

INVESTIGATION INTO THE DEVELOPMENT AND APPLICATION OF
SIMULATIONS IN LEAN CONSTRUCTION

A Thesis

by

VAARUN SANJAY CHHAJED

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

Chair of Committee	Zofia K. Rybkowski
Committee Members	José L. Fernández-Solís Rodney C. Hill
Head of Department	Joseph P. Horlen

August 2015

Major Subject: Construction Management

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ABSTRACT

A substantial number of the activities currently being carried out in the construction industry are non-value adding. Waste is embedded in the system, and one of the ways to reduce this waste is by applying a lean approach. Simulations provide an opportunity to carry out controlled experiments, to generate convincing proof, and to educate personnel about lean construction principles. No study has yet been published to comprehensively inventory the simulations most frequently played when introducing participants to lean construction. Despite its importance, the development and application of lean construction simulations have not been studied comprehensively. The intent of this paper is to address this need and to offer a concise database of simulations that are being implemented in the construction industry. A thorough literature review regarding the utility, impact and necessity of simulations was conducted. Understanding of lean simulations, current and future, was supplemented by live, semi-structured interviews with three academics and/or practitioners who specialize in the development and facilitation of lean construction simulations.

Finally, simulations currently being played most frequently by lean construction educators and practitioners were analyzed and categorized based on the fourteen principles of Liker's *The Toyota Way* and the five principles of Womack and Jones' *Lean Thinking*. Opportunities to fill gaps by developing new simulations were also identified.

ACKNOWLEDGEMENTS

I would like to express my earnest thanks and respect to my chair Dr. Zofia Rybkowski and my committee members Dr. Jose L. Fernandez Solis and Professor Rodney Hill for the guidance and motivation that they have given me to pursue this research and complete it with success.

Thank you to my parents, my sister and my friends for supporting me to pursue my Master's degree at Texas A & M University.

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CHAPTER I

INTRODUCTION

Purpose of Study

The purpose of this research is to investigate the development and application of games in lean construction. This research is important because live playing of simulations substantially contribute to the investigation and propagation of lean thought in construction. Up until now, information about lean construction simulations has been scattered. This study aims to create a concise database of the games and simulations present in the construction industry today.

Background

Smith et al. (2011) stated that “the construction industry is unsafe, inefficient, and fraught with errors and litigation.” Waste is created in the construction industry by flaws in design, supply systems of materials and other non-value adding activities. Fernández-Solis & Rybkowski (2015) argue that when waste is woven into a project, it becomes embedded into the project, because resources that could have been used for generating value were instead consumed for the generation of waste. Because the cost of waste + cost of value = total cost of the project, as the cost of waste decreases, the total cost of the project approaches the cost of value. Taiichi Ohono, the pioneer of TPS (Toyota Production System) defined waste as a “non-value adding activity” (Liker 2004). Carvalho et al. (2013) suggest it is critical to eliminate activities that add no value to the product but which represent a relevant cost. Lean construction has been given many definitions, but arguably involves reducing waste and adding value using

continuous improvement in a culture of respect (Rybkowski et al. 2013). The introduction of lean philosophy has made remarkable improvements in the construction and manufacturing sector since its inception (Mirehei et al. 2011). Training in lean has grown in importance in offices, classrooms and even among skilled labor (Pourabdollahian et al. 2012). Although a comprehensive understanding of Lean cannot be grasped through playing any one game or simulation, simulations enable participants to understand lean principles. They nurture discussion, participation and decision-making, which are fundamental requirements to successful implementation of lean manufacturing--something difficult to obtain through traditional learning methods (Carvalho et al. 2013).

Through informal polling, it is the author's impression that lean simulations or games serve to deliver a "eureka moment" (Lee 2002) to participants, convincing them of the validity of the claims made by the lean construction community in a way that traditional PowerPoint presentations sometimes fail to do. The research assumes that lean games are relatively effective because consultants almost without exception use them wherever lean principles are being taught (Verma 2003).

Research Goal & Objectives

Research Goal

An overarching goal of this research is to gather together disparate threads of information about simulations that are being used to introduce lean principles to construction practitioners.

Objective 1

One objective of this research is to investigate the progression and significance of lean games that have made a contribution to the transmission of lean philosophy to practitioners in various industries, and to begin to develop a descriptive inventory for these simulations.

Objective 2

A second objective of this research is to begin to identify and aggregate lessons learned from the inventoried simulations and games.

Limitations

Limitations of this study include:

1. This study will investigate only those published papers that are available through the database of Texas A&M libraries.
2. There are many games that are played all over the globe, but that do not necessarily have a paper written about them. Lean simulations are sometimes improvised through feedback from participants, and continue to be played if they are effective. However, this study will only investigate the simulations that have been published.

Delimitations

The delimitations of this study are:

1. This study will only investigate simulations from lean philosophy that are being applied in the construction industry, and not any other industry.

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2. This study will not study simulations that are created under different headings, such as management or team building, other than lean.

CHAPTER II

LITERATURE REVIEW

Current Scenario

Traditionally, the context of ‘learning’ was related to formal education. With rapid development in internationalization and globalization has come changes in professional structures and advancement in the fields of information technology and communication. Corrigan et al. (2014) suggest that there is a need for personnel to adapt to function in this environment, thereby creating a space for workplace learning. In today’s competitive environment, it has become obligatory for corporations to find means to improve their performance. Hart (2012) found that only 14 % of establishments believe that traditional learning approaches to corporate training is an effective way for employees to learn in the workplace. This is where serious games and simulations come into play. Carvallho et al. (2013) advised that educating all organizational levels in effective learning methods is critical for success. Aware of this fact, organizations have been making a substantial effort to change the way they educate their personnel.

Games, Simulations and Serious Games

Educational games can be broadly classified into two types. The first type is where learning objectives are layered on top of the educational content. Such games are mostly based on the principle of avoiding mistakes, and can be applied to many different areas. The effectiveness of these games tends to decline as the participant’s experience grows. The other type of game involves lessons being integrated into the game. Most of the simulations being designed today can be included in this category (Graven and

MacKinnon 2006). The beauty of this type of simulation is that the potential of educating the participants depends wholly on the developer. Pasin and Giroux (2011) described simulation as the demonstration of a facet of reality based on a simplified and abstracted prototype. Verma (2003) describes simulation as a tool that makes grasping complex concepts easy and effectively. Simulation games were first applied in the military and aeronautics industry. They are now used for educating in the fields of nursing, medicine, management, and several other fields (Pasin and Giroux 2011). Verma and Devulapalli (2006) explain that simulations bind specific information onto real life problems in ways that participants can understand. Participants at the time of simulations acquire knowledge pertaining to a specific discipline, which they can later apply to their work environment.

Most learning theories have emphasized that active participant engagement in the learning process improves learning outcomes (Pourabdollahian et al. (2012). Serious games are intended to fulfill the main objective of creating an informative or skill improvement setting for the participant. Yusoff (2010) has emphasized there are two distinct perspectives with respect to a serious game: an “educational” perspective, where application and grounded theory of learning are taken into account, and a “psychological” perspective, which assesses the factors that make a game competitive and engaging. Serious games can provide immense learning opportunities. Some of these appear to be crucial requirements for generation X employees who were raised in the modern information age. Education can no longer be constrained to acquiring knowledge of written matter. It also has to deal with applying and implementing this knowledge for

problem solving situations in the workplace. Multifaceted knowledge such as this is about obtaining capabilities such as information technology skills, team building, problem-solving, collaboration, and introspection about everyday difficulties (Hummel et al. 2011). Such competences are usually not addressed by other learning platforms. Some major requirements identified by Graven and MacKinnon (2006) for a well-designed simulation include: high interaction intensity, well-defined goals, introduction of continuous challenges to participants, provision of engagement to players, and avoidance of any possible deviations or distractions.

Lean and Games

Lean manufacturing or lean is a manufacturing philosophy focused on refining the quality of products and customer service, by decreasing time, waste and cost. Gomes et al. (2013) explained that lean is based on a production system created by Toyota in 1945- the TPS (Toyota Production System). There is a need to impart knowledge in this field. The transfer of knowledge about lean principles is presently labor-intensive. Little is known about the extent to which lean philosophy can be applied to industries such as construction--where complexity varies in nature--with that of manufacturing, in which lean production originated (Tarcisio et al. 2013). Rybkowski et al. (2013) showed through an experiment which required its participants to graphically define lean construction on the back of a cocktail napkin that opinions from participants varied, and that a common definition of lean construction is not exactly clear.

It is believed by the Lean Construction community that teaching lean principles through games or simulations is highly effective (Munankami 2012). Pourabdollahian et

al. (2012) suggested that the playing of serious games is aimed to educate, rather than purely to entertain. This has emerged as a prospective learning method. Simulations, serious games and game theory are not only used to teach lessons, but also to study the impact of specific lean interventions (Rybkowski and Kahler 2014). Collaborative learning is an approach that is based on the theory that learning is largely a social activity, involving groups of participants working collectively as a team to find a solution, and collaborating to implement that solution (Corrigan et al. 2014). Many lean games are based on this observation and are structured to foster team work. Most lean trainings start with a brief lecture regarding lean concepts and describing some important lean tools. This is followed by a lean simulation game that demonstrates how one or several lean tools can be implemented and how they affect the performance on the shop floor, the construction site or the office (Mirehei et al. 2011). Tsao et al. (2013) conducted a survey on eight different universities teaching lean construction. The paper demonstrated that all surveyed programs were using active-based learning methods such as simulations and discussions in the classroom.

Prevailing Game's Objective and Deduction

Some simulations used by the lean construction community as of this writing are included in this section. Tommelein et al. (1999) evaluated a game called the 'Parade Game,' developed by Gregory Howell. The game depicts the parade of trades formed by successive subcontractors in the construction industry. Howell concluded that this game offered an effective way to teach concepts regarding the impact of variability on work flow.

Sacks and Harel (2008) developed a formula for implementation of payment to subcontractors; the formula transfers some of the risk for decreased productivity due to instability in planning and incomplete designs from the subcontractor to the general contractor. The formula requires a price for volume to be set as well as a price for the final product, based on a single weighting parameter. Using a game theory-based simulation, use of this formula has been shown to modify behaviors of resource allocation that benefit all parties in unfavorable conditions.

Target value design (TVD) has been shown to generate first cost savings of almost 20%. Some architects raised concerns that implementation of TVD may result in producing aesthetically inferior designs. Rybkowski et al. (2011) developed an exercise to test the impact of cost constraints on aesthetic ranking following target value design. The exercise concluded that there was a slight negative impact on design quality due to reduced cost. Munankami (2012) developed a game for TVD and IPD (Integrated Project Delivery), which is being adopted in the construction industry. Results suggested that participant responses to IPD were satisfactory, whereas for TVD, they were not.

Sacks et al. (2005) proposed the LEAPCON game to simulate the impact of the lean approach on construction of high-rise apartment buildings. The three major variations to the construction management principles incorporated in the game were: smaller batch sizes, multi-skilled teams instead of specialized contractors, and shift to a pull system instead of the traditional push system. There were ten different simulations carried out with various permutations and combinations. Esquenazi and Sacks (2006) evaluated that every change to the construction management system improvised one or

more of the parameters that were being considered. Different changes had different magnitude of impact on different parameters.

Rybkowski and Smith (2013) developed a game called, ‘The Maroon-White Game.’ Built on an existing simulation called the red-black game, this game helps the participants reorient their understanding of long-term benefits from collaboration, when placed in a competitive condition. Contestants can see how in many circumstances collaboration and trust can ultimately result in receiving higher individual gains over time, as well as receiving enhanced results as a whole at any point in time.

In the field of manufacturing, Gomes et al. (2013) proposed a serious digital game to illustrate the 5S method. The five components of the 5S are sort, straighten, shine, standardize and sustain. Even though there is scope for improvement, the game satisfied its objective to act as a motivational tool for educating and training purposes. Verma (2003) conducted an extensive investigation into the current application of simulation tools and training programs in lean manufacturing in the shipbuilding industry. It concluded that none of the seventeen simulation activities being used are designed to address issues such as the design process of ships, repair procedures, and value stream mapping, thus highlighting the loopholes in the implementation of game theory. In the field of lean manufacturing Messaadia et al. (2013) implemented a ‘Muscle Car’ game through ILPE. ILPE (Industrial learning Pilot Events) validates a concept by interacting with stakeholders in the industry. The participants were highly involved and motivated during the game, reinforcing the importance of such activities which enhance the process of learning.

CHAPTER III
METHODOLOGY

Research Methodology

Since one objective of this research was to construct an inventory of published lean simulations, the method adopted for this study was systematic Literature Review. Various articles describing research conducted in the area of games and simulation in lean construction were comprehensively identified and reviewed. Once the simulations were identified, they were described, and potential applications of the simulation principles to construction industry were identified. The specific procedure used was as follows:

STEP 1: Applied for IRB (Institutional Review Board) approval

STEP 2: Searched Texas A&M Library database, and completed the following table:

Date of search	Database searched	Keywords searched	Number of hits	Number of relevant hits	Citation(s)

STEP 3: Summarized games that are currently being played in lean construction. This helped gain a better grasp of the concepts on which the simulations were created, the methodology, and results and discussions that are associated with these games.

STEP 4: Contacted Lean experts--Alan Mossman, Rafael Sacks, and Zofia Rybkowski--to discuss their understanding of the development of Lean Construction simulations.

Furthermore, this interview helped provide a better understanding of the applications and importance of games in lean. The interviews were audio-recorded and summarized.

STEP 5: Constructed an inventory of existing lean simulations and mapped them to the principles they illustrate with respect to the 14 principles described in Liker's *The Toyota Way*.

Results

To inventory the available literature regarding simulations and games that are currently being implemented in academia or practice in lean construction, this investigation included a structured literature review. Table 1 shows the results obtained.

Table 1: Preliminary Results for Literature Search

No.	Date of search	Database searched	Keywords	No. of hits	No. of relevant hits	Citation
1	11/05/14	Engineering Village	Serious games AND Lean manufacturing	9	6	Gomes et al. (2013)
2						Messaadia et al. (2013)
3						Carvalho et al. (2013)
4						Kerga et al. (2013)
5						Cerinsek et al. (2012)
6						Kerga et al. (2014)
7	11/15/14	Engineering Village	Game theory AND Lean construction	17	15	Sacks and Harel (2006a)
8						Sacks and Harel (2006b)

Table 1: Continued

No.	Date of search	Database searched	Keywords	No. of hits	No. of relevant hits	Citation
9						Zhu and Shuquan (2008)
10						Esquenazi and Sacks (2006)
11						Sacks and Goldin (2007)
12						Smith and Rybkowski (2013)
13						Tommelein et al. (1999)
14						Sacks and Harel (2008)
15						Sacks et al. (2005)
16						Sharma and Cui (2012)
17						Rooke et al. (2012)
18						Chen and He (2009)
19						Rybkowski (2010)
20						Graven and MacKinnon (2006)
21						Hsin-Chang et al. (2007)
22	11/16/14	Engineering Village	Simulation AND Lean construction	360	19	Agha et al. (2010)
23						Halpin and Kueckmann (2002)
24						Abbasian-Hosseini et al. (2014)
25						Sacks ET AL. (2007)
26						Breit et al. (2008)
27						Hosseini et al. (2012)

No.	Date of search	Database searched	Keywords	No. of hits	No. of relevant hits	Citation
28						Tsao et al. (2012)
29						Tsao et al. (2013)
30						Rybkowski et al. (2013)
31						Golzarpoor and González (2013)
32						Breit et al. (2010)
33						Yu et al. (2009)
34						Mao and Zhang (2008)
35						Gurumurthy and Kodali (2011)
36						Chae et al. (2010)
37						Rybkowski et al. (2008)
38						Marzouk et al. (2011)
39						Rybkowski (2010)
40						Howell and Liu (2012)
41	11/17/14	Engineering Village	Training in Lean AND simulation AND games	21	9	Wan et al. (2011)
42						Van der Zee and Slomp (2005)
43						Ramos et al. (2013)
44						Mirehei et al. (2011)
45						Baker (2005)
46						Rowlands (2005)

No.	Date of search	Database searched	Keywords	No. of hits	No. of relevant hits	Citation
47						Stausberg et al. (2009)
48						Mohamad and Ito (2013)
49						Verma and Devulapalli (2006)
50	11/24/14	PsycINFO	Serious games AND Productivity OR Collaboration	21	4	Corrigan et al. (2014)
51						Hummel et al. (2011)
52						Sanchez and Olivares (2011)
53						Whittington (2011)

It can be seen from the table that various possible permutations and combinations of words related to this topic were searched. To understand locations of extensive lean research activity, the location of all the researchers was mapped. Figure 1 shows that Israel, some parts of Europe and the United States are actively engaged in lean construction research.

Lean construction is a relatively new field compared to lean manufacturing which originated in Japan between 1948 and 1975. The way lean has transformed the manufacturing industry, offers a benchmark about how lean can improve the construction industry. Tables 2 and 3 summarize simulations used to teach lean to those in the manufacturing industry.

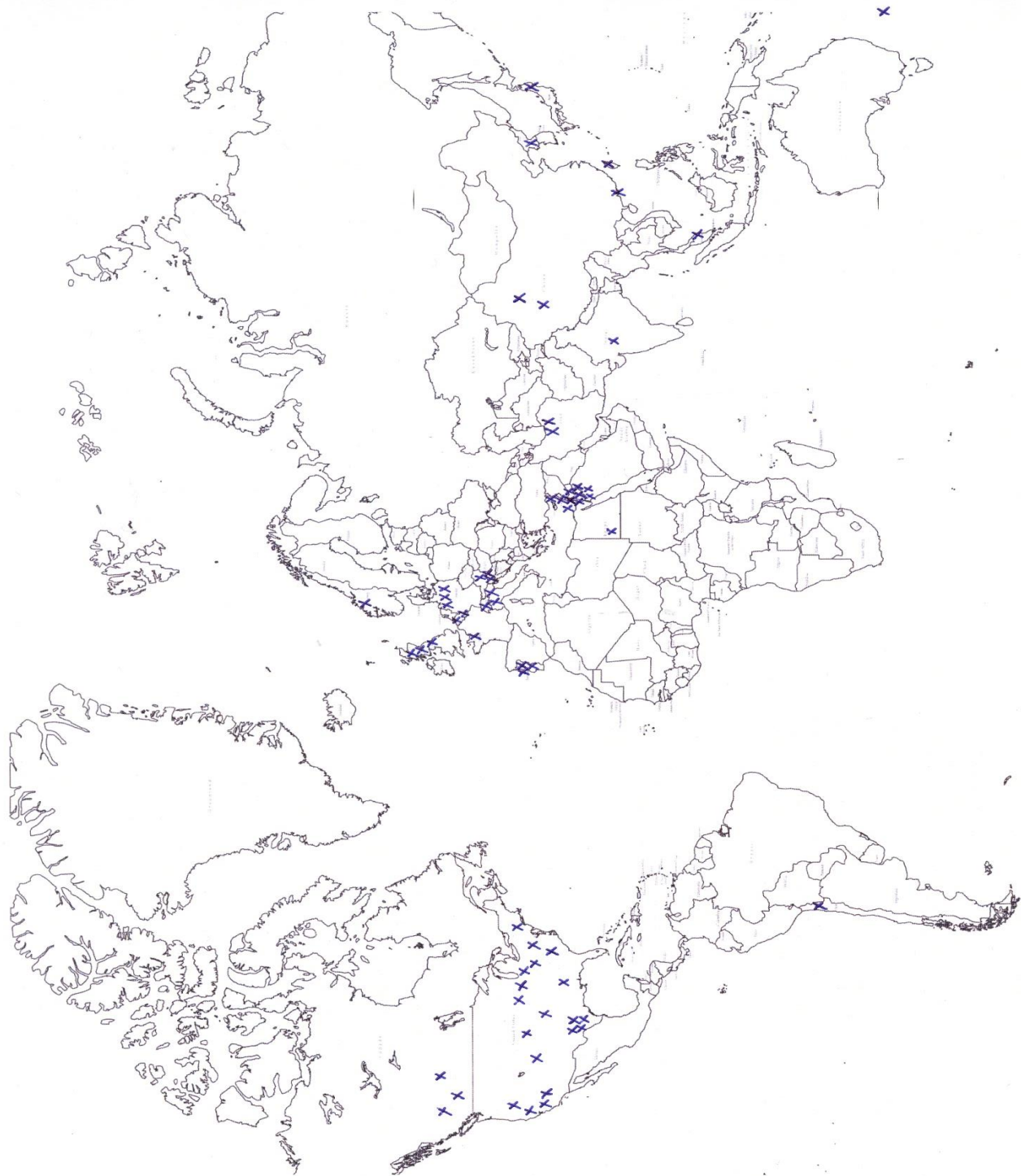


Figure 1: A world map that shows locations where lean construction simulations are being researched. This map is generated from the location of the authors from Table 1

Summary of Lean Manufacturing Simulation and Games

No.	Developers (Published Source)	Year*	Name of Simulation/Game	Focus	Product	Runs	Metrics
1	MIT (Jarmin, 1963)	1963	BEER GAME	Supply chain	NA	M	Yes
2	University of Kentucky (Hall, 1994)	1994	UK PAPER CLIP SIMULATION	Manufacturing	Paper folders	4	Yes
3	University of Kentucky (Lean Training, 1994)	1994	UK CIRCUIT BOARD SIMULATION	Manufacturing	Circuit boards	4	Yes
4	Bicheno (1995)	1995	BUCKINGHAM LEAN GAME	Supply chain	NA	2	Yes
5	NIST-MEP (NIST/MEP, 1998)	1998	CIRCUIT BOARD SIMULATION	Manufacturing	Circuit boards	4	Yes
6	University of Kentucky (Badurdeen et al., 2008; Price, 2008)	2003	CYLINDER FACTORY SIMULATION	Manufacturing	Pneumatic cylinders	3+	Yes
7	MEP (Verma, 2003)	2003	TIMELY SIMULATION	Manufacturing	Clocks	3	Yes
8	University of Dayton (Verma, 2003)	2003	PIPE FACTORY SIMULATION	Manufacturing	Pipe products	5	Yes
9	Donnelly Corporation (Verma, 2003)	2003	LEAN SIM MACHINE	Manufacturing	Metal linkages	M	Yes
10	Lean Aerospace Initiative (McManus et al., 2007)	2003	LEAN ENTERPRISE VALUE SIMULATION	Enterprise	Lego aircraft	2	Yes
11	WCM Associates (Verma, 2003)	2003	BOX GAME SIMULATION	Manufacturing	Box	3	NA
12	Not Known (Verma, 2003)	2003	DICE/PARADE GAME	Manufacturing	NA	NA	NA
13	University of Tennessee (Verma, 2003)	2003	LEAN PRODUCT DEVELOPMENT SIMULATION	Product development	K'nex product	3	Yes
14	Visionary Products Inc. (Verma, 2003)	2003	CELLULAR MANUFACTURING SIMULATION	Manufacturing	Lego aircraft	4	NA
15	Lockwood Greene (Verma, 2003)	2003	WIDGET FACTORY SIMULATION	Manufacturing	Widgets	3	Yes
16	Gary Randall (Verma, 2003)	2003	BALL BEARING FACTORY	Manufacturing	Ball bearings (golf balls)	N	Yes
17	Illinois Manufacturing Extension Center (Stier, 2003)	2003	NIST BUZZ ELECTRONICS SIMULATION	Manufacturing	Circuit boards	4	Yes
18	NIST-MEP (Verma, 2003)	2003	5S SIMULATION	Manufacturing	NA	6	Yes
19	NIST-MEP (Verma, 2003)	2003	SETUP REDUCTION SIMULATION	Manufacturing	Sheet metal	2	Yes
20	Northrop Grumman (Verma, 2003)	2003	PAPER AIRPLANE GAME	Manufacturing	Paper airplane	NA	Yes
21	University of Kentucky (Lean Boot Camp, 2004a)	2004	5S MINI-FACTORY SIMULATION	Manufacturing	Tabletop mini factories	2	Yes
22	Blust and Bates (2004)	2004	WAGONS-R-US SIMULATION	Manufacturing	K'Nex wagons	M	Yes
23	Billington (2004)	2004	PAPER AIRPLANE EXERCISE	Manufacturing	Paper airplane	4	Yes
24	University of Kentucky (Boot camp II Course, 2004a; Badurdeen et al., 2008)	2004	FURNITURE FACTORY SIMULATION	Manufacturing	Wooden furniture	5	Yes

(continued)

Table 2: List of games in Lean Manufacturing (Reprinted from Verma 2003)

No.	Developers (Published Source)	Year*	Name of Simulation/Game	Focus	Product	Runs	Metrics
25	University of Kentucky (Lean Certification, 2004)	2004	VEEBOT SIMULATION	Manufacturing	Lego cars	2	Yes
26	Old Dominion University (Verma, 2007; Verma et al., 2005)	2005	SHIP REPAIR DESIGN PROCESS SIMULATION	Design process	Container ship	3	Yes
27	Old Dominion University (Verma, 2007; Verma et al., 2005)	2005	SHIP REPAIR SUPPLY CHAIN SIMULATION	Supply chain	Submarine	3	Yes
28	Old Dominion University (Verma, 2007; Verma et al., 2005)	2005	SHIP REPAIR VALUE STREAM MAPPING	Boat assembly	Boat	2	Current and future VSM
29	Old Dominion University (Verma, 2007; Verma et al., 2005)	2005	SHIP REPAIR SIMULATION	Ship repair process	Ship (wood and acrylic)	3	Yes
30	Old Dominion University (Verma, 2007; Verma et al., 2005)	2005	SHIP REPAIR SCHEDULING SIMULATION	Scheduling	Ships	3	Yes
31	Verma and Devulapalli (2006), Verma (2007)	2005	VALUE STREAM MAPPING BOARD GAME	Manufacturing	Board game	3	Current and future VSM
32	Verma (2007)	2005	BLOCK TOWER	Manufacturing	Legos	M	Not mentioned
33	Winarchick and Cartisle (2006)	2006	WAGONS-R-US SIMULATION	Manufacturing	K'Nex wagons	M	Not mentioned
34	Lean Aerospace Initiative (McManus & Rebentisch, 2006a, 2006b)	2006	LEAN ENTERPRISE PRODUCT DEVELOPMENT	Product development	—	M	Yes
35	Fang, Cook, and Hauser (2007)	2006	LEAN LEGO SIMULATION	Manufacturing	Lego cars	3	Yes
36	Ncube (2007)	2007	LEAN LEMONADE TYCOON	Manufacturing	Lemonade	N	NA
37	Ozelkan and Galambosi (2007, 2008)	2007	LAMP SHADE GAME	Manufacturing	Lampshades	3	Yes
38	University of Kentucky (Maginnis, 2008)	2007	ENTERPRISE SIMULATION	Enterprise	Card simulation	2+	Yes
39	MacMillian (2007)	2007	NIMA'S BOARD GAME	Manufacturing	NA	NA	NA
40	McManus et al. (2007)	2007	ENGR. DESIGN CLASS	PDCA and DMAIC process	NA	NA	NA

Table 2 continued (Reprinted from Verma 2003)

CHAPTER IV

SUMMARY OF LEAN CONSTRUCTION SIMULATIONS

In this chapter, a summary of key games and simulations that are being implemented in lean construction as of this writing is presented. In each category is a description of how the game is played, which principle(s) of lean the game illustrates, and the key “takeaways” for participants following the game.

Parade of Trades

Introduction

The Parade Game illustrates the impact work flow variability has on the performance of construction trades and their successors. The game consists of simulating a construction process in which resources produced by one trade are prerequisite to work performed by the next trade.

Example parades in construction (Riley and Sanvido 1997) includes:

- Structural Parade: e.g., erecting structural steel (steel erector); placing and securing decking as well as welding shear studs (decking contractor); and placing rebar (rebar contractor), then pouring and finishing concrete (concrete contractor);
- Overhead Work Parade: e.g., installing an HVAC system (mechanical contractor), sprinkler system (fire protection contractor), emergency lighting (electrical contractor), and pipe (plumbing contractor);
- Perimeter Enclosure Parade: e.g., building perimeter walls, placing windows, installing flashing, and applying sealants; and

- Interior Finishes Parade: e.g., installing wall studs, routing electrical conduit, placing insulation materials, hanging drywall, and painting.

When assigning work to crews, it is also important to recognize the extent to which the concentration of work varies by trade throughout the building. If a trade enters an area where there is a great deal of work to do specific to their trade, thereby taking a longer time to complete than the moving parade can tolerate, successors may have to get out of line and perform out-of sequence work elsewhere. Relocation takes extra time, but it may prevent the crew from becoming idle altogether. Out-of sequence installation for one trade does not necessarily impede another trades' work. Finally, different parades move through a building in different directions. Riley and Sanvido (1995) distinguished the work area, prefabrication area, storage area, and product-space patterns to characterize the space behavior of various trades. This crisscrossing of parades makes managing them an even bigger challenge.

Description of Simulation

The Parade of Trades game was inspired by Goldratt's "Boy Scout hike" (Goldratt and Cox 1986). Using the Boy Scout game as a launch point, Howell (Tommelein et al. 1999) developed a game that is easy to play with students in a classroom setting. The game can involve any number of players. The game coordinator splits up large groups into teams of equal size. Each player represents a subcontractor's crew, as is illustrated by the stroboscope symbols Crew A through Crew E in Fig. 2. Each crew is to perform an activity that requires the repeated execution of a process step, for instance, Crew A will repeatedly execute step Sub A. Each team is given a pile of

100 bolts (or any other kind of widget) and its task is to pass all bolts from the front of the line (the input buffer, Input A) to the end (the output buffer, Complete E). When this has been accomplished, the project is completed.

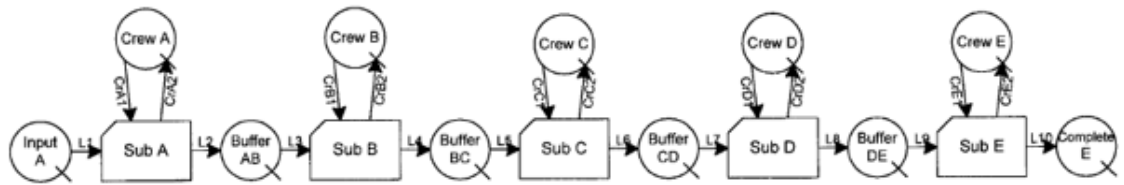


Figure 2: Parade of Trades Line-up (Reprinted from Tommelein et al. 1999)

Each player in line can pass only a limited number of bolts from one side to the other (e.g., Sub A will move them from Input A to Buffer AB) as the number moved is determined by rolling a die. At the beginning of the game, the coordinator will hand each team one of five possible dice: A, B, C, D, or E. After a player has rolled the die and passed the appropriate number of bolts, that player must wait until the next player downstream in turn has rolled the die and taken bolts from the buffer in-between them, before replenishing this buffer. The coordinator can introduce various degrees of variability in the game by writing made-up numbers on each face of each die. This is done prior to handing dice to players. A normal die has faces with values 1, 2, 3, 4, 5, and 6, and so the average roll is 3.5. The writers suggest that the game be played with several different dice. For example, the average of die containing only the numbers 1, 1,

2, 5, 6, and 6 on its six sides is 3.5, and the average of a die containing only the numbers 3, 3, 3, 4, 4, and 4 on its six sides is also 3.5. The difference is that rolling the former dice yields greater variability.

Related Discussion

When players attempt production within the minimum buffer, operations are said to interfere and resources are wasted (Howell et al. 1993). The cost of repetitive-type construction certainly depends on the way the project is executed; it is not solely a function of the measured quantity of work it contains [also noted by Harris and Evans (1977) p. 413]. This is no surprise. The major task of any contractor is to determine means and methods. Nonetheless, means and methods alone are not the only determinates of performance for production. As the Parade Game illustrates, coordination among trades is equally important. Accordingly, contractors price their bids more favorably when they know that a skillful manager will coordinate his work with others on site [e.g., Birrell (1978), (1981), (1985) and Tommelein and Ballard (1997)]. Moreover, the Parade Game also illustrates the need to combine production planning with project planning. Successful project managers put considerable effort into creating reliable flow for succeeding trades, e.g., they take proactive steps to establish buffers to shield crews from work flow variability. Common causes of unreliable flow are change orders, late replies to requests for information, lack of materials, physical interference between materials, work-space congestion, etc. Instead of accepting that delays and disruptions will rear their ugly head, practitioners must anticipate work flow variations and temper (if not eliminate them) by means of careful planning and attention to detail.

This requires a hands-on approach to production management. Ballard and Howell (1998) proposed that crew foremen follow the Last Planner methodology to shield workers from uncertainty and enable them to inject reliability into their work plans.

Other proactive methods include setting flow rates and then requiring contractors to size their crews to meet these rates, while ensuring that work space will be available when needed.

Conclusion

A simple game was presented to illustrate the impact variability has on work flow in a single-line production system, which is so characteristic of the Parade of Trades formed by subcontractors on many a project. It does allow the players to develop a better, intuitive understanding of several fundamental production concepts, including variability and throughput. It was shown that unreliable work flow results in two kinds of waste: (1) Production stations cannot realize their full production capacity because they starve for resources; and (2) intermediate buffers are larger when high variability prevails. Managers interested in schedule compression will benefit from understanding work flow variability's impact on succeeding trade performance.

The Airplane Game

Introduction

A lean simulation often referred to as “The Airplane Game” was developed by Visionary Products, Inc.™ (Visionary Products Inc. 2007; 2008). The simulation is used by the Lean Construction community to introduce new members to lean production principles (Rybkowski et al. 2008). Participants successively assemble a Lego™ airplane.

Lean principles are tested in four separate phases; new principles are added to each phase progressively. The prior phase is used as the successive phase's experimental control. Through the introduction of lean interventions--one by one and progressively during each consecutive round of play--participants develop an understanding of the influence of each discrete lean intervention. Several lean concepts are tested using this game, including cellular layout versus traditional plant layout, one-piece flow versus batching, pull versus push, uni-skilling versus multi-skilling, unequal load versus load levelling, and quality control.

Description of Simulation

The players should be seated around a table in four assembly workstations, one quality control station, and one tear down station as per the instruction manual (Visionary Products Inc. 2007). The arrangement of workstations is cellular and each station is supplied with specific Lego™ blocks. The Lego airplane is snapped together at each workstation. At the last station the airplane is checked for flaws. The concepts pertaining to lean principles (1) pull vs. push, and (2) batching, are the ones examined in this paper to illustrate how a lean game might be used as an organized test. In addition to living playings, the game has also been simulated using EZStrobe or Stroboscope (Martinez 1996, 2001; Martinez and Ioannou 1999) software. Palm-sized airplanes were assembled in workstations using three types of Lego blocks: 4-pin, 8-pin, and 16-pin for the game.

Live Simulation

The following four trial runs are executed: (1) batch size of 5 with push, (2) batch size of 5 with pull, (3) batch size of 1 with push, (4) batch size of 1 with pull. The pieces in the corresponding workstations are to be assembled uniformly and methodically by players according to the guidelines. The sum of assemblies accomplished before being transferred from one workstation to another is referred as Batch size. Push system can be referred to as the process of transferring unfinished goods to the next station member regardless of the needs of the respective station. This is in contrast to a pull system which refers to the process of transferring assemblies and unfinished goods to the next station member only as and when required. This can be understood with the help of an example, e.g. “batch size of 5 with pull” implies that a player must complete 5 assemblies before transferring the batch of 5 to the downstream workstation, and should not manufacture or transfer a batch to the next station until the downstream station demonstrates it is ready to receive one. The simulation runs for exactly six minutes. Figure 3 and Figure 4 shows the step by step completion of the airplane rounds 1 through 3 and round 4 respectively.



Figure 3: Plane building Rounds 1-3



Figure 4: Plane building Round 4

Computer Simulation

EZStrobe is a software used to design a computer prototype to impersonate the activities of the live simulation game. To understand the process, all the timings from

simulation game are fed into the computer prototype. This is done in order to regulate and certify the data obtained from live simulation when processed via the computer prototype. The prototype is used to mimic several lean principles wherein different constraints are introduced. For this particular simulation, constraints such as batch size (B), Kanban size (K), batch transfer timings and workstation activity timings are taken into consideration. The software permits modification of the K & B constraints and simulation of pull and push principles.

Result

In Figure 5, data is presented for both the live simulation and the computer model. There is a similarity in the data; however variations can be attributed to deterministic durations assumed in computer simulation and behavior of the players (such as fatigue, reducing working efficiencies) in the live simulation.

	Transfer type (system)	Planes completed (# of units)	Time elapsed until first plane (sec)	WIP from WS1	WIP from WS2	WIP from WS3	WIP from WS4	WIP Total
				(# of units)				
Batch Size 5								
Computer	Push	15	138	54	4	5	0	63
Live	Push	12	150	30	4	7	1	42
Computer	Pull	10	138	5	1	4	0	10
Live	Pull	10	145	5	2	3	0	10
Batch Size 1								
Computer	Push	20	46	55	0	3	0	58
Live	Push	20	43	51	1	5	0	57*
Computer	Pull	12	46	1	0	1	0	2
Live	Pull	12	39	1	1	0	0	2

*WS1 ran out of pieces at 5'20"

Figure 5: Results from the Airplane Game (Reprinted from Rybkowski et al. 2008)

Discussion

Tommelein et al. (1999), Verma (2003) and Visionary Products Inc. (2007) mentioned that the implemented by managers in lean production simulations serve the purpose of informing participants and increasing their openness through play. There are quantifiable benefits that can be attributed to lean principles and these benefits can be observed when the principles are applied to an actual production situation. Workers understand the concepts when they play the game themselves and see the growth in productivity and reduction in WIP (Work in Progress). Inconsistencies related to the human element (e.g. differences in productivity due to fatigue, inexperience of the players, or increasing productivity due to learning curve) are eliminated using a computer model (Rybkowski et al. 2012). This in turn enhances the researcher's capability to increase the consistency of the results & precisely measure the effects of lean principles.

Conclusion

Lean games are simple to play and perfectly suited as a form of scientific testing for specific lean principles. They also offer educational advantages not available in textbooks.

Nature of Productivity Games during the Airplane Game

Rybkowski et al. (2012) argued that not all who play the airplane game are convinced that lean principles themselves substantially improve productivity because participants naturally increase their abilities with successive rounds of play (i.e. learning curve). The authors utilized the graphic resources of Microsoft Excel™ to generate a

cross-time “snapshot” of the participants and their pieces, second by second, station by station, and compared the resulting metrics from the graphic snapshot against metrics collected during live playings of the game. The intention was to “tease out” the numerous benefits that can be attributed to learning curve and/or Hawthorne Effects from those benefits that can be attributed to the mathematics of lean.

Because transitioning from a scattered to cellular plant layout has obvious, common sense benefits, the authors chose to focus their simulation efforts on Phases 2-4 only, and not on Phase 1.

Phases 2-4 investigated the effects of:

- *Phase 2:* Cellular layout (batch size of 5, push system, unlevelled work load; e.g. “5 Push”)
- *Phase 3:* One-piece flow (batch size of 1, pull system, unlevelled work load; e.g. “1 Pull”)
- *Phase 4:* Load-leveling (batch size of 1, pull system, leveled work load; e.g. “1 Even”)

Additionally, and especially during the first round of the simulation, defective planes were present. However, for the purpose of understanding the impact of lean principles, the authors assumed that all planes were free of imperfections during the simulations. For each subsequent phase of the game, they developed an Excel-based graphic simulation. They chose to add one step between 5 Push and 1 Pull--1 Push--in order to make the shift more gradual and to understand the specific impact of moving from a push to a pull system.

Results

A number of conclusions can be drawn from the second-by-second excel-based simulation.

- Progressing to smaller batch sizes decreases time to first batch (206 s.→46 s.);
- Moving from a push to a pull system is reduced WIP (72→4); and
- Load-leveling increases amount of final product (18→29).

Discussion

As per the tabulated results in Figure 6, the authors were certain that the mechanical intervention of lean principles shows causation, rather than other phenomena such as the Learning Curve and/or Hawthorne Effect. The reasoning for this conclusion is that they created a second-by-second, deterministic (non-stochastic) simulation of the Airplane Game and were able to observe the specific, quantifiable impact of each successively implemented lean principle. Of course, a deterministic simulation differed from several live-playings of the game; displayed averages represented what was, in actuality, a distribution of times.

	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

Figure 6: Results from Excel-based simulation (Reprinted from Rybkowski et al. 2012)

In Figure 7, the authors compared live play to simulated play; therefore there is a certain degree of similarity within the respective rounds. Live playing versus simulated playing during Push processing with Batch size 5, shows that the time to the first batch is actually greater, with the number of planes being fewer, and WIP is smaller for the live playing. Because players are somewhat slower in the first round, this proves the authors' observation that players are still learning. Additionally, this observation is in line with the notion that the average workstation assembly times inputted into the Excel simulation were collected from experienced players, who were already given the chance to learn (Rybkowski et al. 2012). The gap between live and simulated playing metrics decreases, basically becoming insignificant, during successive rounds of the game (5 Push, 1 Pull and 1 Even), as shown in the third row of time to 1st batch, number of successful planes and total Work-in-Progress, in Figure 7. During the final round of the simulation (round 3), information gathered from the live and simulated plays during round match almost precisely, meaning that the possibility of the Learning Curve or implications from a Hawthorne effect had been superseded.

Rnd of play	Batch size & transfer type	Time to 1 st batch (seconds)*			# of successful planes (units)			Total WIP (units)		
		Live play	Excel simulation	Difference	Live play	Excel simulation	Difference	Live play	Excel simulation	Difference
1 st	5 Push	274	206	68	7	10	-3	40	102	-62
2 nd	1 Pull	42	46	-4	15	18	-3	6	4	2
3 rd	1 Even	46	46	0	28	29	-1	4	4	0

Figure 7: Comparison of live play vs Excel simulation (Reprinted from Rybkowski et al. 2012)

Conclusion

This research confirms notions that the mechanistic benefits of lean principles improve productivity, demonstrating that non-mechanistic phenomena are less likely the cause. Therefore, because implementation of lean principles is the primary driver of the observed improvement in productivity, lean practitioners can confidently apply lean principles to a construction project and anticipate positive outcomes.

The 5S Game Numbers Game

Introduction

The 5S method is typically one of the Lean tools that companies choose to implement first. 5S organization lays a foundation that facilitates implementation of other lean principles. It is estimated that introducing good workplace organization can reduce process defects by almost 50%; 5S is important for this reason. Peterson & Smith (1998) defined 5S as a tool to develop systematic planning, classification, order and cleanliness. 5S translates to an increase in productivity, safety, organizational climate, employee motivation--and consequently competitiveness. The name of this tool comes from the five Japanese words that define this methodology of work:

1. *Seiri*, which means Sense of Tidiness (sort);
2. *Seiton*, which means Sense of Orderliness (set in order);
3. *Seiso*, which means Sense of Cleanliness (shine);
4. *Seiketsu*, which means Sense of Standardization (standardize);
5. *Shitsuke* which means Sense of Self-Discipline (sustain).

The main benefits of implementing the 5S methodology are:

- Increased productivity by simplifying the work environment to strictly necessary objects;
- Reduced costs and better use of materials;
- Improved quality of products and services;
- Fewer accidents at work; and
- Greater personal satisfaction for each employee's own performance.

Description of Simulation

This version of the game often by lean construction practitioners is freely available on the Superteams website, the site of a business training organization. The original game was developed by RWD Technologies Ltd. The aim of the game is to increase the performance of employees by exposing them to the benefits of the 5S method. During the first round of the game, participants use a pencil to strike out the numbers 1 to 49 in the correct sequence (Figure 8). The facilitator uses a timer to ensure that teams are given exactly 30 seconds for this task. Once the 30 seconds are over, the facilitator asks participants to call out the highest number they crossed out. The lowest score is the official score for the team. Following the first round of 5S, a second round--that of *sort*--is then played. Numbers 50 to 90 are not necessary to complete this task, so they are removed as shown in Figure 9. The participants are asked to repeat the task of striking out numbers. The scores are circled, and the lowest score is recorded as the team score.

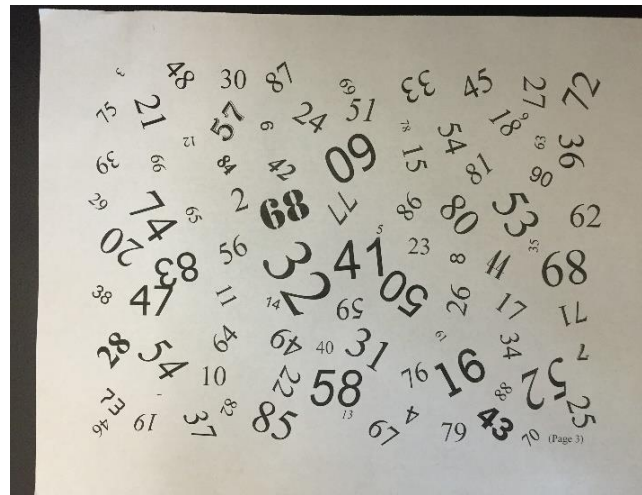


Figure 8: Starting sheet. From Superteams (2015).

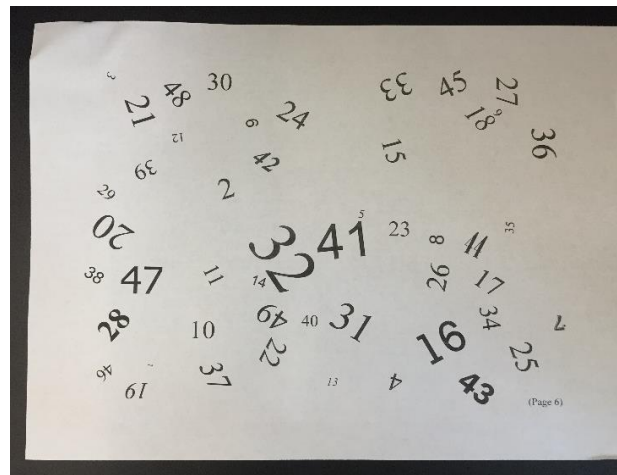


Figure 9: Sheet after 'Sort.' From Superteams (2015).

Participants play subsequent rounds, as shown in Figure 10 and 11. During round three, the numbers are *set in order*--that is, they are divided into nine sections such that every consecutive number will be in a different section and sequenced from left to right and bottom to top. In step four, the numbers are re-organized in a *standardized* manner,

in a way that will ease the completion of the task. As before, players are consistently asked to strike out numbers from 1-49 and their scores are recorded.

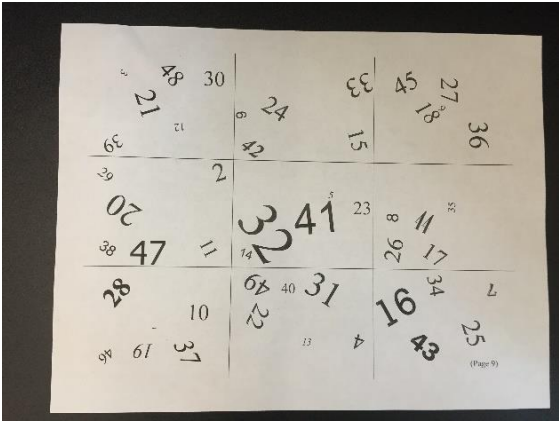


Figure 10: Sheet after 'Set in order.' From Superteams (2015).

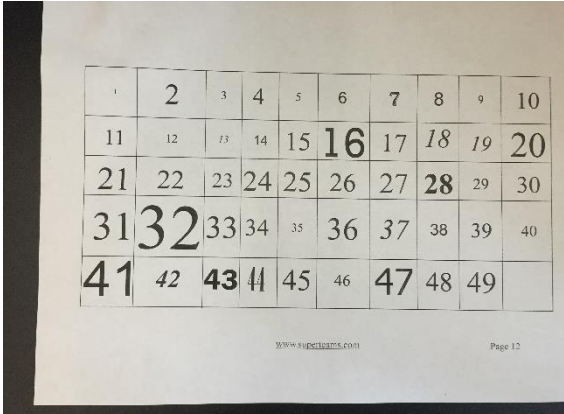


Figure 11: Sheet after 'Standardize.' From Superteams (2015).

Result

Between each round and after the game is over, scores are compared; it is apparent that scores steadily increase with each round. Applying the 5S method made searching for the numbers easier. In fact, it became extremely easy to perform the task during the final round of the game. This step-by-step approach shows the impact of each step of the 5S method.

Discussion and Conclusion

This game illustrates the importance of 5S. Improved productivity and better efficiency clearly result when 5S is applied to construction sites and offices.

LEAPCON

Introduction

Sacks and Goldin (2007) developed a management model for the construction of high-rise apartments to solve issues related to budget and schedule overruns which can lead to long cycle times and loss of control. A simulation was created to test this model before implementation. The proposed management model was intended to illustrate the following key points:

1. Decrease batch size from full floors to single apartments;
2. Replace fixed schedules and networks with pull planning, thereby ensuring finishing work in apartments is performed according to the order in which design details are received;
3. Structure work in such a manner that activities are not dependent on client design information. Some examples of implementation include: separating electrical and

plumbing works from the structural system, locating water supply pipes and electrical conduits in such a manner that they are not embedded in concrete; and

4. Use multi-skilled subcontractors in place of specialty contractors.

Description of Simulation

LEAPCON simulates the construction of an eight story building, with four apartments on each floor. Four participants are given the roles of project manager (PM), client change manager, quality control and tower crane manager, each. There are four more specialty subcontractors that are assigned roles as depicted in Figure 11. The objective of the game is to finish the interior finishes of all 32 apartments in the least possible time. The execution of the finishing work takes place using Lego™ blocks in four distinct steps. Floors are represented by eight pages placed in order on a long table. Two additional participants represent the apartment clients. One is responsible for submitting the design variations, as shown in Figure 12, to the client change manager at regular intervals, while another checks on the completed apartments and pays the project manager \$1500 for each completed apartment.

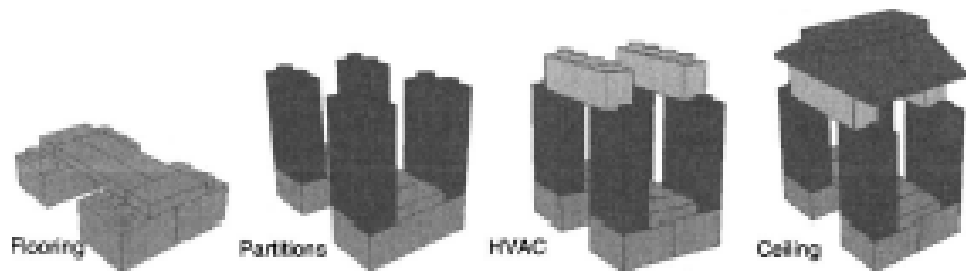


Figure 12: Role of specialty subcontractors (Reprinted from Sacks et al. 2007)

For the first round, which represents the traditional method of construction, the project is provided with a construction plan that calls for the contractors to progress up the building floor by floor. The batch size is of 4, and only one contractor can work on a floor at any given point in time.

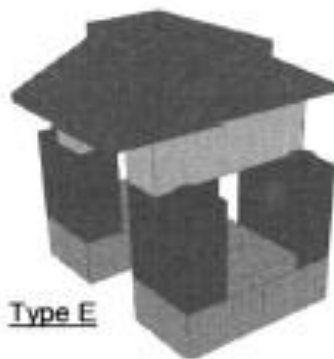
Apartment Design Option E

This option is identical to A, with two exceptions:

- The partitions are two bricks high instead of three,
- The HVAC ducts and the ceiling are rotated 90°



Type A



Type E

Figure 13: Design variation in apartments (Reprinted from Sacks et al. 2007)

After one minute has passed, one client representative randomly begins selecting designs for apartments. Details are passed on to the client change manager every 15 seconds through 8 minutes. Design variations received before work has begun on an apartment are easily executed. Apartments for which design changes are received after work has begun, but before the apartment has been delivered to the client, must be changed. However, only the respective subcontractor can make the changes called for. The project manager must decide whether to withdraw specialty subcontractors from the floors that they are working on and send them to make local changes or to delay the changes. The company is paid only for completed floors of four apartments, while they must invest working capital of one thousand dollars for any incomplete apartment. Subcontractors, in contrast, are paid the same amount for completing their deliverable on a floor, regardless of the state of completion of individual apartments. Their incentive is therefore to complete as many floors as possible. The other client representative records the time at which each complete floor is delivered. Play is stopped after 11 min, and the team's performance is assessed in terms of apartments delivered, quantity of WIP (Work in Progress), cash flow, defective apartments, and time required to deliver the first nonstandard apartment.

The following changes are made in the second round:

- The batch size is reduced from four to one. This means that work can be performed on any one apartment at one time and the deliverables and payments are also made in terms of a single apartment (compared to the first round where payment was made for a whole floor).

- The four specialty contractors become four multi-skilled contractors, such that each can perform all the trades.

- A Pull system replaces the push system.

No work is done during the first minute of play because no designs have yet been delivered. As designs are delivered, the project manager assigns a subcontractor to perform the work on a specific apartment. Play continues for the same total duration of 11 minutes.

Results

Differences between the traditional project delivery methods to the proposed lean method are highlighted as average output increases from 1.3 units/min to 2.0 units/min between the first and second rounds of the game. For example, cash flow changes from negative to positive--that is from $-\$9,100$ to $+\$6,100$ —and the average cycle time is reduced from 5 min 26 s. to 2 min 18 s. Work in progress was drastically reduced, from an average of 14.1 units to 2.0 units.

Discussion and Conclusion

While LEAPCON does not reflect real life customization in high rises, it does provide a reliable means to quantitatively compare the proposed lean approach. It demonstrates that significant improvements can be achieved by making three changes to project delivery: pull system, multiskilling, and smaller deliverables.

Villego

Introduction

The purpose of The Villego simulation is to teach the Last Planner System (LPS). The simulation includes at least of two sequences of construction executed by teams comprising six to 14 participants. During each round, a facilitator instructs the teams to build a Lego™ structure according to the plans, within the defined time frame. Every 10-second interval symbolizes one work day. More precisely, each minute is considered a six day work week.

The Last Planner System, developed by Glenn Ballard and Greg Howell, customizes lean practices and concepts to the field of construction with regards to project management. LPS is a collective approach to planning, which includes the common trade contractor and foremen (the last planners), who completely commit to the essential tasks mandated by the project team (Ballard, 2000). An average of 85 percent completion of the scheduled tasks in a project with proper use of LPS can be demonstrated by reliability performance metrics (e.g. based on PPC, Percent-Planned Complete) versus traditional construction scheduling and project management which yields an average of only 54 percent reliability (Ballard & Howell, 2003).

Description of Simulation

The first round commonly takes one to two hours. Participants practice traditional push scheduling and management methods. Work activities are assigned by means of the Critical Path Method (CPM). No emphasis is placed on cooperation. The principal focus is kept on cash. The organizer familiarizes the participants with the LPS

in between the rounds. Participants employ pull planning and additional lean principles in the second round of the game, which lasts for approximately two hours. According to Villego (2013), simulating the delivery process of the projects that utilize LPS is carried out in the second round.

In the second round, emphasis is placed on pull production. Cooperation and collaboration are accentuated and creating value for the client is of the essence. Scope for learning and improving is high, where planning meetings occur at equal intervals, identifying sources of failures and determining remedial actions to improve future rounds of work. The two-round methodology assists participants to compare and evaluate both traditional and lean management.

A series of questions asked before and after the simulation are used to assess effectiveness of the game from the perspective of the participants.

Discussion and Conclusion

The data shown in Tables 13, 14 and 15 point out improvements made between the first and second rounds. Differences in construction time, profit, and productivity between the two rounds illustrate the impact of applying lean principles to a project. Experiencing the changes through a simulation helps participants develop a more profound understanding of collaborative planning than by simply reading a textbook. Analyzing the data, after participating in the Villego simulation, gave the participants a better understanding about collaborative planning.

	Round 1	Round 2
Construction time	11:31	5:33
Productivity (elements/minute)	8.86	18.38
# Subcontractors on site	96	50
Delivery penalties	8	0
Safety penalties	2	0
Damaged material re-use penalties	6	5
Waste penalties (# Lego studs)	0	0
Profit or loss	(\$117,922.12)	\$84,023.24

Figure 14: Construction Management student results (From Warcup & Reeve 2014)

	Round 1	Round 2
Construction time	12:27	4:37
Productivity (elements/minute)	8.19	22.09
# Subcontractors on site	75	30
Delivery penalties	5	3
Safety penalties	1	1
Damaged material re-use penalties	4	1
Waste penalties (# Lego studs)	44	34
Profit or loss	(\$78,285.64)	\$119,586.76

Figure 15: Construction Professionals- Team 1 (From Warcup & Reeve 2014)

	Round 1	Round 2
Construction time	12:05	4:55
Productivity (elements/minute)	8.44	20.75
# Subcontractors on site	99	39
Delivery penalties	4	5
Safety penalties	2	2
Damaged material re-use penalties	0	2
Waste penalties (# Lego studs)	16	172
Profit or loss	(\$93,721.40)	\$13,034.20

Figure 16: Construction Professionals- Team 2 (From Warcup & Reeve 2014)

When feedback provided by the participants is analyzed, it is evident that the Villego simulation communicates the importance of team work, collaboration, and buy-in of the Last Planner System. Such benefits cannot be achieved through classroom discussion alone. Also, hands-on experience of the participants enhances the process of learning.

The Villego simulation infuses the learning classroom with reality, but in a safe environment. Learning is a crucial and recognized constituent of LPS. Lean philosophy underscores the importance of learning from experience so that errors will not be repeated in the future. As formerly specified, the Percent Planned Complete (PPC) metric aids with the identification and categorization of performance failures (Ballard, 2000, Ballard & Howell, 2003). Reporting and recording PPC results systematically enhances accountability and provides an incentive to managers and team members to increase reliability. When participants compare preliminary plans to their executed performance, they are able to identify variances, and addressing the cause of these variances helps them to not repeat mistakes in the future.

The Villego simulation not only provides intended training, but one can gain experience through errors and struggles. Even temporary paralysis during pull planning can be a significant experience. As a participant struggles to deal with tenuous circumstances, they learn. Through the simulation the participants experience an array of emotions as they make their way through an uncomfortable journey of mistakes, uncertainty, and lack of preparedness.

Tension, anxiety, enthusiasm, impatience, and excitement--all these are considered positive emotions in Villego because they contribute to involvement and a better understanding of LPS (Pekrun 2006). Participating in the Villego simulation is ultimately considered an enjoyable experience, and it has a positive influence on the participants. Analysis suggests that participants are more ready to collaborate with others after playing this simulation. The purpose of the Villego simulation is to teach the Last Planner System (LPS).

Collective Kaizen and Standardization

Introduction

At the heart of lean thinking resides the concept of kaizen—or continuous improvement—and standardization, conducted within a culture of respect. Effective use of collective kaizen and standardization capitalizes on the ability of individuals to innovate, to learn from one another, and to improve their effectiveness, thus helping managers improve time, cost, quality, safety and morale by engaging the employees they already have.

The simulation was developed by students as the final project for a US-based university lean construction course consisting of upper-level undergraduate and graduate-level construction science students (Rybkowski and Kahler 2014). This simulation has been tested in two lean construction classes, two international lean conferences, and a corporation. As per preliminary feedback, modifications have been made.

Continuous improvement (*kaizen*) is essential in any industry for the betterment of procedures and techniques. However, standardization is also critical because it provides a platform from which innovation and improvement can take place. As stated by Gilbreth (1914), “Standardization conserves individual capacity by doing away with the wasteful process of trial and error of the individual workman. It develops individuality by allowing the worker to concentrate his initiative on work that has not before been done, and by providing incentive and reward for innovations.”

Description of Simulation

The facilitator instructs participants to make a 7” long paper airplane in three minutes or less, to the tune of Survivor’s “Eye of the Tiger.” Although there is no meaningful link between the selected music and the objective of the simulation, the piece was chosen by the student inventors and has been retained out of respect for their vision. Most importantly, the music helps generate a festive, playful atmosphere among participants. The facilitator announces that the objective of the game is to have participants make a paper airplane fly as far and as straight as they can. However, participants are not permitted to pre-test their airplanes during the development process. The facilitator consults a stopwatch to arrest the music after three minutes, and then instructs participants to write their initials on their respective planes. At this point, participants are invited to line up at the starting line and, one-by-one, test-fly their airplanes. The plane that travels the farthest and the straightest is declared the winner. Note that the winning participant should be requested to fly his or her airplane again to ensure the result is repeatable (otherwise the next farthest repeatable airplane is instead

declared the winner). Also, if two or more participants have designed airplanes that fly approximately similar distances, they should both re-test their airplanes and count the number of folds used to construct their planes. If two or more airplanes fly a similar distance, the participant who designed the airplane requiring the least number of folds is declared the ultimate “first-rate performer.”

The first-rate performer is then invited to share his or her airplane folding strategy with all participants. He or she is to walk the room and ensure that all participants mimic his or her folding process with a new sheet of scrap paper. Once all participants have had a chance to practice folding airplanes according to the improved process recommended by the “first-rate performer,” the facilitator starts the music and, once again, gives participants three minutes to create a standardized plane—this time based on the folds recommended by the first-rate performer. Finally, participants write initials on their airplanes and test-fly them in the same measured corridor.

Results

Figure 16 photographically captures the variety of paper airplanes constructed during the first, or “pre-” round of play, as well as the second, or “post-” round of play. To generate their designs in the post- round, participants followed the folding patterns of the winning plane (Participant Q in Figure 16). Note that participant Q’s airplane design has been standardized during this round. Airplanes are labeled according to participant identification codes, A through Q. Airplane Q was designed by the “first-rate performer” and served as the model standard for participants A to P to follow during the “post-round” of play (Rybkowski and Kahler 2014).



Figure 17: Airplanes generated by participants (Reprinted from Rybkowski & Kahler 2014)

A table showing pre- and post- results is shown in Figure 17 and graphically represented as a box-and-whisker plot in Figure 4. Note that the mean travel distance during the pre-round test was 6.8 ft; during the post-round test the mean travel distance was 22.7 ft.—a 233% improvement. It can be observed from Figure 17 that a couple of participants had flight distances greater than that of Q, the “first-rate performer”. This can be attributed to the throwing skills and techniques that have not been taken into consideration. Furthermore it will be interesting to see such results in the field where improvement in operations will yield notable profits.

<i>ID</i>	<i>pre-round (ft.)</i>	<i>post-round (ft.)</i>	<i>improvement (ft.)</i>
<i>A</i>	1.5	19.0	17.5
<i>B</i>	8.2	25.0	16.8
<i>C</i>	6.0	16.0	10.0
<i>D</i>	6.0	20.0	14.0
<i>E</i>	20.0	32.0	12.0
<i>F</i>	4.0	31.0	27.0
<i>G</i>	3.0	21.0	18.0
<i>H</i>	8.0	22.0	14.0
<i>I</i>	2.0	24.0	22.0
<i>J</i>	4.0	24.0	20.0
<i>K</i>	6.0	15.0	9.0
<i>L</i>	6.5	17.0	10.5
<i>M</i>	2.0	20.0	18.0
<i>N</i>	6.0	18.0	12.0
<i>O</i>	2.0	22.0	20.0
<i>P</i>	3.0	32.5	29.5
<i>Q</i>	27.0	27.0	0.0
<i>Mean</i>	6.8	22.7	15.9
<i>Standard Deviation</i>	6.8	5.4	7.0
<i>Median</i>	6.0	22.0	16.0
<i>Maximum</i>	27.0	32.5	5.5
<i>Minimum</i>	1.5	15.0	13.5

Figure 18: Pre-round and post-round results (Reprinted from Rybkowski & Kahler 2014)

Discussion

One of the lessons of the game is that it challenges the tendency for managers to assume productivity solutions lie in resources external to their company (e.g. if only we had more intelligent or productive employees working for us, or, if only we had the

resources to hire external consultants, etc., we could be more competitive as a company). Contrary to this tendency of belief, substantially improved performance is achieved during the simulation with employees an organization already has in its employ. Even though continuous improvement and updating standards seems like a viable option, it is not a viable option to change standards recurrently. Change is good, but sometimes if change is incorporated frequently it might create confusion and resentment (Rybkowski and Kahler 2014).

Target Value Design

Introduction

This is a simulation developed to explain the concepts of Target Value Design (TVD) and Integrated Project Delivery (IPD). The simulation superimposes target cost estimating onto the “Marshmallow Challenge” game developed by Peter Skillman. “TVD is a management practice that drives design to deliver customer values, and develops design within project constraints” (Ballard 2009). TVD, along with target costing challenges managers to create links between allowable, target and expected cost. Like TVD, IPD is also an emerging concept in the field of lean construction. Smith (2011) argues that, along with TVD, IPD has helped increase productivity and efficiency for the client. An underlying assumption of IPD is that all parties will benefit from collaboration by reducing waste, increasing efficiency and building long-term relationships.

Description of Simulation

This simulation is played in two rounds. While one round is intended to represent the traditional design bid build (DBB) process, the second signifies the IPD method. In the first round, the owner, design and construction team are all located separately. They are asked to complete the following task: Your client wants you to design and build a tower that is 2'-0" tall, which is capable of holding a marshmallow on top. The tower should be built with the supplied materials as shown in Figure 1.



Figure 19: Materials supplied to participants

The team should abide by the following set of rules in the process of building the tower.

- a. Your tower must be mobile (i.e. do not tape it to the table).
- b. Your tower cannot be more than 2 inches out of plumb (measured at the marshmallow)
- c. Note the time of completion of design as well as construction.
- d. After construction of the tower is complete, find out the cost of the tower using the supplied costing sheet.

The objects that are provided to the participants have unit costs associated with them:

1. Uncooked stick of spaghetti: \$1
2. Coffee stirrer: \$5
3. Drinking straw: \$2
4. Bamboo skewer: \$3
5. Masking tape (per joint): \$0.50

Each participating team is asked to add a profit of 10% to its total cost. Participating teams are asked to keep the following parameters in mind:

- *Market Cost* is the average cost of all the towers that are currently built.
- *Allowable Cost* is calculated by deducting 15%-20% from the market cost.
- *Target Cost* is set by team members; here all participants work to set a “stretch” target below the allowable cost.

In the second round, the participants play according to an IPD format. All the parties are seated together. Every step is proceeded with the consent of all the team members. The following instructions are given to the players for round two:

“Now that you have set the Allowable Cost and Target Cost, let’s try again. Design and build a 2’-0” tower to the same specifications as before. Design and construction teams should work together as a single team this time.”

The following information was shared with the participants regarding their task.

- Design a tower, calculate the cost, and if it exceeds the Allowable Cost, redesign it to lower the total cost.
- If your estimate is below Allowable Cost, build the tower (see how close you can come to your target cost)

All the other rules are identical to the ones applied in the first round.

Result

Results were obtained from conducting the simulation with students and other construction professionals in Nepal. Figures 19 and 20 show photographs of completed towers at the end of rounds one and two, respectively. Figure 4 shows the variation of cost amongst different teams through both the rounds.

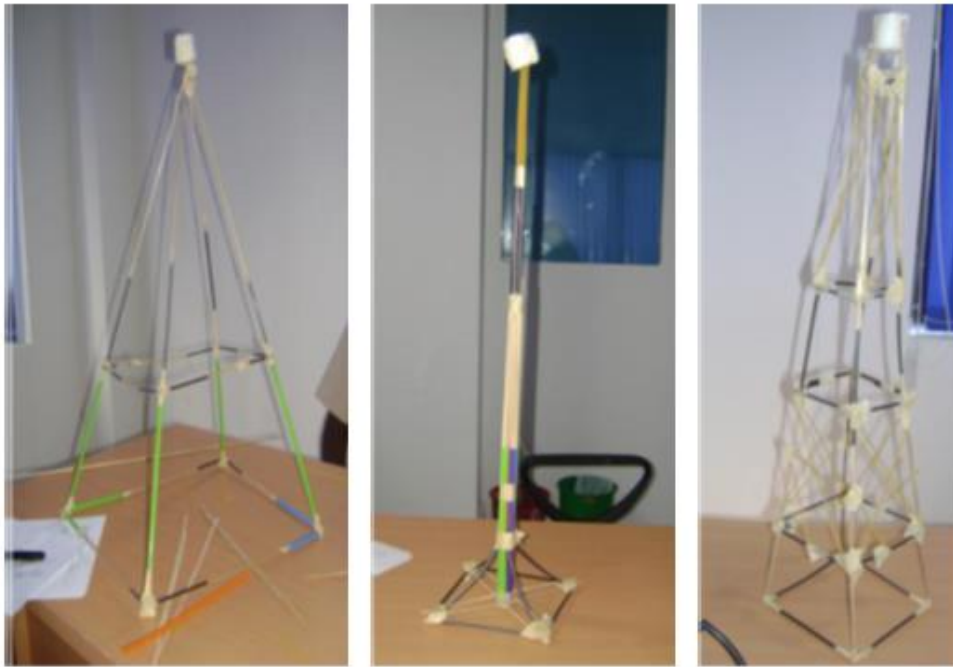


Figure 20: Completed towers at end of round 1 (Reprinted from Munankami, 2012)

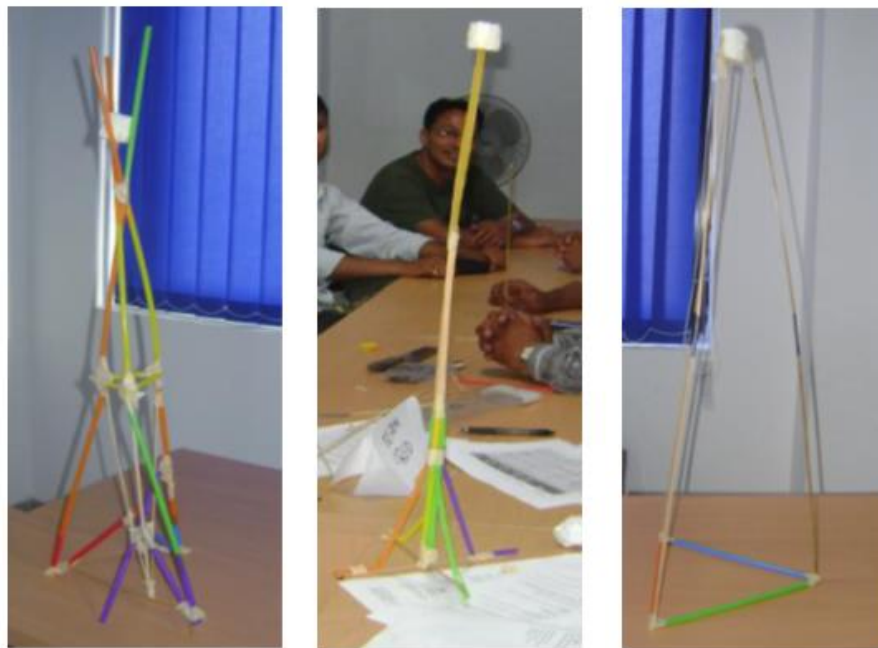


Figure 21: Completed towers at end of round 2 (Reprinted from Munankami 2012)

TEAMS	COSTS
A	\$80.00
B	\$118.00
C	\$239.5
Average cost	\$145.83
Allowable cost 20% less	\$116.66
Target cost	\$60.00

TEAMS	COSTS
Red	\$91.5
White	\$140.5
Blue	\$99.0
Average cost	\$110.33
Allowable cost 20% less	\$88.26
Target cost	\$50.00

Figure 22: Resulting cost of towers (Reprinted from Munankami 2012)

On the completion of the game, some felt that the game was slightly effective while others thought it was very effective. On the whole, the game was able to achieve its objective which is supported by the results.

Conclusion

The questionnaire that was answered by the participants shows that the game was able to convey basic concepts about TVD and IPD, but since only a first run study was conducted, further playing of the game are needed.

The Maroon-White Game

Introduction

The Maroon-White game (Smith and Rybkowski 2013) is inspired from the Red-Black game (Ziegler). The simulation is designed to educate participants in two areas.

One, is the natural tendency of humans to sub-optimize and the second is the effect of sub-optimization on long term relationships and goals. There are many games being played today in the field of lean to teach hard skills such as pull vs push, efficiency, wastage, value stream mapping and kanban, but there are only a few games that teach soft skills. To be able to efficiently apply lean theories, soft skills of the participants need to be developed and the Maroon-White game addresses this issue. This game helps participants grasp the concept of long-term thinking and also the fact that individuals easily revert back to short-term thinking when placed in a competitive situation. Liker (2014) suggested that leaders and managers must not only learn and understand, but live by the lean philosophy.

Description of Simulation

The score chart for the game is as depicted in Figure 22. The facilitator should first divide the group into three teams. Although there is no exact number of players that should comprise a team, 3-5 members per team seems to enhance participation and yield better overall results. Each team should be allotted its own personal space for private discussions as discussion is one of the most important components of the game.

Team Choice	Point Distribution		
M – M – M	50	50	50
W – M – M	100	0	0
W – W – W	0	0	0
(all other combinations)			

Figure 23: Game score chart (Reprinted from Smith and Rybkowski 2013)

The guidelines are as follows:

1. The objective of the game should be stated upfront and repeated often: “The goal of the game is to score as many points as possible.” This needs to be stated frequently while explaining the game.
2. Each team declares a color (either “Maroon” or “White”) for every round. The teams write their response and simultaneously hold up their written color choice the moment the facilitator calls for it.
3. Scores are then distributed according to the combined choice of the teams.

The facilitator can manipulate the game in a number of ways, some of which are as follows:

1. The order of reporting decisions of each team.
2. Whether or not a team can change its decision during the reporting of choices.
3. The number of rounds can be decided by the facilitator, though 4-7 rounds are suggested.
4. Whether or not the leader of each team can communicate with leaders of other teams.

The scores of the game are tabulated as shown in Figure 23.

	Team 1		Team 2		Team 3	
	Color Choice	Points	Color Choice	Points	Color Choice	Points
Round 1						
Round 2						
Round 3						
Round n						
TOTAL						

Figure 24: Scoring Table sample (Reprinted from Smith & Rybkowski 2013)

Typical Results

The Maroon-White game has been played in various settings with substantial variation in the background of the participants, but there has been only minor variation in the results. It is a human tendency to be driven by competition. When given the opportunity, teams will rather sub-optimize at the expense of other teams, than cooperate and build long-term relationships. Furthermore, if the three teams have the maturity to collaborate for greater gains, it will only be a matter of time until one makes a selfish choice; once that is done, none of the remaining teams are willing to place themselves in a situation where they might be taken advantage of.

Discussion

Many questions can be posed to participants between rounds of the game. Participants should be encouraged to reflect on their decisions and analyze if they have

achieved the goals of the game. What could the teams have done to achieve the optimal result? How is the game affected when one team chooses white? How can this lesson be applied to the construction industry?

Conclusion

Though this game does not replicate a scenario in the construction industry, it does showcase familiar emotions of betrayal and distrust that veterans in the construction industry have faced. Decisions such as these are made almost every day by practitioners in the industry. For example, decisions involving change orders, delay on site due to drawings, release of payments to subcontractors or design and operational discrepancies among engineers and architects. The most important lesson that can be learned from this game is that in our industry, the sustainability of our business relationships depends on the decisions we make. We will all benefit from each other if our decisions are made based on a broader perspective rather than one individual job.

The OOPS Game

Introduction

This simulation answers the question that is faced by every planner, “Should I spend more (time, money, resources) to improve my plan or go forward with what I have and more likely suffer an “Oops” (Howell & Liu, 2012)? This simple game tries to provide a solution by investigating the benefits of planning, in terms of both financial and human effort. There are three strategies in this game. The first is the “no planning” approach, also known as the “guts ball.” In this approach, planning is lowest and the risk of an “Oops” is the highest. The second approach is the “judgement” approach wherein

the decision is based on analyzing the risks involved and the possible outcomes. The third approach is the approach where time and money is invested in planning, to negate the occurrence of an “Oops.”

Description of Simulation

This game must involve at least three participants in a team. There are three roles: a project manager, a superintendent and project controller. The project manager announces the choice for each card, the superintendent moves the cards as per directions and the project controller is responsible for assuring that the rules are followed. The objective of the game is to complete a nine card project as shown in Figure 24. Figure 25 shows the location and cost associated with the cards.

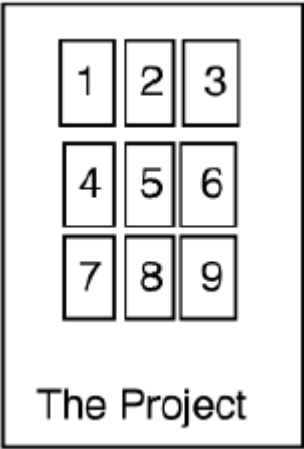


Figure 25: Sample Completed Project (Reprinted from Howell & Liu 2012)

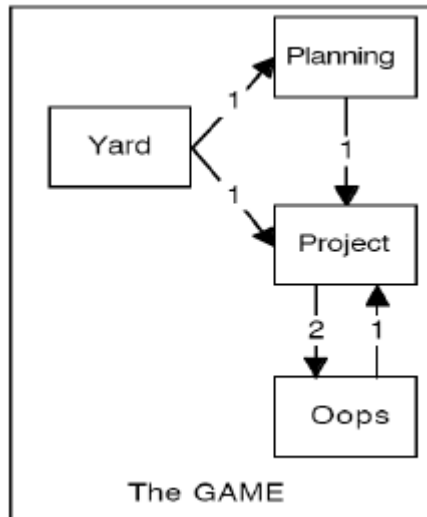


Figure 26: Configuration & Scoring (Reprinted from Howell & Liu 2012)

The procedure for the game is as follows.

1. The first card is turned face up and placed in its respective position and a mark is made on the “Build” column on the score sheet.
2. All subsequent cards can be placed on the project if they share an adjacent edge with a card that is already on the project. Corner to corner connections are not allowed. For example, if the first card drawn is a 9, then only the cards 8 and 6 can be placed directly on the project.
3. Before each of the remaining cards is turned over, the project manager has to decide to either “build” or “plan” it. If “plan” is decided, the card is placed face-up in “planning” and a mark is made in the planning column on the score sheet. The cards in the planning spot can be placed on the project only if it shares an adjacent side with the card that is already placed on the project. If “build” is decided, a mark on the build

column is placed on the score sheet. If the card shares a side with a card that is on the project, it can be placed on the project. If not, the card will be placed in the “Oops” and a mark will be made on the score sheet.

4. After every turn, review to see if a card placed in planning or build can be placed on the project.

5. The simulation is complete when all the 9 cards are placed on the project.

“Project controls” ensures that the rules for placing cards is followed and the “superintendent” ensures that the scores are entered correctly.

Discussion

Variations such as making a team play with the “guts ball” approach can be made to see the outcomes. These outcomes can be analyzed by plotting the scores on a histogram and checking the range, average and frequency of outcomes. These analysis can be used to further discuss respective applications and outcomes in the real world. Students learn better when patterns of varied outcomes are observed. A more competitive version where fake money is introduced can lead to better profits.

Cocktail Napkin

Introduction

The purpose of the Cocktail Napkin exercise is to help a facilitator understand the depth of participant understanding of lean by asking them to sketch their own graphic definition of Lean Construction. Sketches made on the back of a cocktail napkin have been a tradition in the architectural design fields and construction. The exercise also demonstrates to participants the potential to speedily communicate key aspects and

benefits of applying lean philosophies to construction to those trying to understand and possibly implement lean.

Description of Simulation

This game is similar to the elevator speech for a business idea, only this exercise is more visual. The exercise has been played at workshops and conferences related to Lean Construction. Participants are provided with a cocktail napkin and are given ten minutes to sketch something on the back of the napkin that can easily explain the fundamental concepts of lean construction. Once time is up, volunteers come up to the front of the room and reproduce their sketch on a white board. Then another volunteer is asked to come up and present his or her interpretation of the sketch. The latter part of the exercise is to give feedback to the sketch's author about the effectiveness of the visual.



Figure 27: Example of sketches from participants (Reprinted from Rybkowski et al. 2013)

Discussion and Conclusion

This exercise has been helpful because, to date, there has been no firm definition of lean. Unlike an object, lean is a philosophy that is open to interpretation of guidelines and concepts. Graphic representation aids to enhance understanding of the lean philosophy. As explained by Rybkowski et al. (2013), one metaphor is that the collective revelations of lean construction represent the blind men who are each touching a different part of a single elephant (e.g. trunk, tusk, leg, tail and side; Schmaltz 2003) and arriving at different conclusions about the final form of the elephant. Taken together, the various napkin sketches help us understand the overall elephant.

Magic Stick

Introduction

The Magic stick game, also known as the Helium Stick game is a simulation designed to teach the importance of collaboration and teamwork. It help participants realize the need for TVD and IPD. The objective of this game is to lower the stick to the ground while obeying only one condition, which is to rest the stick on both index fingers of every member of the team. This game challenges the participants to act in a unified manner in order to complete the objective.

Description of Simulation

1. Divide the participants in groups of 8-12.
2. Arrange each group, so that one-half of the participants are facing the other half at about an arm's length.

3. Each group is asked in turn, to raise their forearms to the horizontal with both index fingers pointing to the person opposite, so that all the index fingers are in a line.
4. Lay a bamboo on the extended index fingers and 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.
5. Restart the process whenever any member is not in compliance with the rules.
6. Allow the groups to continue until they have completed the task; watch for rule violations.
7. Review the exercise with participants after completion. If there is more than one group, explore different strategies. Record comments on a flip chart, if desired. Explore similarities and differences with respect to what happens on projects.

Discussion and Conclusion

This game can be played with a group starting by planning the exercise for five minutes. The game will yield better results in following rounds if a team leader is appointed from among the team members. This can be related to real construction projects with the help of introducing IPD and TVD. These concepts show that collaboration and working as a unified team will yield better results, and help each subcontractor achieve its goals.

CHAPTER V

RESULTS: SUMMARY OF INTERVIEWS

This chapter briefly summarizes interviews that took place with three members of the lean construction community who specialize in playing and/or developing lean simulations: Alan Mossman, Rafael Sacks, and Zofia Rybkowski. Each interviewee also regularly facilitates live simulations for students and building stakeholders, including owners, architects, and contractors. The interviews were done either in person or electronically via Skype. They were audio-recorded and their remarks summarized.

Alan Mossman: Lean consultant and coach, Managing Director of The Change Business Ltd.

Mr. Mossman became involved with lean construction around 2001. He had been working for 3-5 years as a management and organizational development consultant. He had been learning about lean and studying Deming's ideas for some time when his professor recommend for him to get involved in a collaboration between lean and architecture. This is how his journey in lean construction began. According to Mr. Mossman, simulations give people a quick hands-on experiential feeling into some aspect in the lean world. Mr. Mossman was involved in lean thinking even before the term "lean" was coined. Mr. Mossman has been researching the use of simulations for outdoor management development techniques and its importance for his PhD since 1982. He feels that simulations engage people's hearts, minds, and guts, and help in training because they activate the limbic parts of their brains via activities that induce more emotional involvement and thereby more effective learning experiences. Mr.

Mossman has slightly changed the Parade of Trades game by playing six trades and 24 units of work in place of seven trades and 35 units of work, but with similar results--just a little quicker. Mr. Mossman has created a variant in the airplane game that better suits the construction industry. In the manufacturing industry, the work moves past the workers, whereas in the construction industry, the workers move past the work. So in Mr. Mossman's version of the game, the card* is a post-it note stuck to a wall. In his opinion, the areas that need more simulations in lean construction include Integrated Project Delivery, Target Value Design and Big Room design (*Note: "dot card" is a version of the Airplane Game that asks workers to stick colored dot stickers on a card instead of building an airplane).

Villego is a game that uses the Last Planner System to give participants access to the logic and the importance of lean and the LPS. Villego is just one of many LPS simulations that are used, but one which has been widely played and receives rave reviews from participants. Participants from a workshop that included the Parade of Trades game, Villego, and the Repairmen thought experiment** indicated key learning points included:

- Teamwork, collaboration
- Understanding project properly before beginning execution
- Importance of planning and time management
- Team is key
- Negotiations
- Review lessons learned

- Ability to say no and accept reality
- Planning from finish to start i.e. from right to left

The “Repairman thought experiment” is an activity where a facilitator asks participants to brainstorm all the possible reasons that would keep a repairman from reaching a target number of customer calls in one day. The activity is intended to help participants see that the very nature of many corporate systems prevent even the most diligent workers from reaching expressed corporate targets. In other words, the repairman is not able to meet expressed corporate goals of 8 home calls per day if traffic is bad, customers keep them longer than they should, job repair time estimates are incorrect, etc.

**Rafael Sacks, PhD: Associate Professor, Department of Civil Engineering,
Technion, Israel Institute of Technology**

According to Dr. Sacks, Lean Construction can be defined as an approach to design and production control that emphasizes flow and reduces the waste of waiting; lean tries to align the flow of work to the flow of a crew. Dr. Sacks has been involved with lean construction for the past 15 years. He went to Arizona State University to attend their lean construction academic forum. On the basis of his experience in construction science, it was felt that lean was a necessary and a new way of thinking about how to organize construction. Dr. Sacks’ main involvement in lean up to that point was in information systems and his engagement in the industry was through Building Information Modeling (BIM). A metro fix was the next project to try to use BIM to make construction work leaner. There were many other opportunities to visit sites with

students in research projects, to see how work was being done and all the problems that had been described in lean construction discussions. It became apparent that these problems are strongly embedded in the local construction industries. Dr. Sacks began collaborating about 11 years ago on a series of projects where research was carried out with construction companies and where researchers could learn from the way the companies operate. The industry learned how to realign its production. Most research conducted by Dr. Sacks is done through engagement with industry.

When Dr. Sacks began work in lean construction, lean had just started four to five years ago. Lean construction had also just been introduced in the past four to five years in the US. He reckons that the LCI (Lean Construction Institute) has had a huge impact on the lean construction industry. However, even though knowledge about lean is very broad, depth of implementation and understanding of lean is not great. LCI has 15 plus lean communities in the US and each community has an average of twenty contractors associated with each branch, proving that the degree of involvement is much greater than what it was when Dr. Sacks began working in lean construction. But even now, a majority of those in the construction industry do not completely understand what lean construction is. Knowledge of lean and BIM will act as a catalyst for any company to grow. When smaller companies adopt these systems and attract young and aspiring employees, the bigger companies will need an organizational setting and culture that adopts these techniques. Acquiring the smaller companies could accomplish this and this would then create a shift in the nature of the construction industry.

Dr. Sacks differentiated between the construction and manufacturing industries. While most of the time wasted in manufacturing plants is due to issues with flow, in construction, time is not wasted in flow activities, but more to just waiting. Furthermore, operations that take place in manufacturing are different from activities or tasks that take place in construction. Even measuring flow is not easy in the construction industry because things don't flow; in this industry flow is abstract. Simulations and training therefore help participants visualize abstract concepts.

Simulations are used both in academia and in the practice of lean construction. Use of computer simulations in construction projects is at an advanced level because these projects are very technically sophisticated. The simulations in these projects are used at a very intense level compared to those that are used in academia, where the use of simulation for the purpose of research is common. The appeal in using lean in both situations is that it allows users to try different scenarios. Trying different scenarios, even though different in complexity is just a fraction of the cost of applying actual projects. Also, in simulations, parameters and effects can be observed and impacts can be understood. Concepts of flow, pull and other abstractions are difficult to explain and understand, whereas they can be easily understood with the help of simulations.

According to Dr. Sacks, one of the most important simulations is the Parade of Trades game. It focuses on only one concept, that is, the impact of variability. Since it is so narrow, the simulation is widely played and accepted. Another game that Dr. Sacks suggested was very effective is SimLean.

**Zofia Rybkowski, PhD: Assistant Professor, Department of Construction Science,
Texas A&M University**

Lean as defined by Dr. Rybkowski is a philosophy that allows users to reduce waste and increase value using continuous improvement, in a culture of respect. The reason to adopt this definition she traces to the first midyear IGLC meeting that she attended in New York City. In the presence of lean pioneers such as Lauri Koskela and Iris Tommelein, she distributed cocktail napkins and asked participants to draw on it what they perceived to represent Lean Construction. With the help of a graduate student, Patrick Daniels, and the ideas of Dr. Jose Fernandez-Solis, the composite graphic definition she adopted shows gains by reducing waste and increasing value in the process. Also keeping continuous improvement and the morale of team in context, Dr. Rybkowski has arrived at this precise definition of lean.

According to her, lean has already begun to influence the construction industry. Keeping time, cost, quality, safety and morale at the epicenter of lean, the traditional belief is that there must be a time-cost trade-off. But the relationship between time reduction and increased cost is being proven wrong with the promise of lean. By applying lean and devoting time to the methods that are a part of this process, results have started to show improvement in all five metrics of project management simultaneously. There is another part of lean that is contributing to this improvement, and that is of enhanced *learning*. When junior players are introduced in the team, they are exposed much more quickly to all these processes and this adds learning to the five metrics of lean project management, namely time, cost, quality, safety and morale.

During Dr. Rybkowski's professional experience in Japan, China, Hong Kong and US, she felt that the transfer of practical knowledge was very slow, unlike in the sciences. She felt that there was a need to have a more refined system for educating professionals in the practical field of building design and construction, and so as a doctoral student she decided to study lean construction which had been introduced relatively recently at the University of California in Berkeley. It seemed like a missing piece in the puzzle that she had finally found. Lean was a solution to the disconnect between bodies of knowledge that could help individuals progress more quickly in their professions. In spite of initially being a slow believer in lean, there has been a stronger connection as time has progressed and challenging lean at every step has given her a more thorough understanding of the world of lean.

Dr. Rybkowski stated that simulations are the closest one can get to randomized controlled trials, which gives us a level of certainty in the theory of lean, as in the fields of medicine and biology. Simulations also allow us to see the magnitude of the impact of some innovations. Furthermore, we can test statistical significance; we can establish controls and 'n' values. Scientifically controlled experimentation is not easily done on construction sites, but is possible for simulations. The Airplane game was one of the first that Dr. Rybkowski was introduced to in lean constructions. After a long path in studying lean games and simulations, when she began in academia, the idea of challenging students to create games turned out to be an effective way to test the level of understanding of students in the subject of lean. This was also an opportunity to use simulations as a research tool to explore human behaviors to answer critical questions.

Looking at the simulations that some of her students have since created, this idea turned out to be a huge success. The TVD game developed by Munankami as an adaptation of Peter Skillman's Marshmallow Challenge was one such example. Another such example was that of Collective Kaizen and Standardization Game. Simulations have made it possible to determine results on a preliminary basis that could not have been figured out otherwise. The example of educational background having no effect on results obtained on the maroon and white game, and the team of estimators versus superintendents and project managers on willingness to collaborate are perfect examples of how simulations can help clarify the distinction between beliefs versus facts.

Two of the most powerful and important simulations are the Parade of Trades game and the Airplane game. These games have been played year after year, and so far there is nothing that can replace them. Dr. Rybkowski feels that most of the original games were based on the manufacturing industry, but it would help to redesign these games to make them more visceral in people's understanding. Even linking them to case studies to actual construction sites would make people better understand the lean philosophy.

CHAPTER VI

ANALYSIS

The games summarized above have been analyzed according to the 14 principles of Liker's *The Toyota Way*. Table 4 is also a concise database of most of the games that are currently being facilitated by lean researchers, academics and trainers, as well as the principles the simulations teach. The interviews and Table 4 have been analyzed to determine which of the 14 principles are lacking games that need to be developed to educate participants about those principles. The table may also serve as a reference for facilitators who wish to select appropriate simulations to fill a specific educational need.

Fourteen Principles of the Toyota Way

Liker (2004) grouped the 14 principles of *The Toyota Way* into four sections, namely:

1. Long-Term Philosophy
2. Right processes produce the right results
3. Developing your people will add value to the organization
4. Organizational learning is compelled by solving root problems

The principles are listed below:

Section 1

Principle 1: All management decisions should be based on a long-term philosophy, even at the expense of short-term financial goals. Relationships and collaboration should be based on long-term understanding, and not be based on fulfilling short-term goals.

Section 2

Principle 2: Create continuous process flow to bring problems to the surface. Work processes should be redefined to eliminate all kinds of wastes through the process of continuous improvement or kaizen. Eight types of waste or *muda* are: Overproduction, waiting, unnecessary transport, over-processing, excess inventory, unnecessary movement, defects and unused employee creativity.

Principle 3: Use “pull” systems to avoid overproduction. This is a method where *kanban* systems are used to signal to a predecessor about a need for more material. A pull system produces material only when required, and in the quantities required, thus reducing overproduction and excess inventory.

Principle 4: Workload levelling or *heijunka*. This helps in achieving minimal waste (*muda*), using humans and equipment within their capacities (*muri*), and not creating uneven production levels (*mura*).

Principle 5: Build a culture of stopping to fix problems and getting quality right the first time. In this system quality takes precedence (*jidoka*). Any employee should have the authority to stop work process to signal a quality issue.

Principle 6: Standardization tasks and processes form the foundation for continuous improvement and employee empowerment. Employees thereby aid in the development and improvement of the company.

Principle 7: This principle describes the 5S system. The 5S's stand for

- Sort: Sort out unneeded items

- Straighten: Have a place for everything
- Shine: Keep the area clean
- Standardize: Create rules and standard operating procedures
- Sustain: Maintain the system and continue to improve it

Principle 8: Reliable and thoroughly tested technology must be used to serve the people and processes. Technology is pulled by construction and not pushed to construction.

Section 3

Principle 9: Grow leaders who live the lean way. They should pay constant attention to learning and teaching others the philosophy of lean. This will help to spread awareness and to better apply these principles.

Principle 10: Develop teams that follow the philosophy of their company. Success is dependent on effective teamwork and not solely on individual performance.

Principle 11: Respect the extended network of colleagues, partners and contractors. Treating suppliers as a part of your organization and challenging them and helping them improve will yield great results for any organization.

Section 4

Principle 12: Go and see for yourselves to understand the severity of any situation. Without observing any situation firsthand, it is difficult to evaluate the

situation and provide a solution for the same. Following are some important management guidelines.

- Always keep the final target in mind;
- Clearly assign tasks to yourself and others;
- Take full advantage of the wisdom and experiences of others to send, gather or discuss information; and
- Always report, inform and consult in a timely manner.

Principle 13: Make decisions by consensus of all related personnel, thoroughly considering all alternatives. Implement these decisions rapidly (*nemawashi*).

Principle 14: Become a learning organization through relentless reflection (*hansei*) and continuous improvement (*kaizen*). Opt for the following problem-solving technique after the initial problem perception: Clarify the problem, locate area/point of cause, investigate root cause (5 whys), identify a countermeasure to address the root cause, test the countermeasure, evaluate, and standardize if improvement is noted.

Sr.No.	Principles	Collective Kaizen and Standardization	Parade of Trades	5S Game	Airplane Game	Maroon-White Game	TVD Game	LEAPC ON	Cocktail Napkin	The OOPS Game	Magic Stick Game	Villego
1	Long-Term Philosophy					✓						
2	Eliminate <i>muda</i>				✓			✓		✓		
3	Pull system				✓			✓				✓
4	<i>Heijunka</i>		✓		✓							
5	<i>Jiboka</i>				✓							✓
6	Standardization &	✓										✓
7	5S			✓								
8	Technology											
9	Create Leaders								✓			
10	Develop Teams						✓					
11	Respect workers					✓					✓	
12	<i>Gancho</i>											
13	<i>Gembutsu</i>											
14	<i>Nemawashi</i>					✓					✓	
14	<i>Hansei</i> and	✓				✓						✓

Table 3: Analysis of games based on 14 Toyota principles

Lean Thinking, Womack and Jones

Simulations were also analyzed with respect to the 5 Principles described in *Lean Thinking* by Womack and Jones (2003). A brief list and description of the five principles are as follows.

1. Value

Value is that which is beneficial and important to the customer. Fulfilling this requires an accurate understanding of what the customer wants. It is said that 95% of processes and activities are non-value adding (Womack and Jones 2003).

2. Value Stream

Value stream may be defined as any practice or series of activities, when carried out in an orderly manner, produce something that is of value to the customer. A lean organization manages all its activities in such a manner that they produce optimum value for the customer. This is executed by eliminating wasteful and unnecessary activities and continuously improving value-adding ones for the customer.

3. Flow

Work should flow steadily and without any interruption from one value-adding activity to another, in a lean organization. This can be done by minimum wait time between activities, levelled batching and resource levelling. All efforts should be directed to avoid bottlenecks and obstacles to flow.

4. Pull

Activities should be pulled into construction rather than being pushed onto construction. This chain begins from the vendor responding to demand and travels backwards to the suppliers. Pull reduces overproduction and excessive inventory.

5. Perfection

Understanding and implementing the first four principles, and continuously improving by generating ideas to achieve them, creates perfection. In a perfect lean organization, the right amount of value is delivered to the customer by making every step value-adding, avoiding delays, producing the right quantity and quality at the right time and the execution of work, in compliance with the first four principles.

Sr.No.	Principles	Collective Kaizen and Standardization	Parade of Trades	5S Game	Airplane Game	Maroon-White Game	TVD Game	LEAPCON Napkin	Cocktail Game	The OOPS Game	Magic Stick Game	Villego
1	Value						X					
2	Value stream											
3	Flow				X			X				X
4	Pull				X			X				X
5	Perfection	X										

Table 4: Analysis by five principles of Lean Thinking

CHAPTER VII

DISCUSSION

This research generated an inventory of current simulations that have become an integral part of lean construction. Simulations provide a control-based validity of lean philosophy. The inventory includes descriptions of the simulations and lessons they are intended to impart.

An analysis of the simulations with respect to the 14 principle of *The Toyota Way* demonstrated there is a need for games in the areas of technology, creating leaders and the importance of ‘go and see for yourself’ technique for solving problems.

Analysis of simulations on the five principles discussed in *Lean Thinking* by Womack and Jones suggest that these five principles do not encompass all the core values of lean construction. This was illustrated by Table 5, which shows that there are many simulations that do not fall under any of the five principles.

Discussions with those who are active in facilitating lean construction simulations and in developing new ones were revealing. Mr. Alan Mossman suggested that additional simulations related to TVD and IPD need to be invented to educate participants in these areas. Dr. Sacks suggested that lean construction is currently poorly understood by much of the industry and that simulations can help greatly to enhance understanding. Dr. Rybkowski suggested there is a need to redesign simulations that have been created for the manufacturing industry, to better suit the construction industry.

CHAPTER VIII

CONCLUSION

This paper represents a compilation of the simulations being played to educate students and practitioners in lean construction. It also shows the importance of each simulation, and how that simulation assists participants enhance their understanding of complex lean concepts. Simulations are developed to involve multiple senses, thereby vividly demonstrating the effect specific lean principles can have when applied to construction projects. Further research is required in this area to link specific principles to case study applications to support the implementation of lean in the construction industry.

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