits of making and keeping promises
- It helps build the project team
- It develops understanding of how each participant benefits

Target Audience

Employees, subcontractor staff, other project participants, clients

Scale of Difficulty

[(Audience, Facilitator) (1=easy to 5= hard)]

- Audience : 3
- Facilitator : 3

Number of players per facilitation

Minimum of two rounds played amongst six and 14 participants

Duration per facilitation

- Round one (explanation, preparation , construction): 120 minutes
- Introduction to Last Planner System and Lean Construction: 60 minutes
- Round two (explanation, preparation , construction): 120 minutes
- Recap, discussion, questions : 30 – 60 minutes

Materials required per facilitation

- Instruction manual
- An excel file for calculating scores
- Personal protective equipment
- Site safety marking
- 6 colors of stickie's
- Lego material for the material supplier
- Skip/dumpster for waste
- Copies of all large consumables for the first use
- A USB stick containing PDF copies of all printed consumables so that you can reprint as required
- Flipchart
- Pens/pencils

- Laptop and data projector
- Pair of scissors
- Your own LPS presentation

Room Logistics per facilitation

A large room with at least 20 linear feet/6m of clear wall to attach planning forms

Facilitation Guidelines

- In the first round, which generally takes one to two hours, participants use traditional push scheduling and management techniques. According to Villego® (2013), round one simulates the way participants currently deliver projects:
    - Work is pushed into production as detailed by the critical path.
    - Cooperation is not emphasized.
    - Information is not shared.
    - Costs are the primary focus.
    - When problems occur, blame reigns as individuals focus on protecting themselves rather than advancing the project.
- In the second round, which takes approximately two hours, participants utilize pull planning and other lean philosophies. According to Villego® (2013), round two simulates the way projects that use the LPS® are delivered. The LPS® techniques are characterized by the following:
    - Work is pulled into production.
    - Project management uses real time, in-process data and coaching.
    - Continuous collaboration and cooperation are emphasized.
    - Information is shared.
    - Customer value is the primary focus.
    - Teams focus on learning and continuous improvement.
- During round two, planning sessions occur after each week (60-second interval) where the team identifies failures from the previous week and determines appropriate corrective measures to improve future performance.
- During the planning period, the team also collaboratively adjusts the project strategy going forward and precisely plans the work for the upcoming period. This process is repeated until the second structure is completed.

Figure 1: Preparation for round one

Figure 2: Construction in round one

Figure 3: Collaborative pull-planning

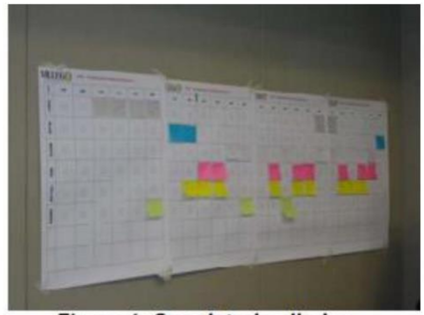


Figure 4: Completed pull-plan

Discussion

- The two-round approach helps participants compare traditional management with lean management. Monetary bonuses for on-time completion, penalties for safety violations, fees for material delivery, and other considerations enhance the simulation.
- At the conclusion of both rounds, the facilitator compares scorecards and results for each round and helps participants identify specific experiences that emphasize lean principles.
- The pre- (and post-) simulation questions were:
  - Describe the strengths of traditional scheduling methods.
  - Describe the weaknesses of traditional scheduling methods.
  - What is flow on construction projects?
  - How can flow be created on construction projects? After completion of the simulation, participants answered these same four questions along with several other questions, requesting an account of their experiences throughout the simulation.
- The remaining post-simulation questions were:
  - What were your key “take-aways” from the simulation?
  - What specific experiences demonstrated those “take-aways?”
  - What will you implement right away?
  - What was unclear or frustrating to you?
  - What did you enjoy most about the experience?

References

Lean Construction Institute (2015). “LCI Simulation Matrix.” <http://www.leanconstruction.org/simulation/> (March 23, 2016)

Warcup, R., and Reeve, E. (2014). "Using the Villego® Simulation to Teach the Last Planner® System". Lean Construction Journal, January 1.

“Villego Kit.” <http://www.villego.com/workshop-simulation> (March 22, 2016)

“Villego Last Planner Simulation - Pull Planning - Lean Construction” <https://www.youtube.com/watch?v=hBn6O6stVjM> (March 23, 2016)

APPENDIX G SECTION 5.7: LEAN SIMULATION FACILITATION GUIDELINES

Target Value Design simulation

TARGET VALUE DESIGN

Courtesy: Dr. Zofia Rybkowski, Texas A&M University

Lean Concept Illustrated

To illustrate the importance of Target Value Design

Learning Objective

- Stakeholders need to understand importance of pulling design to client's financial resources
- To help participants understand the basic principles of Target Value Design (TVD) within the Integrated Project Delivery (IPD) process

Target Audience

Anyone in the industry

Scale of Difficulty

- Easier for those with creative skills
- Difficult for those without the necessary creative skills

Number of players per facilitation

- Divide participants into teams of 6-10 people each.
- Within each team, form the following groups:
    - Owners
    - Designers
    - Constructers

Duration per facilitation

- This simulation is played in two rounds. The first round simulates traditional Design Bid Build (DBB) processes and second round simulates a TVD-IPD processes.
    - Setup: 15 minutes
    - Play: 30 minutes
    - Debrief: 15 minutes

Materials required per facilitation

- Desk tops with 6 participants per table
- Masking tape
- Bamboo skewers
- Drinking straws
- Uncooked spaghetti
- Coffee stirrers
- Marshmallows
- Design sheets for Round 1
- Costing sheets for Round 1

- Design sheets for Round 2
- Costing sheets for Round 2
- Stopwatch

Facilitation Guidelines

- The game applies TVD processes to Peter Skillman and Tom Wujec's "Marshmallow Challenge."(*See*: http://thebuildnetwork.com/team-building/team-building-what-a-marshmallow-reveals-about-collaboration/)
- Instruct all teams: "The Owner wants to design and build a tower that is 2'-0" tall which is capable of holding a marshmallow at the top and that is no more than 2" out-of-plumb. The tower must be constructed with supplied materials and must be free- standing (i.e. cannot be taped to a table).
- First round (traditional Design Bid Build project delivery). Figure 1 shows the arrangement of different stakeholders for this round.

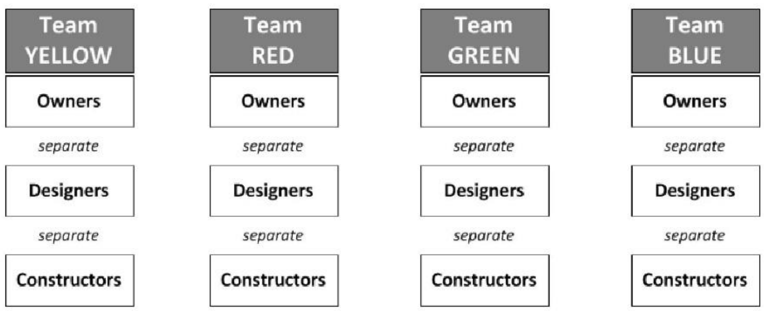


Figure 1: Reprinted from TVD Simulations Instructions, Department of Construction Science, , Texas A&M University : Seating arrangement for all stakeholders.

- The designers should design a tower using the instructions in the design sheet, obtain approval from the owner and then deliver the design to be constructed to the construction team. Figure 2 illustrates a design sheet used by the designers.

Design I: Team: ________ Time of completion (design): _________ Time of completion (construction): _________

Request for information (how many times):____________

Instructions:
Client wants to build a 2'0" high tower to hold Marshmallow, Designer will draw a model in this sheet (use following materials and give specifications in the drawing)

Spaghetti (9" long)
Coffee stirrers (4" long)
Straw (7" long)
Skewers (11" long)
Paper tape

Figure 2: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : Design sheet for round 1

- After completing the construction, each team should calculate the total cost of their tower based on the material cost illustrated in Table 1

Table 1: Costing sheet to calculate cost of the constructed tower

Round 1			
Team Name_____________			
Item	**Unit cost**	**Number of units**	**Subtotal**
Spaghetti sticks	$1.00		
Coffee stirrers	$5.00		
Drinking straws	$2.00		
Bamboo skewers	$3.00		
Masking tape (per joint)	$0.50		
Profit (10%)			
		Total Cost:	

- Before proceeding to the next round it is essential to calculate various costs as follows :

- Market cost is the average cost of all towers built during Round 1
- Allowable cost is calculated by deducting 15-20% from the market cost
- Target cost is set by the participants and it is less than the allowable cost

- Table 2 illustrates a sample costing sheet for design 1.

Table 2: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : Costing sheet for Design 1 illustrating market cost, allowable cost and target cost.

				Design I				
		Spaghetti	Coffee mixture	Straw	Skewer	Paper tape		TOTAL COST
	Costs	$1.00	$5.00	$2.00	$3.00	$0.50		
RED	No.		2	4	8	1		
	Costs	$0.00	$10.00	$8.00	$24.00	$0.50		$42.50
BLUE	No.	0	4	5	8	1		
	Costs	$0.00	$20.00	$10.00	$24.00	$0.50		$54.50
YELLOW	No.	0	4	3	7	7		
	Costs	$0.00	$20.00	$6.00	$21.00	$3.50		$50.50
GREEN	No.	6	4	6	6	18		
	Costs	$6.00	$20.00	$12.00	$18.00	$9.00		$65.00
Average cost								$53.13
15% - 20% less								$42.50
Target cost								$30.00

- For the second round (TVD- IPD format). Figure 3 shows the arrangement of different stakeholders for this round.

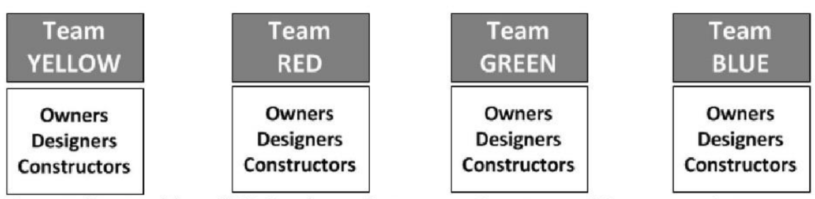


Figure 3: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : Room setup for second round

- The objective is to build a 2"0 tower with designers, owners and constructors working as a single team. Figure 4 illustrates the design sheet for round 2.

Design II: Team:________ Time of completion (design):_________ Time of completion (construction):_________

Request for information:___________

Instructions:

Client wants to build a 2'0" high tower to hold Marshmallow, Designer will draw a model in this sheet (use following materials and give specifications in the drawing)

Spaghetti (9" long)
Coffee stirrers (4" long)
Straw (7" long)
Skewers (11" long)
Paper tape

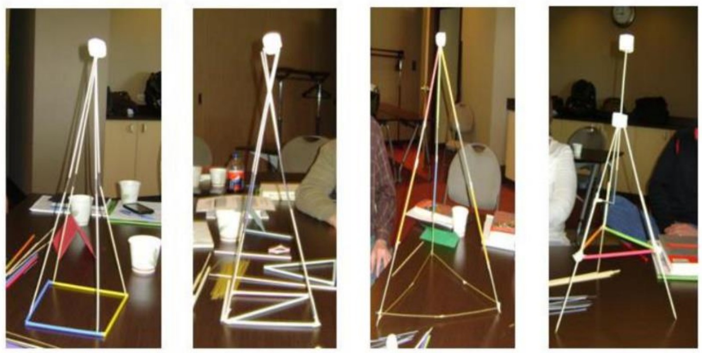
Figure 4: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : Design sheet for round 2

- Table 3 illustrates the costing sheet for round 2 to calculate the cost of the tower.

Table 4: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : Costing sheet for round 2

Round 2			
Team Name____________			
Item	**Unit cost**	**Number of units**	**Subtotal**
Spaghetti sticks	$1.00		
Coffee stirrers	$5.00		
Drinking straws	$2.00		
Bamboo skewers	$3.00		
Masking tape (per joint)	$0.50		
Profit (10%)			
		Total Cost:	

- During round 2 , a few things should be taken into consideration before calculating the final cost
    - Design tower to owner's requirements and calculate the total cost. If it exceeds the Allowable Cost, see if you can redesign it until you reach Allowable Cost.
    - If your estimate is below the Allowable Cost, see if you can redesign to reach the Target Cost.
- Figure 5 illustrates the towers constructed during round 1



(RED TEAM) (BLUE TEAM) (GREEN TEAM) (YELLOW TEAM)

Figure 5: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : towers constructed during round 1

- Figure 6 illustrates the towers constructed during round 2

(YELLOW TEAM) (RED TEAM) (GREEN TEAM) (BLUE TEAM)

Figure 6: Reprinted from TVD Simulations Instructions, Department of Construction Science,, Texas A&M University : towers constructed during round 2

Discussion

- What "light bulb moments" did you have after playing the game?
- What were some basic differences between two rounds?
- How did the decision-making processes differ between the two rounds?
- Which round was more stressful to you? Less stressful?
- Which round offered better cooperation?
- In which real life circumstances might Round 1 be more appropriate? How about Round 2?
- How might these process be applied to your real life projects?

References

Lean Construction Institute (2015). "LCI Simulation Matrix" *<http://www.leanconstruction.org/simulation/>, (March 23,2016)*

Rybkowski, Z.K."TVD Simulation Instructions". *Department of Construction Science, Texas A&M University*

Rybkowski, Z. K., Munankami, M., Gottipati, U., Fernańdez-Solis, J., and Lavy, S. (2011). "Toward an Understanding of Cost and Aesthetics: Impact of Cost Constraints on Aesthetic Ranking Following Target Value Design Exercises". *Proceedings of 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 Jul 2011.*