DEVELOPMENT AND TESTING OF A SIMULATION TO ILLUSTRATE HOW TO LOWER THE RIVER TO REVEAL THE ROCKS

A Thesis

by

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ABSTRACT

Toyota's chief engineer Taiichi Ohno urged organizations to "lower the river to reveal the rocks" as a way to identify buffers of time, capacity, inventory, and money. The concept is to temporarily stress a system so that sources of variation hidden by buffers can be made apparent and addressed. The question this research asked was: How might one more effectively communicate Ohno's principle? The purpose of the paper was to develop and test a 50-minute simulation that uses modest and inexpensive materials to help lean construction educators and facilitators clearly convey the Ohno principle as a means for continuous improvement. For research method employed, a simulation was developed and tested as a first run study, and preliminary results and participant experiences analyzed to hone the simulation toward its final form. The simulation was tested on construction science students, and data from results of the simulation analyzed. It was found that the stress levels experienced decreased, and the perceived efficiency increased once the rocks were identified and removed. The simulation was also found to be effective in demonstrating the process of "lowering the river to reveal the rocks". One limitation of this research is that its scope is confined to reduction of time buffers - i.e. it does not consider other critical buffers as well. However the intent is to offer a launching point from which discussions with participants about applicability to their delivery processes can emerge. The simulation also offers the potential to serve as a base onto which additional stressors can be subsequently added and tested. Despite the pursuit of continuous improvement by lean construction

practitioners, there is still a lack of awareness of how reduction of buffers can highlight opportunities for improvement. The intended implication and value of this work is that the developed simulation can be used to teach the Ohno philosophy to construction management students in academic settings, as well as to lean construction practitioners and stakeholders who may benefit from the inclusion of lean thinking in their practices.

DEDICATION

For Dad.

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1. INTRODUCTION

Lean construction is a philosophy that aims to minimize the waste of time, resources, and effort in order to produce the maximum possible amount of value in the process (Koskela et al. 2002). Toyota constantly reinvents itself, not just as a response to change, but in anticipation of any changes. It does so by methodically and systematically putting the system through stress by reducing the buffers of capacity, inventory, time, and money that cushion and absorb variation that causes waste. This process reveals where there is scope for improvement, and was expressed simply in Ohno’s metaphor to “lower the river to reveal the rocks” (Ohno 1988).

1.1 Problem Statement

The purpose of this research was to develop and test a simulation which demonstrates how “lowering the river can reveal the rocks,” - i.e. how systematically reducing buffers in a process - can lead to discovery of its scope for improvement.

Opportunities for improvement, especially in productivity, almost always exist in complex processes such as those that occur in the construction industry. Yet, these opportunities are frequently not pursued because they are often not discovered. Taiichi Ohno had a solution for this, which was to “lower the river to reveal the rocks,” which implies that the buffers of a system, such as time, capacity, inventory, and money, must be decreased in order to find where variability lies. Using Ohno’s directive, opportunities for improvement can be found, and variability can be adjusted to match the actual required variation in the process (Ohno 1988). This research aimed at understanding and then communicating this theory through the mode of a simulation.

1.2 Research Goal & Objectives

Research Goal

Taiichi Ohno's approach to Continuous Improvement via the metaphor, "lower the river to reveal the rocks," is not widely implemented in construction. Even when comprehended correctly, the true value and depth of this concept is not often grasped. There is considerable scope for improvements in construction processes, and the industry can benefit by a greater application of this principle.

Objectives

The objective of this research was to develop and test a simulation to distinctly communicate the value of "lowering the river to reveal the rocks" on continuous improvement. The simulation helps the participants understand the meaning of Ohno's metaphor, and how the reducing buffers in a process can eventually lead to improvement.

Further, it was explored through the simulation's testing whether providing solutions (Continuous Improvement: Kaizen) after temporarily stressing the system (lowering the river) and finding variation (revealing the rocks) can: 1) Lower the stress experienced as part of the process; and 2) Increase the perceived efficiency of the process.

2. REVIEW OF LITERATURE

2.1 Wastes in the Construction Industry

A recurring problem in the construction industry is the tendency of construction projects to generate a lot of waste, representing up to 30-35% of the total cost. Carlsson (2012) divides construction waste into four categories: Errors & controls, Use of resources, Health & security, and Systems & structures. Wastage owing to errors and controls represent more than 10% of production cost.

There is a high correlation between errors and rework (Nagapan et al. 2012). Rework affects both cost and schedule performance throughout the construction industry. Research by the Construction Industry Institute shows that direct costs incurred due to rework represent about 5% of total construction costs (Hwang et al., 2009).

2.1.1 *Muda*: Eight Wastes in Construction

1. *Movement* is considered waste when people and materials are unnecessarily relocated. This signifies the unnecessary additional steps taken by personnel to account for incompetent processes, excessive production, and inventory. Motion requires time and it often does not add value to a process. When people move and it adds value to a process, it can be considered work. When people move and value is not added, it is motion, and a type of waste.

2. *Untapped Potential* is considered waste when the chance to use abilities of appropriate individuals is overlooked. Employees are hired for specific skills. Usually, these employees have other skills too, and to not take advantage of these is considered a waste.

3. *Rework* is considered waste when tasks must be redone because they were completed incorrectly the first time. Products, services, or materials that do not meet specifications or quality expected, need to be reworked upon. These defective products/services are considered a waste, along with the material and time spent on them.

4. *Overproduction* is considered waste when a surplus is created because there was more produced than required. It could be a by reason of producing more than what is required, before than required, or faster than is required. The results are having surplus, and the costs associated with it are considered a waste.

5. *Waiting* is considered waste when personnel or equipment staying idle while waiting for work. This can occur due to the preceding work not finishing on time, or poor scheduling. Waiting, referred to usually as delay, is a period of inactivity. No value adding activity is performed, and increases the delivery time.

6. *Transportation (Or Conveyance)* is considered waste when the movement of materials or products is redundant. Conveyance should be regularized primarily as it adds unnecessary time to the process, and also the material may suffer damages during transport and handling. Neither of these helps in adding value to the process.

7. *Over-processing* is considered waste when work sometimes is not shared for various reasons. This causes the work to be recreated. It also refers to waste due to added communication, multiple processing, double checking, etc. These all add no value to the process.

8. *Inventory* is considered waste when loss of storage space, as well as risk of damages to the material occurs because of early procurement. Any supply surplus of what is needed at the time does not add value. Not all of the inventory can be considered a waste, but surplus inventory can tie down space and also costs and resources (Ohno 1988).

Toyota Production Systems defines waste as deviation from the optimal utilization of resources, and classifies waste in terms of *Muri* (overburden), *Mura* (inconsistency), and *Muda* (waste: non-value-adding activities). The eight wastes in construction are depicted in Fig. 1.

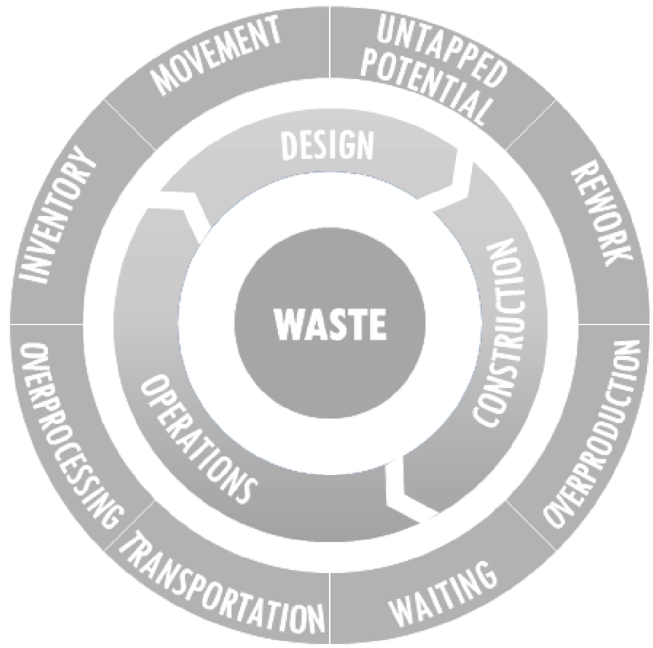

Figure 1: Eight types of wastes

2.2 Continuous Improvement

2.2.1 Productivity

As shown in Fig. 2, The US Department of Commerce reports that the increase in productivity (1990-2000) was lower in the construction industry (0.8%) as compared to other industries (2%) (Forbes and Ahmed 2011). There are studies which also state that the productivity of the construction industry is actually declining, when measured against contract dollars of new construction work per hour (Teicholz 2004). Waste caused by inefficiency of resource (i.e. labor, material, etc.) control increases costs, ranging from 25-50% (Forbes and Ahmed 2011). There is also wastage of time. Approximately 50% of the time spent in construction may be deemed as wasteful (Smith et al. 2011).

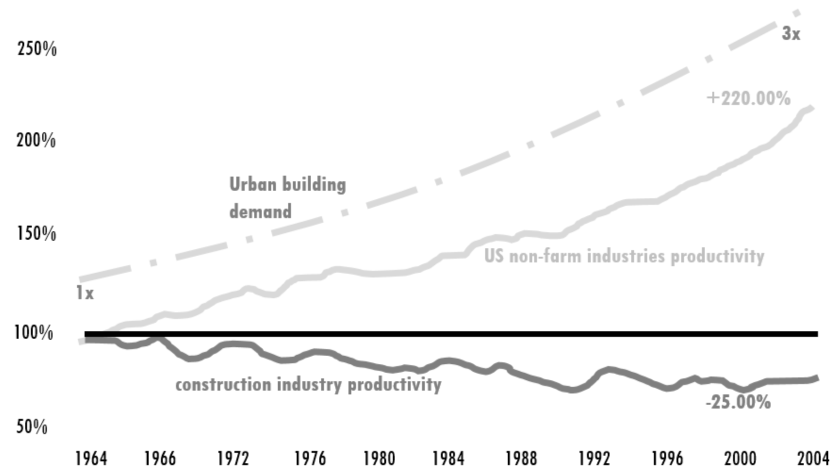

Figure 2: Productivity index
Adapted from (Attia, 2010)

The philosophy behind kaizen is often credited to W. Edwards Deming. Kaizen, also known as continuous improvement, is an approach toward work that systematically seeks to achieve incremental changes in processes in order to improve efficiency and quality (Rouse 2009). It is an effort to improve products, services, or processes, and is also a method for identifying opportunities for streamlining work. If the workflow is made efficient, it can save valuable resources, and assist in the reduction of waste in the forms of cost, time, and quality (ex. defects).

2.2.2 Continuous Improvement

Kaizen, or Continuous Improvement, suggests that there in an effort in progress which is incremental in nature, to improve any processes, services, products, and projects (Imai 1986). Continuous Improvement can be described as a "process intended to achieve improvement" instead of just a string of unrelated activities for improvement

(Jha et al. 1996). Continuous improvement, along with being a management strategy by itself, is a process within a broader strategy for quality improvement.

The 4P model by Liker (2004) shown in Fig. 3 is a method of categorizing Lean production principles. All 14 of *The Toyota Way* principles fit under the 4 Ps in the pyramid. The model moves Continuous Improvement and learning to the top of the pyramid, with the base being built on long-term thinking, an emphasis on process, and development and respect for people. Once the three Ps forming the base have been developed, emphasis is placed on the 4^{th} P, Problem-solving, to ensure continuous improvement.

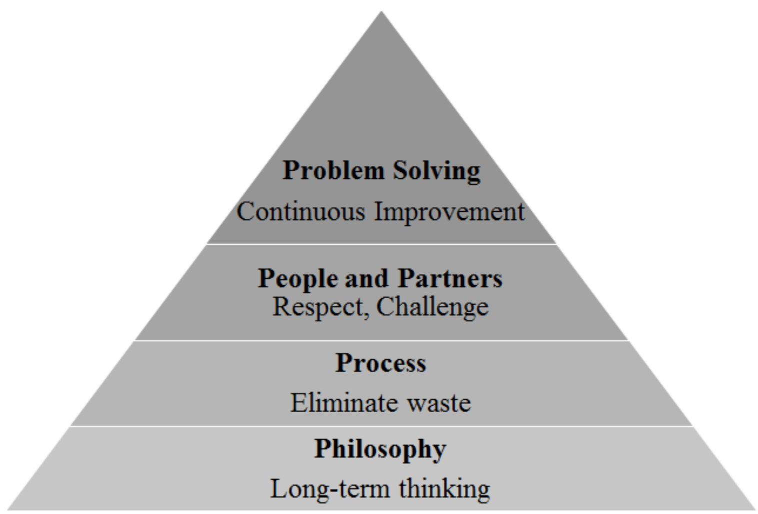

Figure 3: The 4P model
Adapted from (Liker, 2004)

Continuous improvement is a way for companies to identify opportunities and integrate improvements into their processes. Usually, projects which involve complexities such as shifting deadlines, and changing priorities have undiscovered opportunities to improve. The practice of continuous improvement was formalized in manufacturing, and is being implemented by different industries to improve their own processes. The philosophy is also being applied to design and construction.

2.2.3 The PDCA Cycle

The PDCA cycle illustrated in Fig. 4, was developed in the 1930's by Walter Shewhart. It is also called the Shewhart cycle or the Deming cycle. The cycle can be used as a model for improvement. The four elements of the cycle are:

- Plan: Prospects are identified and a change is planned.

Avoid *Muri* (unreasonableness, overloading) – through Standardized Work

- Do: Small scale implementation is done to test and study the change.

Avoid *Mura* (control inconsistencies) – through JIT (Just in Time) Delivery

- Check: The tests are analyzed and reviewed.

Avoid *Muda* (find waste in variation of outcomes) – through Analysis

- Act: Action must be taken to either disregard or implement change.

Indicates the will, motivation & determination of management (Ballard 2007).

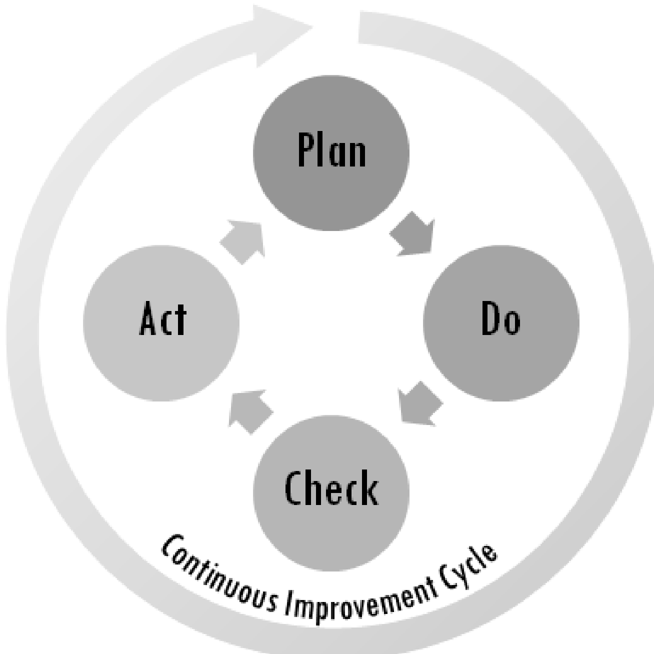

Figure 4: PDCA cycle
Adapted from (Deming, 1952)

The cycle of improvement begins again, and continues to achieve a state of continuous improvement. Continuous Improvement can be visualized through the PDCA cycle in terms of the Kaizen staircase (Fig. 5). This adds a fifth element, which is to *sustain* the achieved improvement through each successfully implemented change.

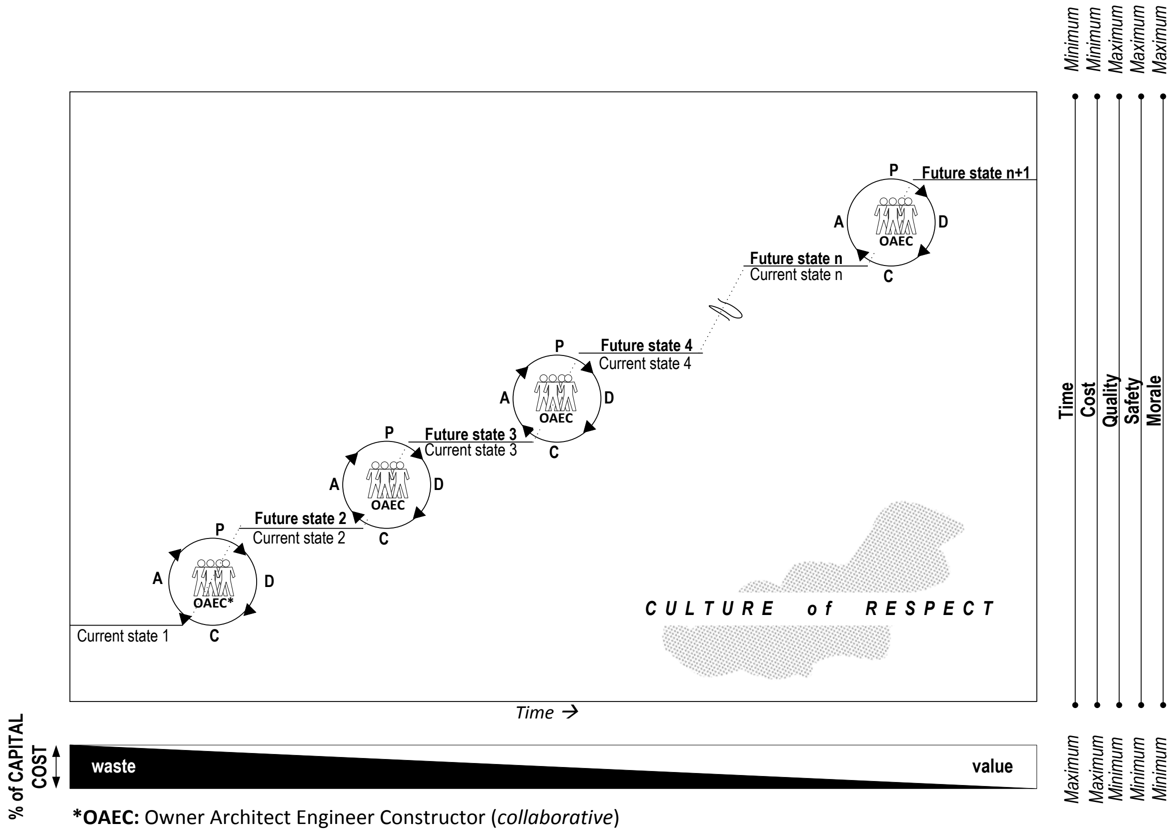

Figure 5: The staircase to continuous improvement; kaizen stairway
Reprinted with permission from (Rybkowski and Kahler, 2014)

2.3 Uncertainty and Variation

Construction is a process which is complex. This aspect combined with the rising economic demand to deliver projects ever faster and cheaper typically introduces uncertainty into the construction process. Uncertainty was described by the Oxford dictionary as a "presence of doubt, changeability, and a lack of assurance or reliability."

Research has been conducted on that which affects productivity, along with ensuing variation. Variation is defined as the difference between what was planned and what had occurred (Wambeke et al. 2011). Variation can be further comprehended as a difference between a target state and the actual state over a duration of time.

2.4 Buffers

Constraints are elements of a process or system which limit performance. Variation is one of those elements. Buffers are elements of the process or system which cushion the effect of variation, as well as other constraints. The three conventional buffer types known in manufacturing are capacity, time, and inventory. When the system is project-based, a fourth buffer is added, i.e. financial contingency.

Fig. 6 graphically depicts the figurative effect of variation and buffers on a system. The first image (a) shows a system in balance. When there is variation in a system, and the system is thrown off balance as in the second image (b), the buffers are what bring balance to the system, as in the third image (c).

The more the variation in a system, the bigger the buffers must be to absorb the variation and hence permit the system to function despite its constraints.

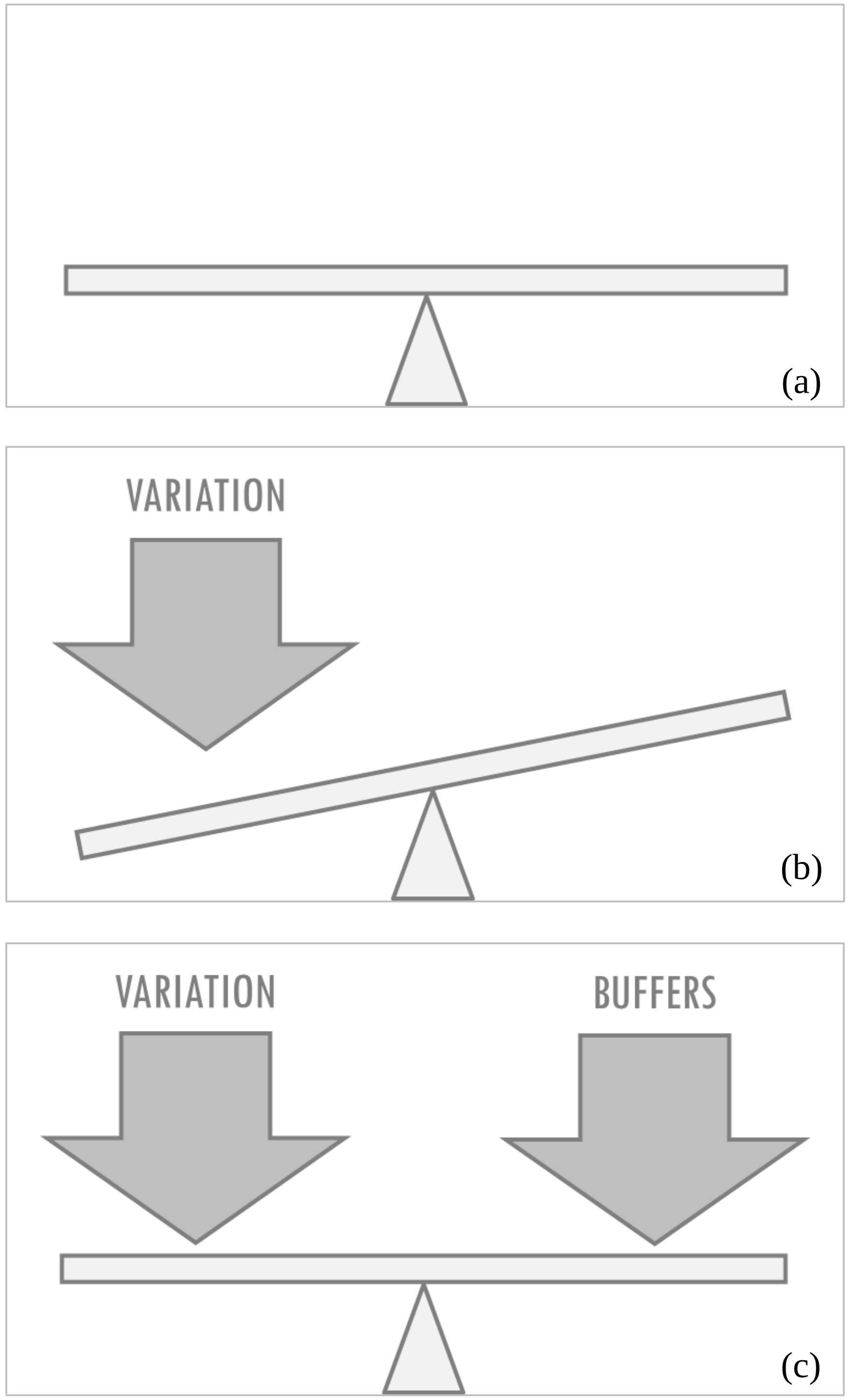

Figure 6: Buffers offsetting variability; stabilizing the process/system.

Table 1: Types of buffers
Adapted from (Russell et al., 2013)

BUFFER TYPE	DESCRIPTION
TIME	Buffer that takes the form of additional time added into a task to protect against uncertainty and to absorb variation; the concept of float is one such use of a time buffer and is seen in the critical path method. Float provides some flexibility in determining start dates for activities, without delaying the project's completion (Alves and Tommelein 2004). A similar example is the use of a deliberate pause or time lag inserted between steps in an operation (Horman and Thomas 2005). Lee et al. (2006) point out that time buffers have been used mainly as a contingency such as adding a percentage of the activity duration at the end of the activity to accommodate uncertain and variable conditions.
INVENTORY	Buffers of physical material stockpiles (Horman and Thomas 2005); large buffers of inventory can lead to congestion, which impedes performance, but material stockpiles that are too low can lead to stopped, slowed, or disrupted production.
CAPACITY	Buffers of additional manpower or equipment provided to an operation beyond the anticipated need for completion (Horman and Thomas 2005); additional capacity gives an operation the ability to rapidly respond to situations caused by uncertainty and variability; too much capacity buffer can also result in inefficient labor and equipment use.
FINANCE	Money in construction project budget reserved to pay for unforeseen design or construction costs (Risner 2010).

Many types of buffers exist, as shown in Fig. 7. The common ones are inventories (material stores), work in progress (one work preceding the other), time lags (lead times), capacity buffers (surplus equipment), etc. It illustrates how different mechanisms, functioning as buffers, provide different levels of responsiveness. Some buffers can be more easily recovered, or converted, than others. How easily they are converted relates to responsiveness.

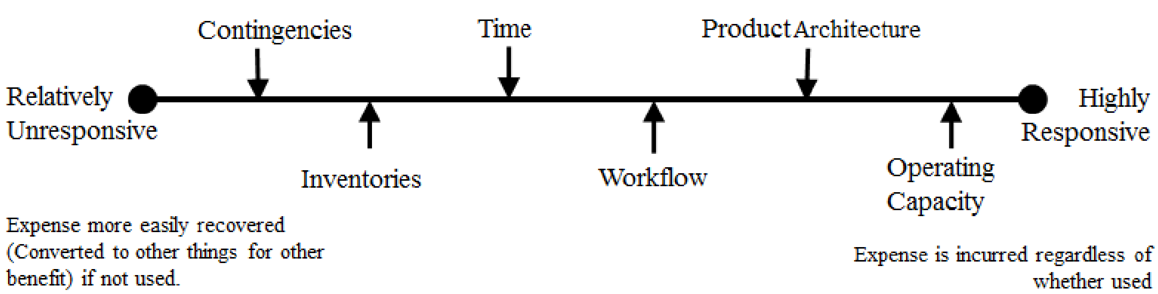

Figure 7: Characterization of the responsiveness of different types of buffers.
Adapted from (Horman, 2000)

When buffers are handled appropriately, they provide not just protection, but also the ability to proficiently counter variable conditions, hence improving the overall performance of the system. When issues arise causing harsh conditions cannot be handled with proper planning, buffers help improve performance. Optimally, buffers provide the ability to counter unstable conditions while retaining performance standards (Horman 2000).

2.4.1 Time as a Buffer

According to Russell et al. (2014), time as a buffer is defined as the additional time added, usually by various construction personnel, to individual task durations while planning, mainly to counteract variation in workflow and general uncertainty. Standard practice for most of the workforce is to form as much buffer into the task duration for which they are responsible. Construction personnel who work with planning of a project planning have a natural tendency to counteract uncertainty in the construction environment by adding buffers to absorb variations in the work plan (Ballard 2000). This practice helps desensitize the project from disturbances. While this seems good, too much of a buffer in terms of time is considered waste i.e. workers waiting for work, and too little of a time buffer can lead to a project experiencing losses due to a schedule being crashed and low productivity i.e. work waiting for workers in case of variability (Russell et al. 2014).

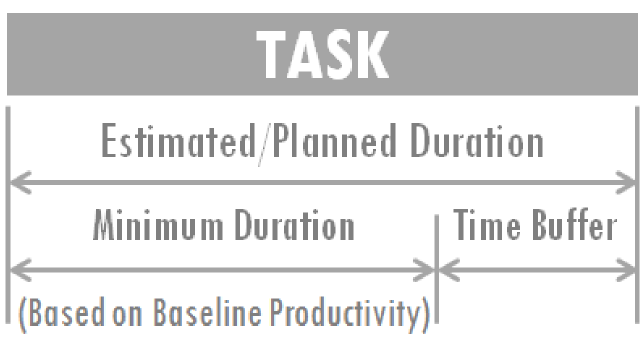

Figure 8: Time buffer in a task
Adapted from (Russell et al., 2013)

The time buffer is the time difference between the duration planned in the schedule and the minimum duration possible, as illustrated in Fig. 8. This buffer when added to tasks usually can tend to follow either *Parkinson's Law* or *Student Syndrome* (Lechler et al. 2005). According to Parkinson's Law, the time buffer is always utilized, as the task will expand to take the entire time given for it. The student syndrome is the tendency to procrastinate the task and starting the task later than originally planned, whiling away the buffer time in the process. Either of these practices can result in time being wasted, and it also impacts productivity.

The most common reasons for the need to include time buffer are complexity of the projects, quality, size and scale, extensive coordination required between all parties involved, changes of work and scope, weather conditions, etc. (Russell et al. 2014).

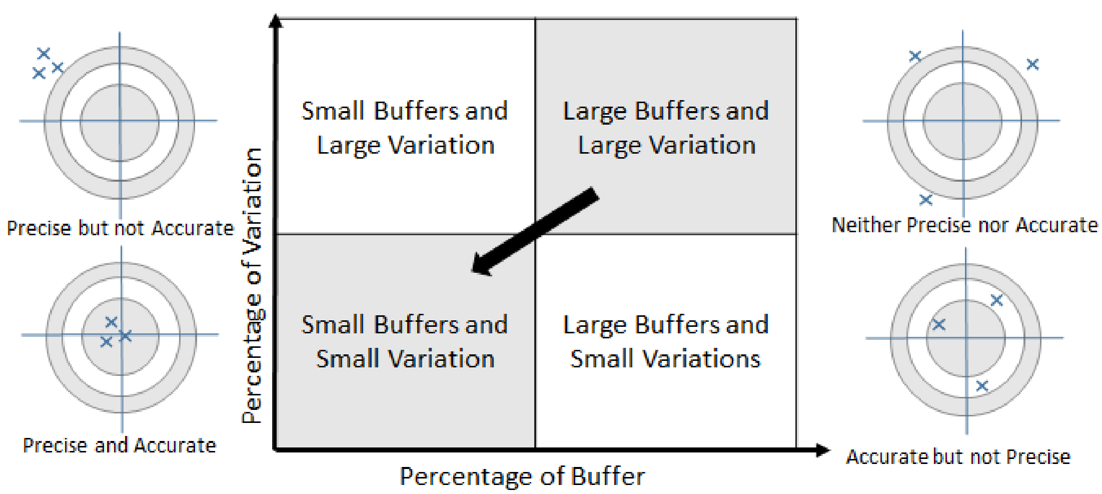

Figure 9: Targeted time buffer and variation for reduction
Adapted from (Russell et al., 2014)

The size of the buffer added may indicate the amount of uncertainty and variation expected (Howell and Ballard 1996). Smaller buffers show that the uncertainty or variation can be mitigated, thereby saving money and time. This permutation of low time buffer and low variation is most often sought. Fig. 9 shows the matrix of comparative buffer and variation sizes and how these relate to precision and accuracy. A low time buffer correlated with high precision, while low variation in tasks relates to high accuracy (Russell et al. 2014). Any activity not falling under the optimum grid in the matrix can be improved. These include activities which are 'neither precise nor accurate', 'precise but not accurate', and 'accurate but not precise'.

Generally, activities must be worked towards moving first left, i.e. lessen the time buffer, and then down, i.e. lessen the variation in the matrix (Russell et al. 2014). Identification of the root causes of the larger variation, and subsequently the larger time buffer, will help in ultimately optimizing the process.

2.5 Lower the River to Reveal the Rocks

In a lean system, problems need to be made visible and opportunities for improvement to be pursued. Taiichi Ohno famously said, "Lower the river to reveal the rocks," as a method to perceive problems that can lead to continuous improvement.

According to Ballard, variation is a constraint, limiting the performance of a system. It is defined as the difference over time between a target condition and an actual condition. Reducing variability can greatly facilitate improvement of a process. Buffers in the project processes, namely time, capacity, inventory, and financial contingency, mitigate the impact of variation and other such constraints (Ballard 2009).

Ohno believed that a current process must be analyzed, and areas which may be streamlined must be studied for prospects to reduce variability (Ohno 1988). For improvement, a buffer should be decreased, stressing the system to the point where opportunities for improvement become visible. It should be noted that the stress being put on the system is a temporary situation, done for the cause of enhancing the process. There are many examples of this theory in the processes of the construction industry.

2.5.1 The Inventory Buffer

Often, setting the appropriate size of material stored on a project site is done instinctively. Having stores of material, or inventory, on a site help mitigate any possible variation in construction. However, reducing inventory is a method to foster Just-In-Time (JIT) material deliveries. The inventory buffer can be reduced by limiting space on a construction site, so that just-in-time deliveries are encouraged. There is reduction in variation, and the management of activities to facilitate such deliveries is increased (Ballard 2009).

2.5.2 The Time Buffer

Time buffer manifests itself in the Critical Path Method of project planning as *float*. Float offers some flexibility in establishing start dates for construction activities, without delaying other activities or the project’s final completion. Reverse phase scheduling offers one example of how to reduce time buffer. It is a collaborative form of planning, where the schedule is planned backward from a target milestone. This enables innovation in the way work is planned, and also creativity to redefine the way a certain work is done, ultimately reducing the duration of tasks (Ballard 2009).

2.5.3 The Capacity Buffer

Capacity buffers consist of elements such as surplus manpower or surplus equipment allocated to a process or project. Setting target productivity helps spur innovation by lowering the buffer of capacity.

General contractors often bear the risk of schedule overruns, while subcontractors bear the risk of capacity loss. This is an adversarial situation, where the general pushes subs to maintain sufficient resources to take advantage of opportunities to accelerate, and the sub resists bringing labor and equipment to site until sufficient work is available (Ballard 2007).

2.5.4 The Money Buffer

Money in a construction project financial budget reserved to finance unforeseen conditions, i.e. contingency is considered a buffer. Target Costing is a method to reduce contingency and lower the final cost of the project or activity to a point that becomes feasible for the owner. Including additional stretch goals helps push innovation, and drive down overall costs (Ballard 2009).

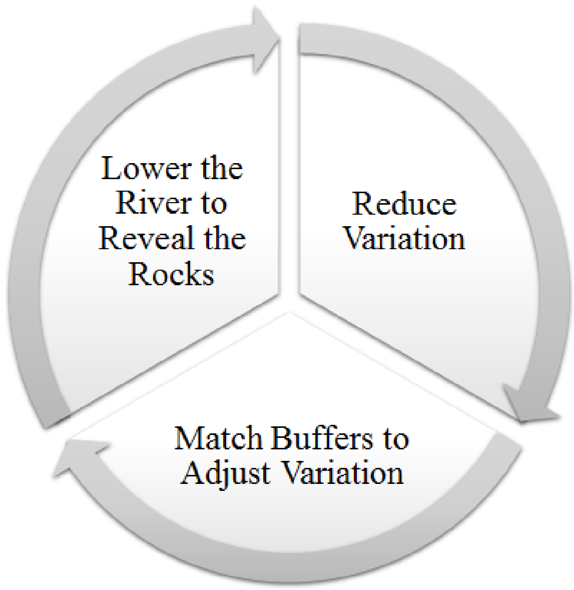

Figure 10: Improvement cycle
Adapted from (Ballard, 2008)

Ultimately, the theory calls to first reduce the buffers, i.e. 'lower the river', to find instances where variation occurs, i.e. 'the rocks'. The next step is to reduce the variation without affecting the quality or the workflow of the process. The buffers are lastly matched to the adjusted variation. This is a cyclical process, as shown in Fig. 10, and continually following that cycle is a step towards continuous improvement.

2.7 Simulations

Knowing something in an abstract form - and understanding that information - are two separate types of knowledge. Learning has been suggested to be the act of making knowledge tangible through action, or an act which is referred to as 'forming connections' between islands of knowledge (Siemens 2004).

With this perception of learning, we can postulate that learning must result from experience, as experience is what helps the process of forming connections. These experiences need to be designed in such a way that the information is reinforced in their mind, and connections are made between different ‘islands of knowledge’.

Simulations, also known as educational games or serious games, are well designed experiences, and have been shown to be a remarkably effective method of communication and the teaching of various concepts. These simulations are a particular form of instructional methods that can enhance learning through active participation. Simulation can be a very useful tool due to their complex interactions between different participants, or also interactions with the processes (Hassan, 2006).

Educational games can be generally grouped into two categories. The first category is where learning objectives are layered on top of the educational material. The effectiveness of these games tends to reduce as the participant’s experience grows. The other category involves the lessons being incorporated into the game. Most of the educational games being designed today can be put in this category (Graven and MacKinnon 2006).

2.7.1 Simulations in Lean Construction

Simulations are especially valuable in the construction industry and construction education. Many simulations have been developed and used by construction educators and professionals alike in the past: examples include: “Constructo”, a simulation by

Halpin and Woodhead in 1973, the “Parade of Trade” game by Tommelein, Riley, and Howell in 1999, and the “Negotiating Game” by Dubziak and Hendrickson in 1988.

Simulations are very popular as a medium of instruction in the Lean community. Whether it be for manufacturing or construction, Lean Principles are conveyed exceptionally well through the playing of ‘lean games’. The principles, despite seeming to be rather simple and straightforward, have great depth to them that are made apparent through experiencing these simulations. The simulations allow users to understand Lean Thinking at an intuitive level, and practice lean tools in a realistic setting (McManus et al. 2007). The participants of the simulations experience what can be called a ‘light bulb moment’, wherein the significance of the application of the principles is comprehended.

Simulations are helpful in not just teaching lessons, but also are useful in studying the effect of particular lean interventions (Rybkowski and Kahler 2014). Learning collaboratively is a method established on the theory that learning is a social pursuit. It involves participants in groups, working in collaboratively as a unit to solve a given problem (Corrigan et al. 2014). Many lean games try to encompass this theory and promote team work.

Training sessions typically begin with a short address to the participants about lean concepts, or a particular concept in general. Followed by this, lean simulation games demonstrating lean concepts are introduced and played. These then lead to discussions on how the concept can be applied, implemented, and also how the processes are affected.

There are several benefits of teaching lean with simulations:

- Simulations demonstrate Lean principles in action;
- Games involve your audience;
- Games are perfect team building activities;
- Simulations are small and flexible;
- Games are confidence builders;
- Simulations offer a low-risk way to first test real processes (Boersema 2011).

3. SIGNIFICANCE OF STUDY

Despite the pursuit of continuous improvement by lean construction practitioners, there is still a lack of awareness of how reduction of buffers can highlight opportunities for improvement. The intended implication and value of this work is that the developed simulation can be used to teach the Ohno philosophy to construction management students in academic settings, as well as to lean construction practitioners and stakeholders who may benefit from the inclusion of lean thinking in their practices.

4. RESEARCH METHOD

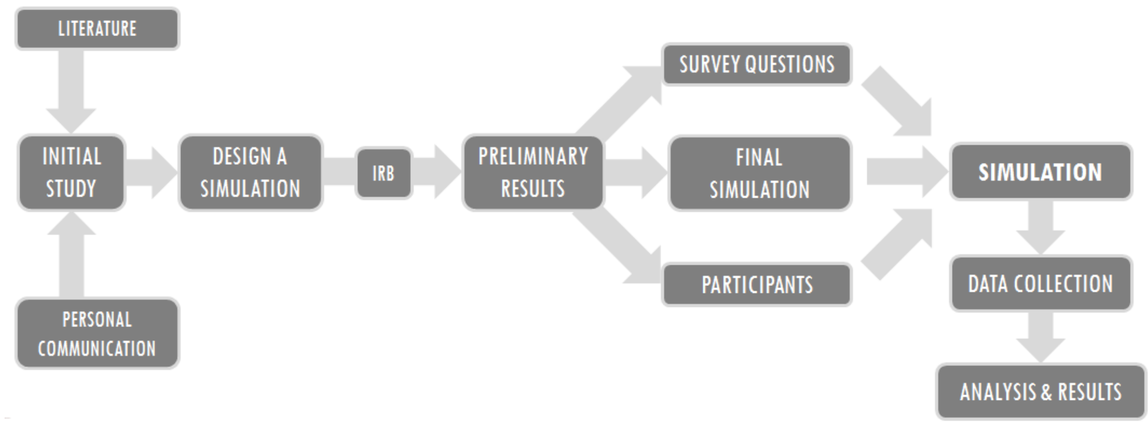

Figure 11: Research methods

Fig. 11 illustrates the research methods associated with the development and testing of the game. The first phase was to understand continuous improvement and related principles, and the second phase was developing and testing of the simulation demonstrating it.

4.1 Understanding Continuous Improvement

To understand "Lower the River to Reveal the Rocks" for the purpose of this research, understanding Continuous Improvement and the use of buffers was essential. Available literature on Wastes in Construction, Kaizen and Continuous Improvement, Uncertainty and Variation, and Buffers was studied.

To develop perspective of the relevance of the concept in the construction industry, experts in the field were contacted. Insight to the principle and its significance with relation to continuous improvement was provided by Zofia Rybkowski (personal communication, Spring ‘15 – Fall ‘15). Literature related to the subject for further reading and study was provided by Gregory Howell (personal communication, Feb 21, 2016). Examples of the principle’s application in actual construction projects and construction-related activities, as well as the impacts of this specific lean intervention were provided by Glenn Ballard (personal communication, July 12, 2015).

4.2 Design a Simulation for “Lower the River to Reveal the Rocks”

Study was done on simulations and their effectiveness. Other simulations were reviewed to understand better how a lean game could be structured. A simulation called the “hacky-sack game” was found (Appendix E). Although it demonstrated a different principle, the simulation was based on the systematic lowering of time in each round. With the knowledge from the study, a simulation for “Lower the River to Reveal the Rocks” was designed. A script and a presentation were designed for conducting the simulation, shown in Appendix C. The simulation explains the basic concept behind the principle. Results and data collected from the simulations testing were later analyzed.

4.2.1 The Simulation: The River-Rock Game

The game was based on a process to be completed by the participants. The idea was to systematically reduce the time buffer. With the system being stressed, the areas of the process which could be improved upon were revealed. The buffers could hence be adjusted, making the process more efficient.

Objective: The game was to be played in *groups of three*. The objective of the game was for each group to successfully ‘construct’ houses using paper to close out a residential neighborhood. The work was spread out over *three rounds* called phases. Each phase required *four houses* to be built, and a *total of twelve*. Once the houses were built and placed on the site, the process was complete.

Procedure & Set-Up: Participants were introduced to the game. The process was explained to them, and instructions for the construction of houses were given using a script. A trial construction of a house was demonstrated at this point. The participants were advised that similar quality of construction as shown in Fig. 14 was required for the process to be considered complete.

Participants were divided into groups of three. Once settled, each group was handed the following material:

1. A site map (with designated spots for the houses in each phase) as shown in Fig. 12;
2. Three different colored sheets of paper in A4 size; and
3. A single stick of glue, as shown in Fig. 13.

This was all the material that was allowed to be used for construction. No additional external material or tools were to be used. Unless directed, there was to be no discussion during the play regarding strategy or prior planning.

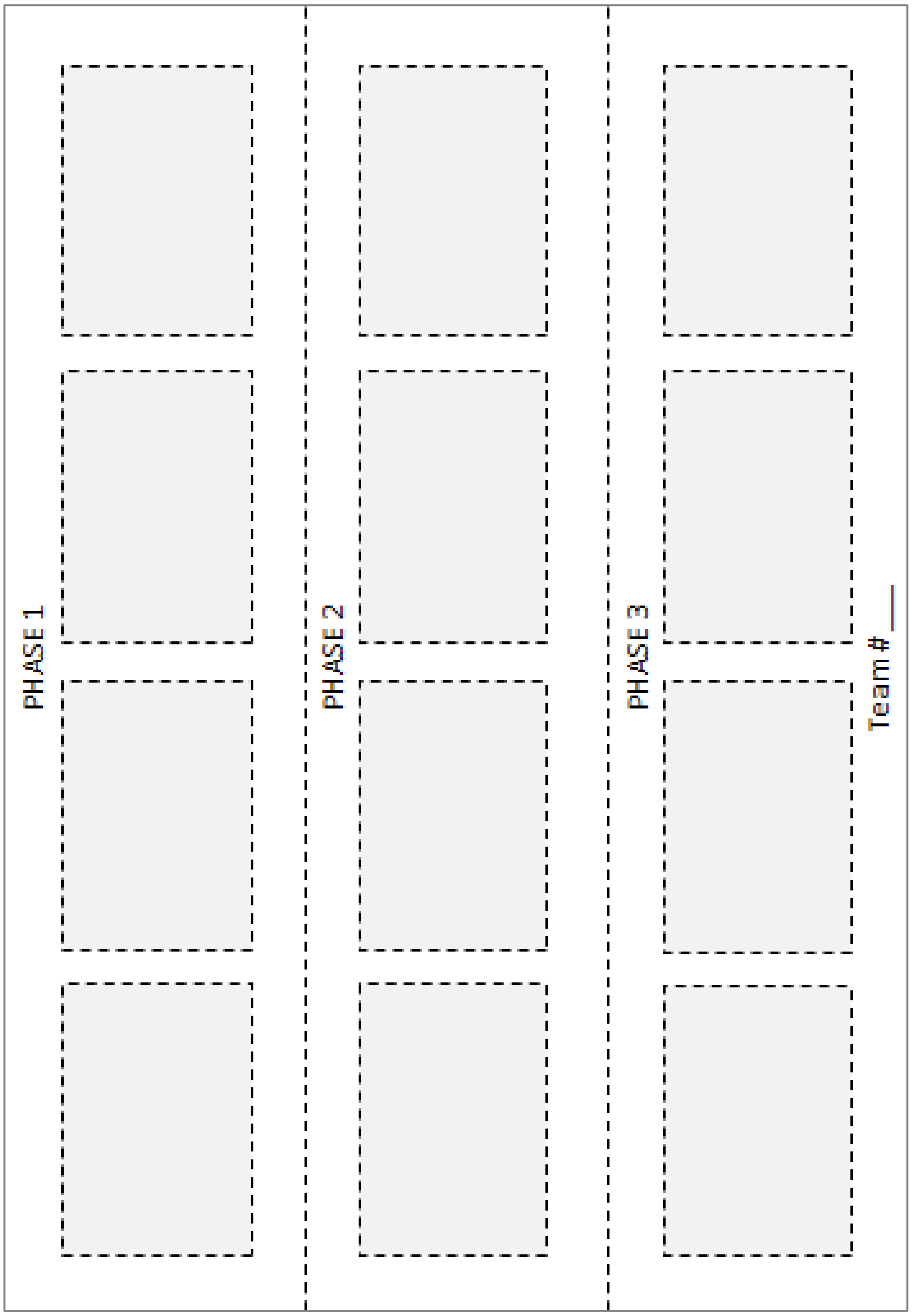

Figure 12: Site map onto which participants placed paper houses.

Figure 13: Material used included 3 sheets of paper and a glue stick

Figure 14: Examples of paper houses

First Round: Phase 1: The time allotted was 10 (ten) minutes. Construction began. Once the allotted time was up, the amount of work completed by each group was recorded. By design, typically, this was to be close to 100%. This marked the end of Phase 1.

Second Round: Phase 2: The time allotted was 3 (three) minutes. Construction began. Once the allotted time was up, the amount of work completed by each group was recorded. By design, typically, this was to be lesser than 100%. This marked the end of Phase 2.

Mid-Game Discussion: The participants were questioned about problems they found in the process of work. With all the 'cushioning' time taken away, what part of construction was it that they found to be problematic. Possible suggestions were asked and noted.

After discussion, a (pre-decided) solution to improve the process was offered: an additional two sticks of glue for each team would be provided. Moreover, planning and strategy making would be encouraged. This formed a foundation for the third round.

Third Round: Phase 3: The time allotted was 3 (three) minutes. Construction began. Once the allotted time was up, the amount of work completed by each group was recorded. By design, typically, this was to be higher than round two, closer to 100%. This marked the end of Phase 3.

End of Game Discussion: The concepts of Continuous Improvement and "Lower the River to Reveal the Rocks" were discussed. Uncertainty, Variation, and Buffers were also discussed.

4.3 Sources of Data

This research aimed to test the effectiveness of the game with different people involved in the construction industry, primarily students. The simulation was played with students of the College of Architecture at Texas A&M University, primarily in the Department of Construction Science, and additionally in the Department of Architecture. Professors of the College were approached, and with their consent, their students were asked to volunteer in the testing of the simulation. In total, 114 students participated in the research.

4.4 Assumptions

It was assumed that the simulation represents a process, and that the knowledge obtained about ‘lowering the river to reveal the rocks’ is transferable to construction processes.

Every philosophy has both commendation and criticism against it. For the purpose of this research, this philosophy of reducing the buffers to find areas for improvement was considered to hold true.

4.5 Delimitations and Limitations

There are many philosophies, and many techniques which are said to lead to enhancement of the process, and continuous improvement. This research only dealt with one technique, recommended by Taiichi Ohno, which is to “lower the river to reveal the rocks”.

The simulation developed illustrates only the *stress* on the system caused by the systematic reduction of buffers, and how it helps identify where improvements to the system are possible.

There are four different kinds of buffers that exist in processes, namely time, capacity, inventory, and money. The simulation from this research only demonstrates the effect of the reduction of time.

The simulation did not take cultural and other differences of participants into account for the purpose of this research. The active learning curve of the participants in subsequent rounds of the simulation was not taken into consideration.

5. RESULTS

5.1 Participants of the Study

Participants of the study were all from the College of Architecture at Texas A&M University. In total, 5 sessions were conducted, and a total of 114 students participated in the research. 84 were from the department of Construction Science, and 30 were from the department of Architecture.

5.2 Pre-Game Metrics

Participants were asked if they had any prior knowledge of Lean Methodology and Simulation Games via a pre-game questionnaire (Appendix B). These responses were recorded in Table 2 and Table 3.

Table 2: Awareness of Lean Methodology

Aware	Not Aware
65	49

Table 3: Played Simulation Games before

Yes	No
62	52

There was a slight majority in the number of participants who were aware of lean methodology beforehand compared to those who did not, and there was no significant difference between the participants who had played a simulation game before and those who did not.

Of all the participants, only a few participants could correctly describe the metaphor of “lowering the river to reveal the rocks” prior to playing the game. Many were in the right direction, but not quite close. It was noted that participants who had responded that they knew of lean, and had played lean games before were better at guessing the meaning of the metaphor.

After the game was complete, many more could describe the phrase, and had answered in the right direction of thought. Another point noted was that at the end of the game, many of the participants had started linking the metaphor directly with ‘time’. A majority mentioned ‘finding problems beneath the surface’ in their answers.

5.3 Data Collection and Analysis

Photographs taken of participants and the game during various stages of play are shown in Appendix A. Data was collected at different stages with handouts shown in Appendix B and subsequently analyzed.

Box and whisker plots were used to depict the data, and were useful for easier comparison between all three phases. The means were shown to illustrate the average of all the participants, and the medians were shown to illustrate the most common value of all the participants. The mean and median together provide a more comprehensive representation of the collected data.

5.3.1 Percentage of Work Completed

Data was collected at the end of each round of play. A system was devised to calculate quickly the approximate percentage of completion of each round. The data recorded was depicted in Fig. 15 and Fig. 16. It was found that at the end of the first round, all teams had managed to finish 100% of the work. At the end of the second round however, with the reduction in time, these percentages dropped, with the average being close to 72%. At the end of the third round, with some solutions to problems faced in the game being implemented, the percentages rose, and the average was close to 95%.

From observation of Fig. 15, the amount of work completed in the third round was higher than that in the second round. Both the rounds were comparable in all terms, including time, except for the simple solutions of additional resources and strategy discussion being included in the third round.

It can also be observed that while the second round showed some variation in results, the first and third round showed results less so in comparison.

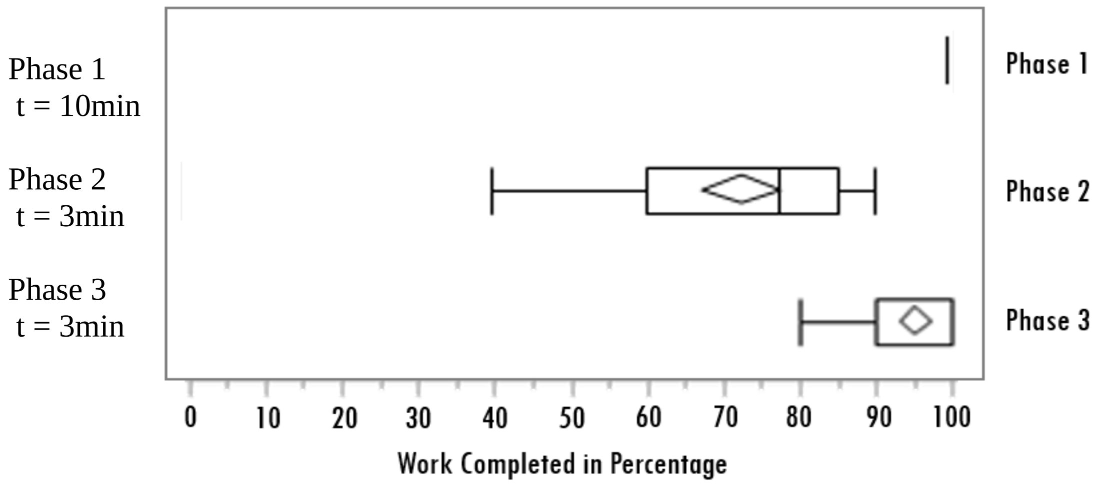

Figure 15: Box and whisker plot – work completed

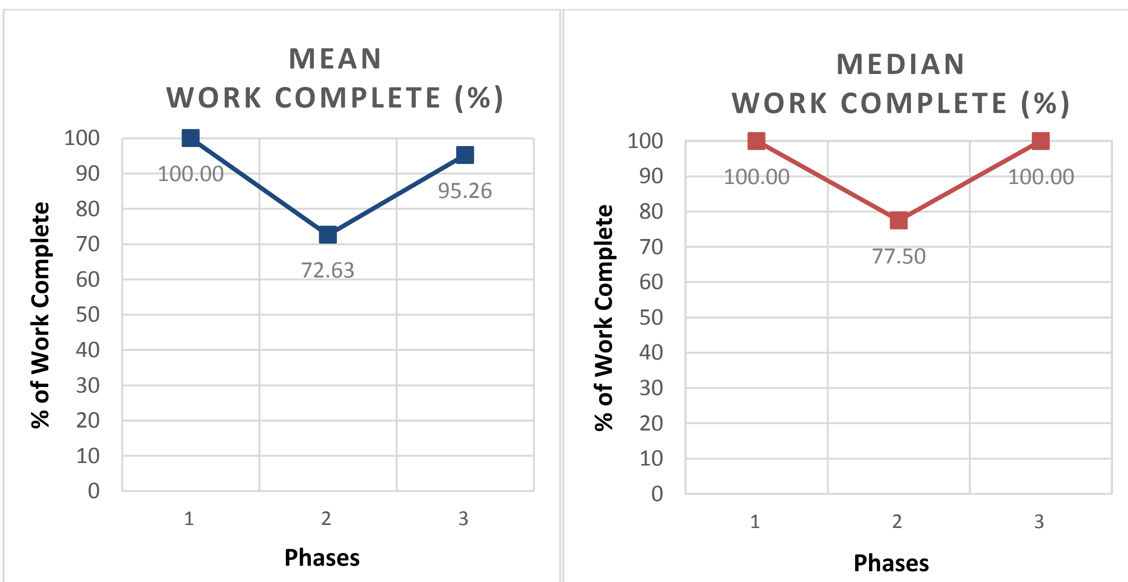

Figure 16: Mean and median plots – work completed

5.2.2 Stress Level Reported

Stress Levels Experienced was recorded on a Rating Card by each individual participant (Appendix B). The data recorded was depicted in Fig. 17 and Fig. 18. The participants reported their stress levels at the end of the first round with great variation. The range of results is from 1 to 9, although the majority of results are between 2 and 6. This round, however, should be considered as a base off of which the other two rounds are reported by the participants.

The trend in the second round shows that there is an increase in the stress level, as the majority of the participants have indicated stress levels between 6 and 9. This, of course, was the intention of the round, and the data shows that the system was indeed, stressed.

The third round, similar to the second in terms of time duration, but different due to additional resources being provided, shows a decrease in stress levels. The majority of the participants reported a stress level between 3 and 6. This shows that with the solutions provided for the problem found in the process, i.e. the lack of resources, was reducing the stress in an already stressed system.

What is also to be observed, with way of the mean and median plots in Fig. 18, is that the stress level reported in the third round is relatively close to the stress levels reported in the first round with excessive time buffer.

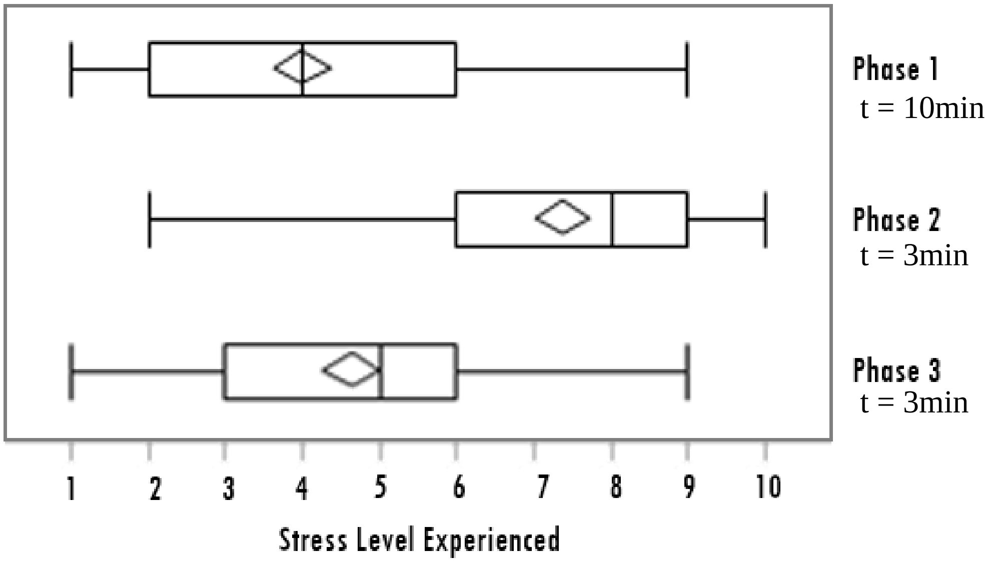

Figure 17: Box and whisker plot – stress level experienced

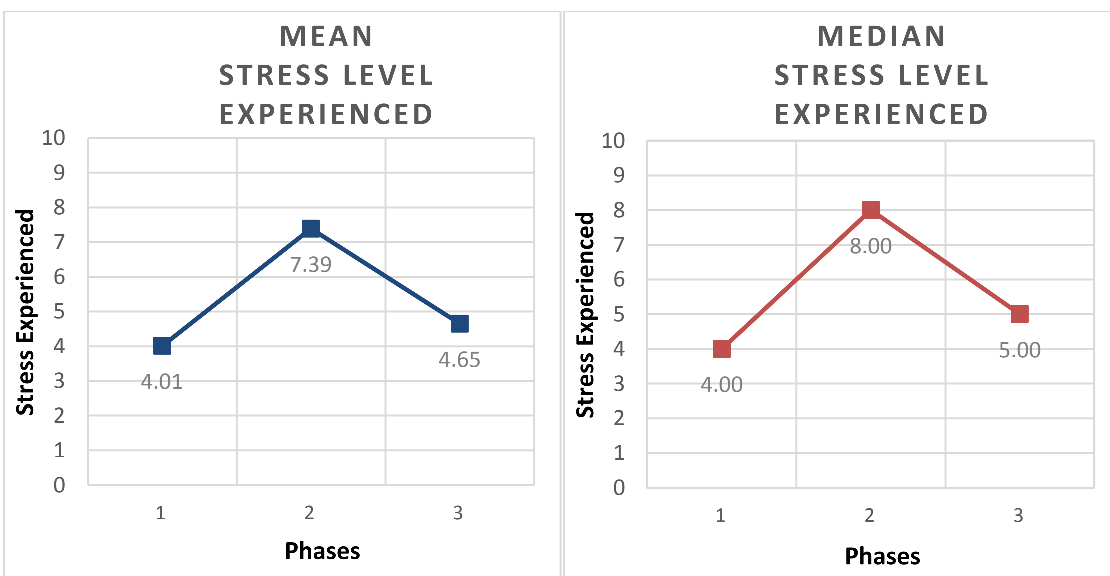

Figure 18: Mean and median plots – stress levels experienced

5.2.3 Perceived Efficiency Level Reported

Perceived Efficiency Level was recorded on a Rating Card by each individual participant (Appendix B). The data recorded was depicted in Fig. 19 and Fig. 20. The participants reported their teams' perceived efficiency levels at the end of the first round with lesser variation than was expected. The range of results is from 3 to 10, although the majority lies between 6 and 8. Again, this round should be considered as a base off of which the other two rounds are reported by participants.

The second round's reported perceived efficiency has perhaps the widest range in all the data, yet the majority of the participants reported efficiency between 4 and 7. By looking at the mean and median for the round, we can see that the perceived efficiency on a whole has reduced. The only difference in the first and second round is the amount of time allotted and it is clear that the reduction of the time buffer has made it clear to the participants that their efficiency was lacking, and could be improved.

With this in mind, the participants raised questions on the possible solutions to improve this efficiency. The third round, implementing the additional resources as a solution, had participants report results of higher perceived efficiency. The majority of the data lies between 7 and 10.

It must also be noted that the mean and median of perceived efficiency for the third round are not just higher than the second round, but it is higher than the first round, with excessive buffers, as well.

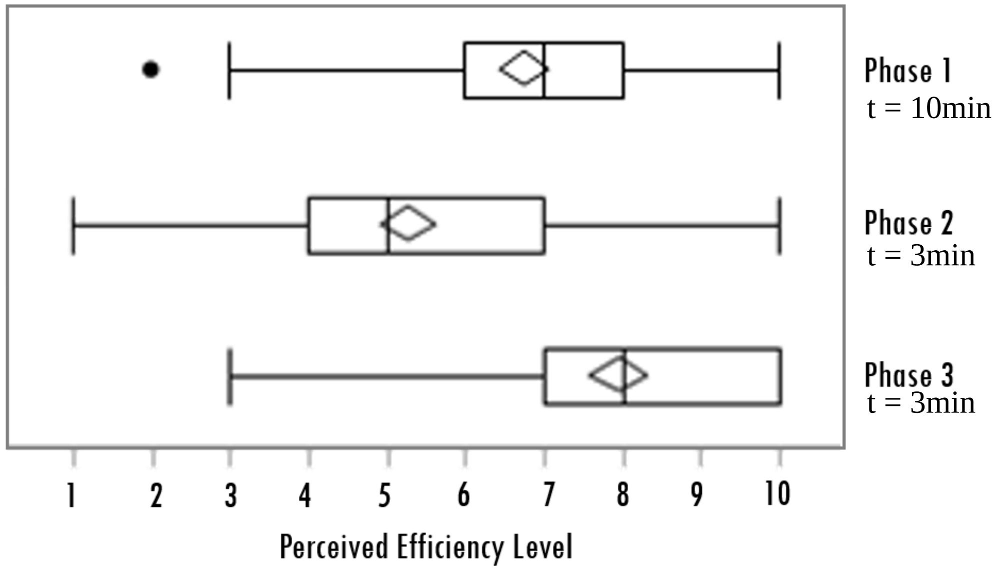

Figure 19: Box and whisker plot – perceived efficiency level

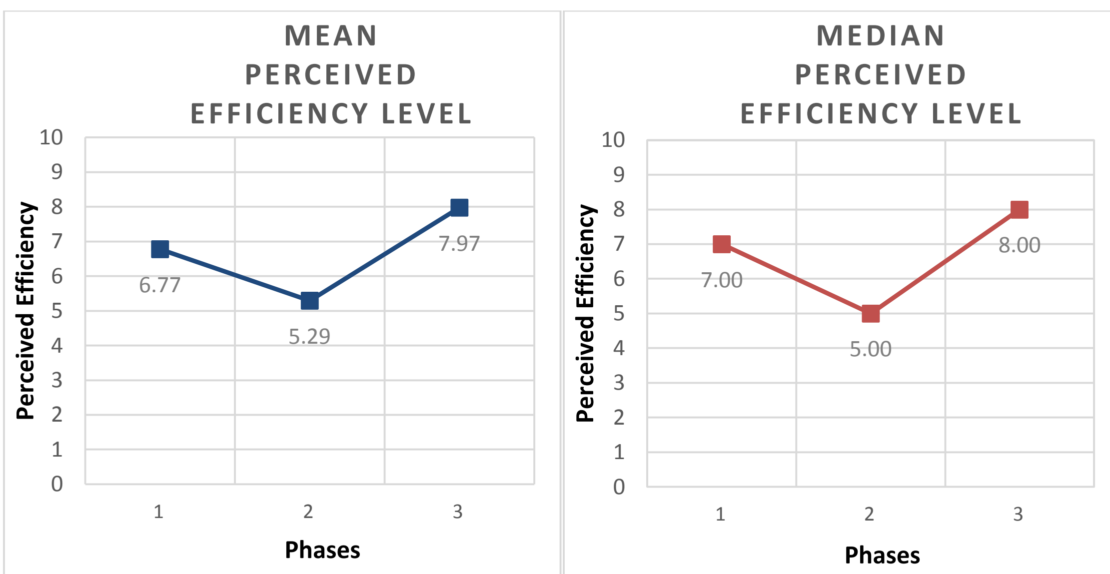

Figure 20: Mean and median plots – perceived efficiency level

5.2.4 Effectiveness of the Simulation

The participants were asked questions related to the effectiveness of the simulation via a post-game questionnaire, shown in Appendix B. Fig. 21 and Fig. 22 illustrate the responses of the participants on a scale of 1 – 6.

a. How well did the simulation demonstrate the process of achieving improvement (as a means for Continuous Improvement)?

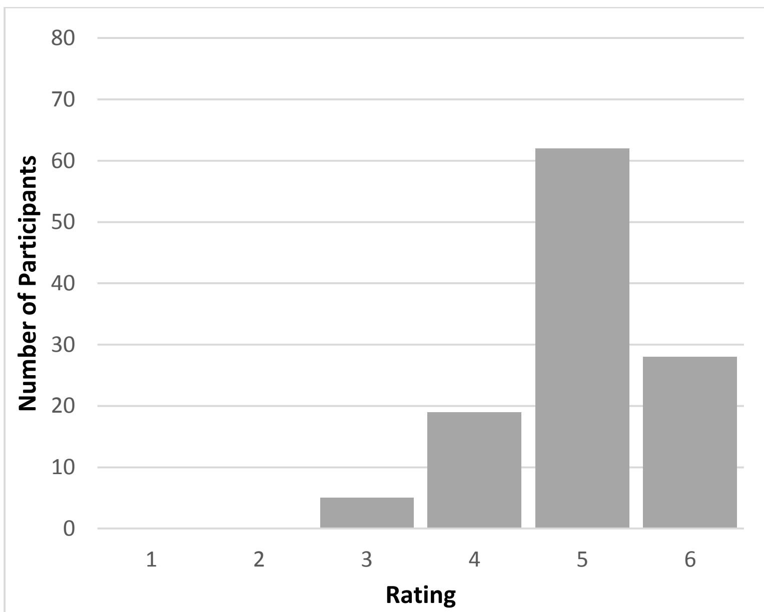

Figure 21: Histogram – effectiveness (a)

b. How helpful do you feel the lowering of time was in finding scope for improvement?

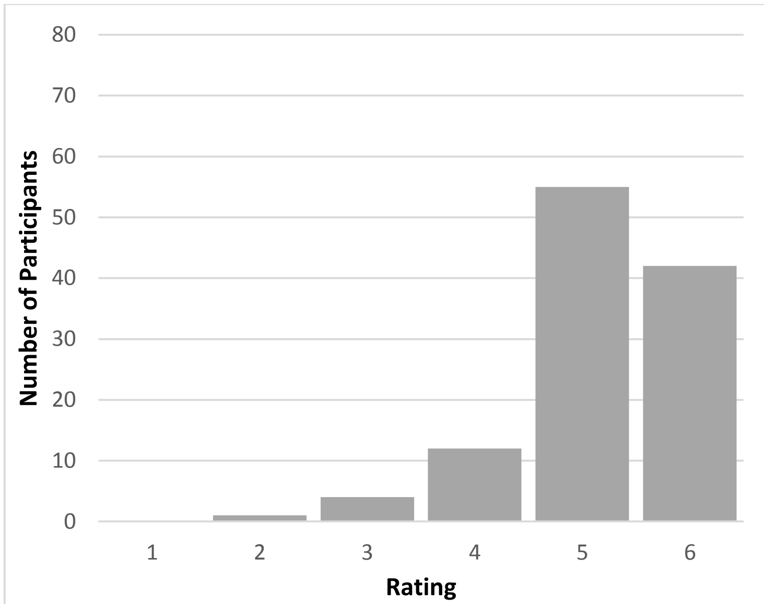

Figure 22: Histogram – effectiveness (b)

In case of both the questions, the majority of results are reported to be 5 and 6 on a scale of 1 to 6. The simulation appears to be effective in demonstrating the process of achieving improvement through the technique of lowering the buffer to reveal problems and variability. It also appears to be effective in demonstrating that the reduction of buffers is a method to bring underlying problems to the surface.

6. DISCUSSION

The objective of this research was to develop and test a new lean simulation, illustrating a concept that had not previously been taught by means of a simulation. The process of development and testing was systematic and methodical, and the simulation took the form several iterations until finalized. During the course of this research, it was observed that minor tweaks in how the game was presented drastically changed the perceptions and understanding of the participants. For final data collection, tested best practices in terms of presentation, material and handout delivery, timing, etc. were used.

Results from this research show correlations between perceived stress levels in each round, as well as perceived levels of efficiency. These correlations need to be investigated further, to determine a relationship between the two factors, should it exist. The amount of work completed during the rounds could also play an informative role.

This simulation was tested on construction science students, ranging from freshman undergraduates to second year graduate students. A surprising trend was discovered. The younger students seemed more receptive to how simulations are intended to be played-- that the boundaries and rules are established to illustrate a concept. The more advanced the classes, the students generally seemed more interested in “beating” the game and bending the rules. This may offer a point of future study, to see how participants from different years in school or levels of experience in the industry receive simulations and other training.

During the development and testing of this game, something that was noted was that on many occasions there was an observed tension between members of the teams. This ranged from minor misunderstandings, mitigated in the spirit of the game, to accusations for failure. This tendency was usually observed during and after the second round of play, i.e. after the system had been stressed. The human and behavioral aspect was not studied within the scope of this research, but is worthy of future exploration.

This research was designed to serve as a starting point for discussions with participants about the applicability of stressing systems in order to reveal ways to improve a delivery process. The simulation also offers the potential to serve as a base onto which additional stressors can be subsequently added and tested. Although the simulation in its current state tests only the buffer of time, capacity, money, and inventory buffers can be introduced and variations of the game can be developed.

7. CONCLUSION

Continuous improvement is an endeavor to enhance the productivity of processes. Productivity is vital to maximize that which can be achieved with limited resources, and even if it is not instantly visible, there is always scope for improvement. Taiichi Ohno's philosophy to "lower the river to reveal the rocks" is a metaphor to systematically and intentionally stress the system by reducing the buffers of time, capacity, inventory, and money, which often exist to conceal variability. The reduction of this variability leads to improvement of the process.

This research introduces and tests the effectiveness of a new lean simulation, demonstrating this concept by utilizing time as a buffer. The developed simulation can be used to teach the Ohno philosophy to construction management students in academic settings, as well as to lean construction practitioners and stakeholders who may benefit from the inclusion of lean thinking in their practices.

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APPENDIX A

Pictures taken during playing of the simulation

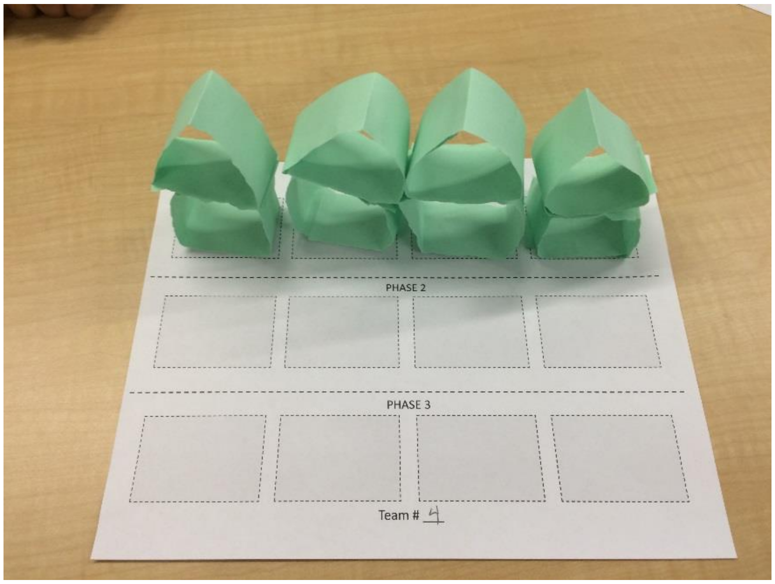


Figure 23: End of Phase 1

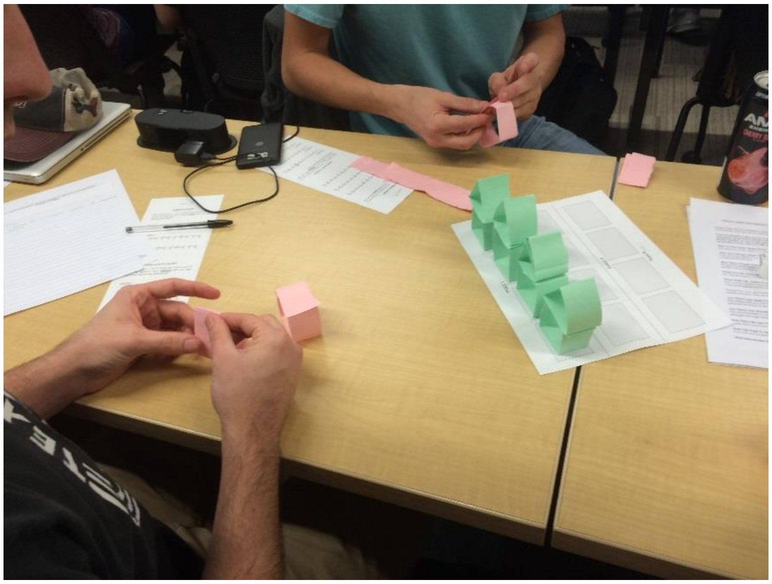


Figure 24: Participants starting work on Phase 2

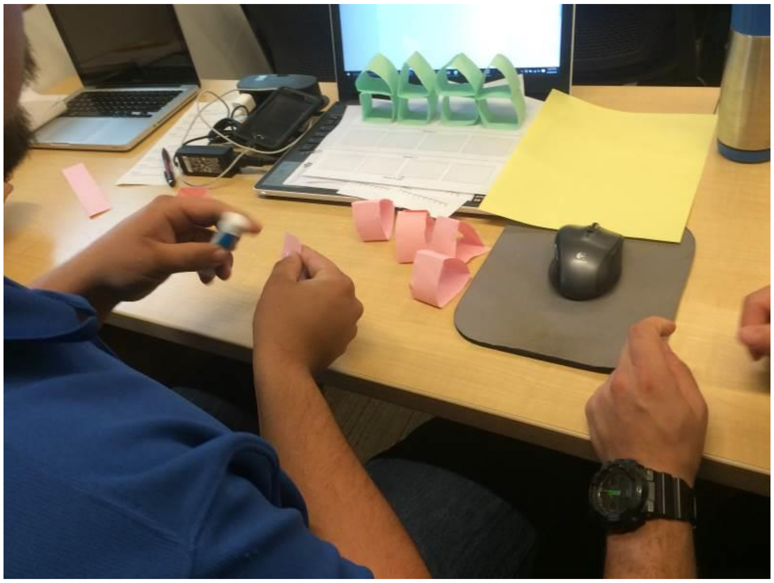


Figure 25: Participants working on Phase 2

Figure 26: Completing Phase 2

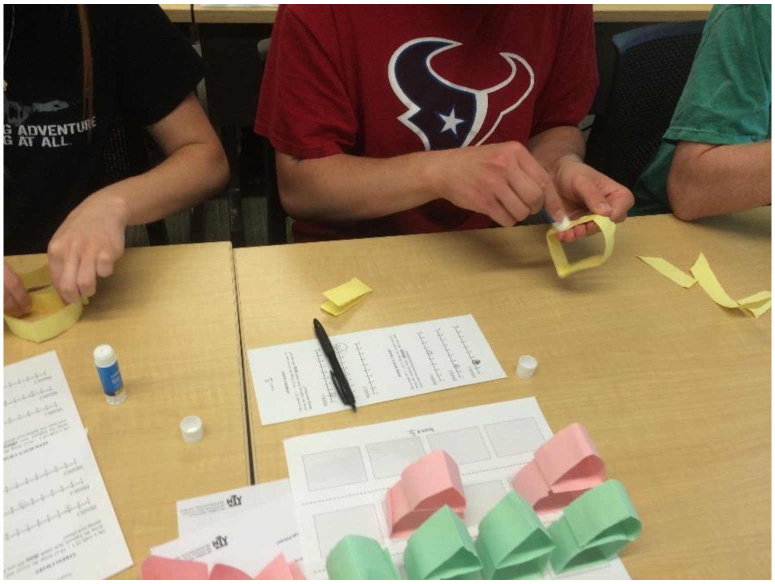


Figure 27: Participants working on Phase 3

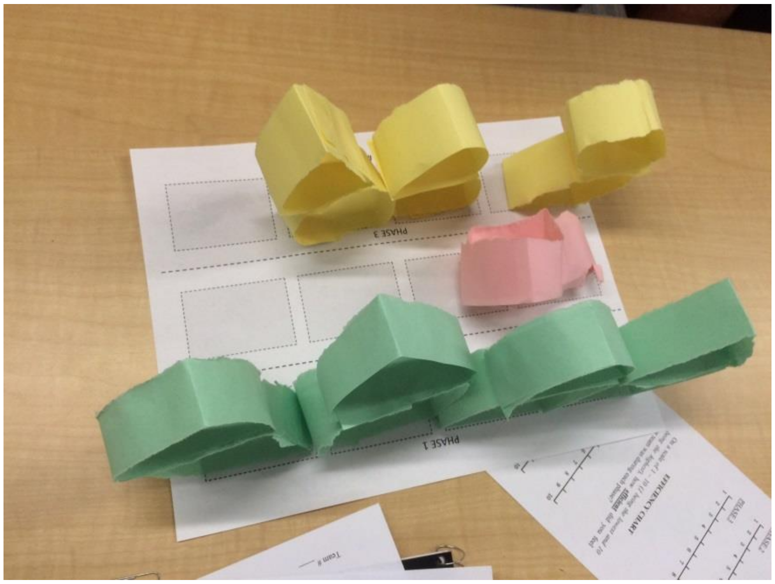


Figure 28: Participants completing Phase 3

Figure 29: At the end of the simulation - 1

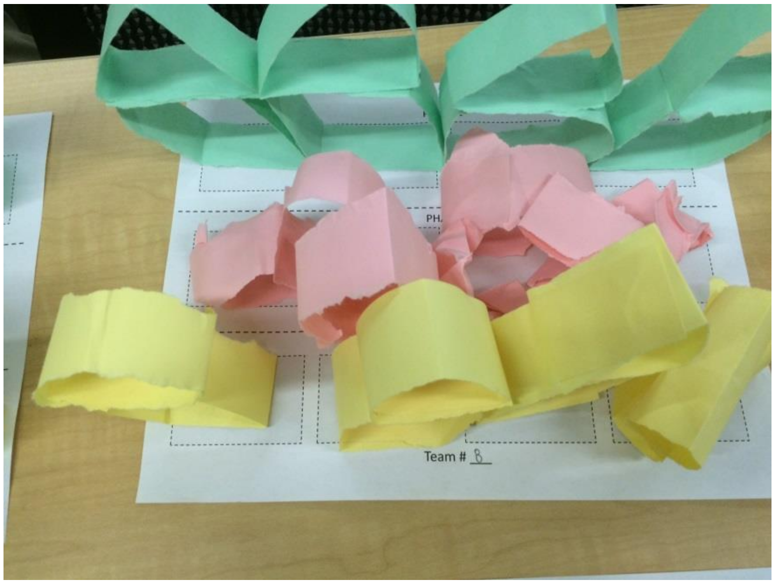


Figure 30: At the end of the simulation - 2

APPENDIX B

Handouts to Participants used for data collection

PRE GAME QUESTIONNAIRE

1) Are you aware of Lean Methodology? ☐ Yes ☐ No

2) Have you ever played a simulation game before? ☐ Yes ☐ No

3) If yes, please mention the games and the concept it teaches:

4) What do you think the metaphor, "Lower the River to Reveal the Rocks" means?

   Please be specific:

Team # __

POST GAME QUESTIONNAIRE

1) What do you think the metaphor, "Lower the River to Reveal the Rocks" means? Please be specific:

2) How do you think this principle can help in the field of Construction?

3) Do you think the concept of the principle was clear from the game?

☐ Yes ☐ No

On a scale of 1 to 6 (*1 being the lowest and 6 being the highest*), please rate:

4) How well do you feel the simulation demonstrated the achieving of improvement in a process (as a means for Continuous Improvement)?

☐1 ☐2 ☐3 ☐4 ☐5 ☐6

5) How helpful do you feel the lowering of time was in finding scope for improvement?

☐1 ☐2 ☐3 ☐4 ☐5 ☐6

Team # __

RATING CARD: Stress Experienced and Perceived Efficiency

STRESS CHART

On a scale of 1 – 10 (*1 being the lowest and 10 being the highest*), how much **stress** did you feel during each phase?

PHASE 1

1 2 3 4 5 6 7 8 9 10

PHASE 2

1 2 3 4 5 6 7 8 9 10

PHASE 3

1 2 3 4 5 6 7 8 9 10

EFFICIENCY CHART

On a scale of 1 – 10 (*1 being the lowest and 10 being the highest*), how **efficient** did you feel your team was during each phase?

PHASE 1

1 2 3 4 5 6 7 8 9 10

PHASE 2

1 2 3 4 5 6 7 8 9 10

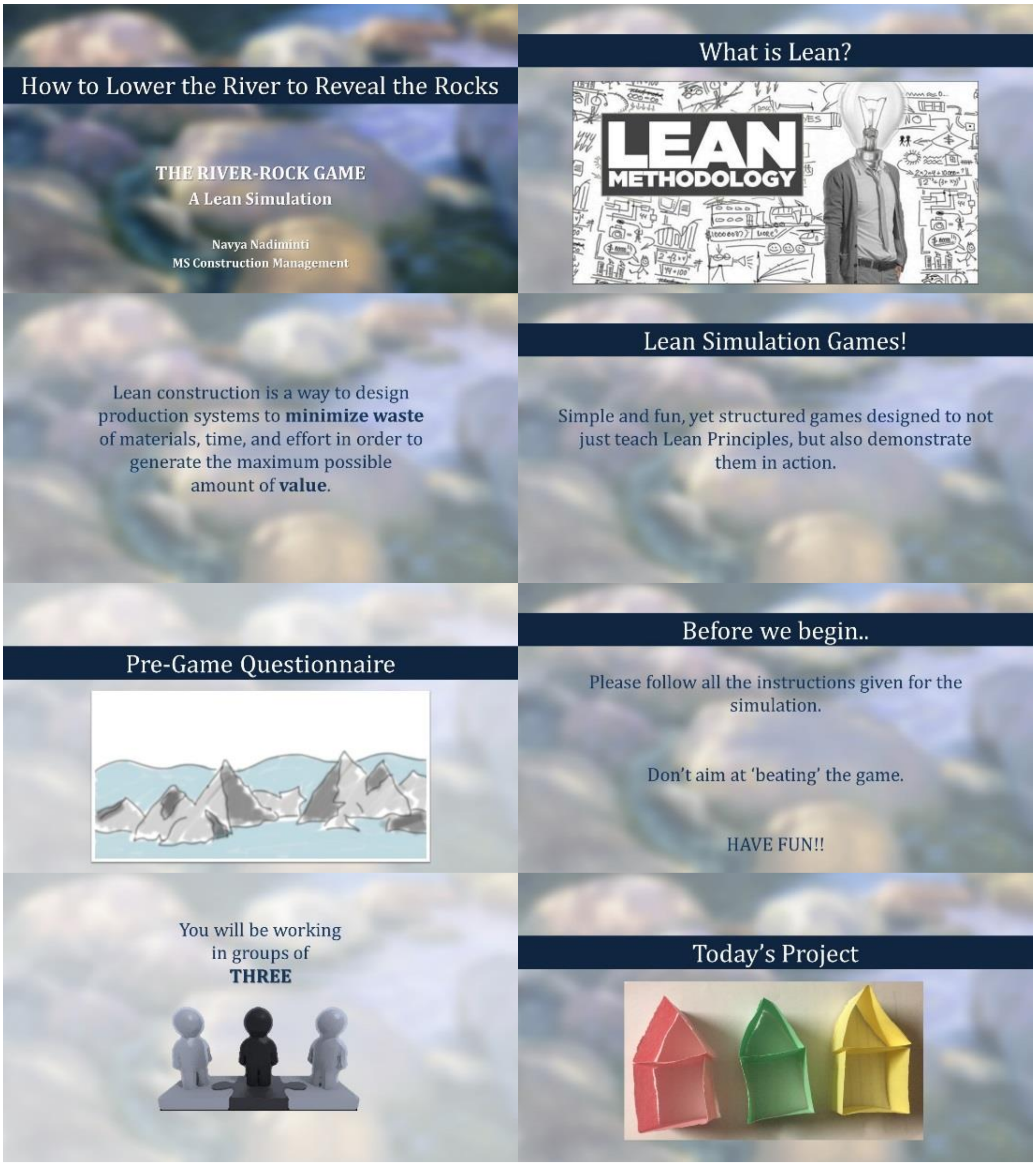
PHASE 3

1 2 3 4 5 6 7 8 9 10

Team # ___

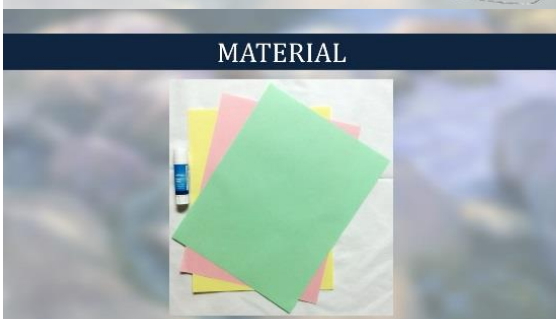
APPENDIX C

Presentation used to conduct the simulation



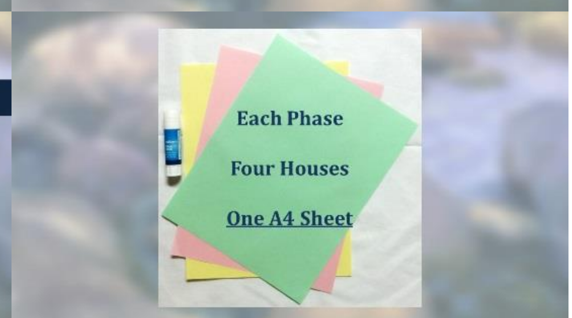

The objective for each group is to successfully close out a residential neighborhood.

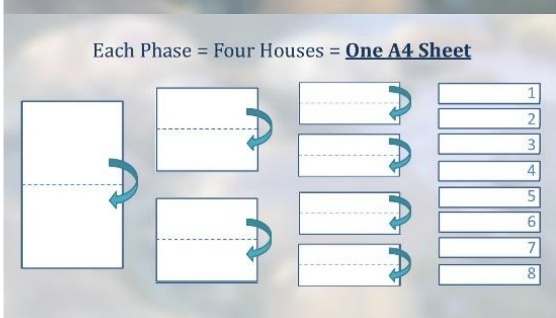

The work will be spread out evenly over THREE phases.
Each phase will require FOUR houses.

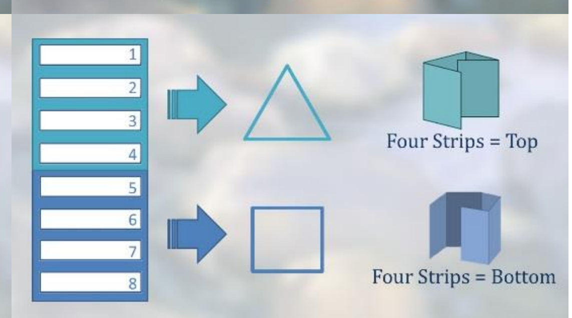

MATERIAL

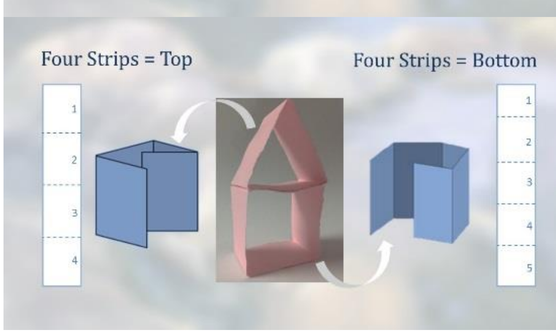

RULES
No additional material to be used.
No strategizing or planning unless instructed to do so.
Houses should be of minimum quality.

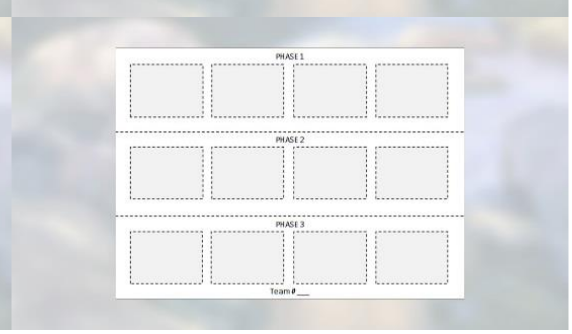

HOW DO WE BUILD?

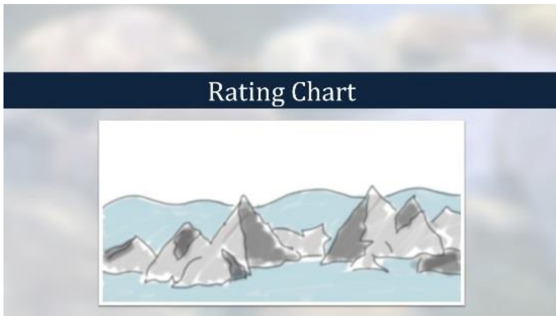

Each Phase
Four Houses
One A4 Sheet

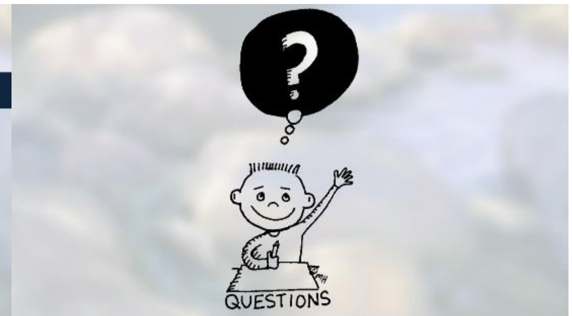

Each Phase = Four Houses = One A4 Sheet
1
2
3
4
5
6
7
8


1
2
3
4
5
6
7
8
Four Strips = Top
Four Strips = Bottom

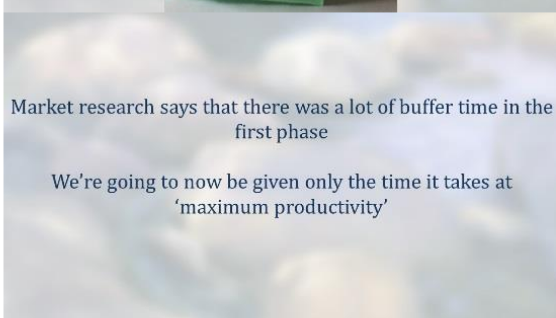

Four Strips = Top
Four Strips = Bottom
1
2
3
4
1
2
3
4
5

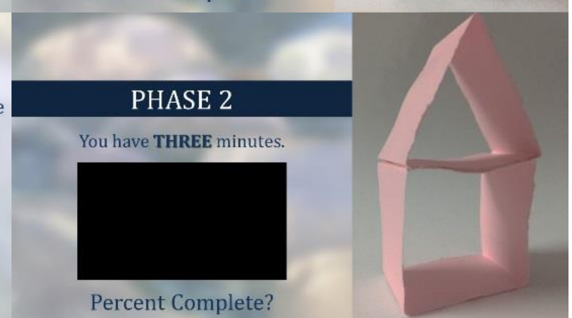

PHASE 1
PHASE 2
PHASE 3


Rating Chart


QUESTIONS


PHASE 1
You have **TEN** minutes.
Percent Complete?


Market research says that there was a lot of buffer time in the first phase
We're going to now be given only the time it takes at 'maximum productivity'


PHASE 2
You have **THREE** minutes.
Percent Complete?


Problems in the PROCESS?


MORE GLUE!
Strategize


We're not getting our time back.
We've solved some problems, though. Lets see if it helps.


PHASE 3
You have **THREE** minutes.
Percent Complete?

Problems in the PROCESS?

Strategy

Coordination

Resources

Technology

Identified the problems.

Now what?

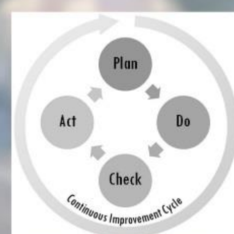
Improving the Process

Removing the problems discovered helps improve the process.

Post-Game Questionnaire

Continuous Improvement

An approach to systematically seek to achieve changes in processes in order to improve efficiency and quality.



Plan: Prospects are identified and a change is planned.

Do: Small scale implementation is done to test and study the change.

Check: The tests are analyzed and reviewed.

Act: Action must be taken to either disregard or implement change.

A take on continuous improvement:

"Lower the River to Reveal the Rocks".

This means that in a process or system, problems should be made visible, by intentionally and methodically **lowering the buffers** in the system to **uncover opportunities for improvement.**

Variation & Buffers

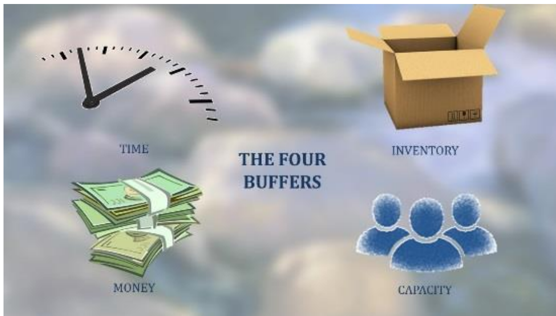
Variation is the difference between a target state and the actual state over a duration of time.

Buffers are elements of the process or system which cushion the effect of variation, as well as other constraints.

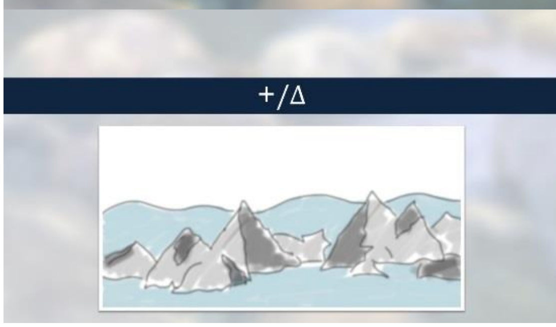
The more the variation in a system, the bigger the buffers must be to absorb the variation and hence permit the system despite its constraints.

The **rocks** are the problems, or scope for improvement. This is where the variability lies.

The **river** is the buffer which cushions the effects of the rocks. It absorbs variability.


TIME
THE FOUR BUFFERS
INVENTORY
MONEY
CAPACITY


Examples..
Communication
Finances
Just-in-Time delivery
Reverse Phase Scheduling


+/Δ


Thank You

APPENDIX D

Raw Data Collected

1. Percentage of Work Completed (on a scale of 0% to 100%):

	Team	Phase 1 % Work Completed	Phase 2 % Work Completed	Phase 3 % Work Completed
Session I	#1	100	60	85
	#2	100	85	100
	#3	100	75	100
	#4	100	70	90
Session II	#5	100	85	100
	#6	100	60	90
	#7	100	80	100
	#8	100	50	100
	#9	100	70	85
	#10	100	65	90
Session III	#11	100	85	100
	#12	100	85	100
	#13	100	70	95
	#14	100	85	100
	#15	100	65	90
	#16	100	70	95
	#17	100	50	85
	#18	100	90	100
	#19	100	80	100
	#20	100	90	100
Session IV	#21	100	45	90
	#22	100	80	100
	#23	100	90	100
	#24	100	50	85
	#25	100	85	100
	#26	100	55	90
	#27	100	90	100
	#28	100	85	100
	#29	100	40	85
	#30	100	85	100
Session V	#31	100	75	100
	#32	100	50	90
	#33	100	80	100
	#34	100	90	100
	#35	100	60	95
	#36	100	85	100
	#37	100	90	100
	#38	100	55	80

2. Stress Levels reported (on a scale of 1 – 10):

	Participant	Phase 1	Phase 2	Phase 3		Participant	Phase 1	Phase 2	Phase 3
Session I	# 1	4	6	3		# 58	2	8	3
	# 2	4	5	2		# 59	2	6	4
	# 3	3	4	4		# 60	3	5	3
	# 4	5	5	4	Session IV	# 61	3	7	6
	# 5	4	7	9		# 62	2	10	9
	# 6	6	9	4		# 63	3	7	6
	# 7	7	10	5		# 64	4	9	6
	# 8	7	9	6		# 65	4	9	6
	# 9	7	9	5		# 66	4	9	6
	# 10	2	8	5		# 67	7	8	5
	# 11	5	9	6		# 68	5	8	6
	# 12	1	4	1		# 69	8	9	6
Session II	# 13	8	7	5		# 70	4	6	5
	# 14	7	9	4		# 71	6	8	4
	# 15	8	9	6		# 72	7	9	2
	# 16	2	3	1		# 73	2	5	2
	# 17	1	2	1		# 74	2	8	6
	# 18	1	3	1		# 75	4	8	5
	# 19	5	9	3		# 76	2	8	7
	# 20	6	5	4		# 77	2	9	6
	# 21	3	4	2		# 78	1	7	3
	# 22	4	8	2		# 79	9	10	1
	# 23	5	5	3		# 80	4	8	2
	# 24	5	8	7		# 81	4	10	7
	# 25	6	7	5		# 82	3	7	4
	# 26	2	7	5		# 83	3	7	2
	# 27	8	10	7		# 84	3	7	4
	# 28	7	9	5		# 85	6	10	9
	# 29	5	8	6		# 86	7	10	8
	# 30	7	10	6		# 87	6	10	9
Session III	# 31	3	5	1		# 88	3	6	4
	# 32	2	8	3		# 89	4	6	5
	# 33	2	5	3		# 90	4	7	5
	# 34	6	10	8	Session V	# 91	2	9	6
	# 35	5	10	6		# 92	3	7	6
	# 36	7	10	5		# 93	3	10	7
	# 37	7	8	6		# 94	4	6	4
	# 38	1	5	3		# 95	6	8	5
	# 39	2	5	4		# 96	5	9	6
	# 40	5	8	6		# 97	4	6	5
	# 41	5	7	6		# 98	4	7	6
	# 42	3	6	4		# 99	4	8	6
	# 43	6	9	8		# 100	3	6	5
	# 44	7	9	7		# 101	2	8	6
	# 45	4	8	6		# 102	2	6	4
	# 46	2	6	3		# 103	1	5	1
	# 47	2	7	4		# 104	1	10	4
	# 48	2	6	3		# 105	2	8	3
	# 49	2	9	4		# 106	2	5	3
	# 50	3	8	5		# 107	1	4	2
	# 51	3	9	4		# 108	2	6	3
	# 52	6	8	6		# 109	6	9	8
	# 53	4	7	5		# 110	2	9	7
	# 54	6	8	5		# 111	3	7	6
	# 55	2	6	3		# 112	5	7	4
	# 56	2	5	2		# 113	5	7	3
	# 57	2	7	3		# 114	6	7	4

3. Perceived Efficiency reported (on a scale of 1 – 10):

	Participant	Phase 1	Phase 2	Phase 3
Session I	# 1	7	3	6
	# 2	6	4	8
	# 3	8	4	7
	# 4	5	2	4
	# 5	7	4	6
	# 6	6	3	4
	# 7	8	5	5
	# 8	5	3	6
	# 9	5	5	5
	# 10	7	4	5
	# 11	4	2	4
	# 12	7	3	4
Session II	# 13	9	6	7
	# 14	6	4	6
	# 15	8	5	7
	# 16	7	3	4
	# 17	4	3	5
	# 18	8	5	7
	# 19	3	2	4
	# 20	6	5	4
	# 21	5	4	6
	# 22	7	5	8
	# 23	4	3	6
	# 24	6	8	10
	# 25	7	5	8
	# 26	8	5	7
	# 27	5	6	7
	# 28	6	5	4
	# 29	7	6	9
	# 30	5	4	6
Session III	# 31	9	8	10
	# 32	7	9	10
	# 33	9	9	10
	# 34	6	1	3
	# 35	6	1	3
	# 36	10	3	8
	# 37	7	5	8
	# 38	6	8	9
	# 39	5	4	7
	# 40	6	8	9
	# 41	4	6	7
	# 42	5	6	8
	# 43	8	4	6
	# 44	8	8	9
	# 45	7	7	8
	# 46	8	7	10
	# 47	8	6	9
	# 48	7	7	9
	# 49	8	5	10
	# 50	8	6	10
	# 51	7	5	9
	# 52	4	5	9
	# 53	3	4	9
	# 54	3	5	9
	# 55	8	6	10
	# 56	8	7	10
	# 57	10	5	8
	# 58	8	5	10
	# 59	7	5	10
	# 60	8	6	10
Session IV	# 61	8	3	6
	# 62	6	3	5
	# 63	7	5	8
	# 64	6	8	10
	# 65	6	8	10
	# 66	6	8	10
	# 67	4	2	7
	# 68	4	3	7
	# 69	6	2	10
	# 70	7	7	10
	# 71	9	2	10
	# 72	9	1	10
	# 73	8	7	10
	# 74	8	7	10
	# 75	6	5	8
	# 76	9	4	7
	# 77	9	7	10
	# 78	10	8	10
	# 79	9	6	10
	# 80	7	8	10
	# 81	7	10	10
	# 82	9	9	9
	# 83	9	8	10
	# 84	9	9	10
	# 85	6	7	10
	# 86	6	8	8
	# 87	7	7	9
	# 88	3	6	8
	# 89	2	8	9
	# 90	3	6	9
Session V	# 91	8	6	10
	# 92	8	5	10
	# 93	10	5	8
	# 94	9	6	8
	# 95	8	6	9
	# 96	7	4	8
	# 97	7	6	9
	# 98	8	5	9
	# 99	7	7	9
	# 100	8	6	8
	# 101	7	5	9
	# 102	6	8	9
	# 103	5	5	10
	# 104	5	3	10
	# 105	4	4	10
	# 106	9	6	9
	# 107	8	6	9
	# 108	7	5	8
	# 109	8	4	7
	# 110	8	3	4
	# 111	8	4	6
	# 112	7	6	8
	# 113	6	5	8
	# 114	5	4	8

4. Simulation Effectiveness (on a scale of 1 – 6):

How well do you feel the simulation demonstrated the achieving of improvement in a process (as a means for Continuous Improvement)?

	Participant	Rating (1-6)		Participant	Rating (1-6)
Session I	# 1	5		# 58	6
	# 2	4		# 59	5
	# 3	6		# 60	4
	# 4	3	Session IV	# 61	6
	# 5	5		# 62	5
	# 6	6		# 63	5
	# 7	6		# 64	5
	# 8	5		# 65	5
	# 9	5		# 66	4
	# 10	6		# 67	5
	# 11	4		# 68	5
	# 12	5		# 69	5
Session II	# 13	6		# 70	5
	# 14	5		# 71	5
	# 15	5		# 72	5
	# 16	4		# 73	5
	# 17	6		# 74	6
	# 18	5		# 75	4
	# 19	6		# 76	5
	# 20	5		# 77	5
	# 21	5		# 78	3
	# 22	6		# 79	5
	# 23	4		# 80	5
	# 24	4		# 81	5
	# 25	5		# 82	4
	# 26	5		# 83	6
	# 27	6		# 84	5
	# 28	5		# 85	5
	# 29	6		# 86	5
	# 30	6		# 87	5
Session III	# 31	4		# 88	3
	# 32	4		# 89	4
	# 33	5		# 90	5
	# 34	6	Session V	# 91	4
	# 35	6		# 92	5
	# 36	6		# 93	5
	# 37	5		# 94	5
	# 38	5		# 95	5
	# 39	4		# 96	5
	# 40	4		# 97	5
	# 41	3		# 98	6
	# 42	5		# 99	5
	# 43	6		# 100	5
	# 44	4		# 101	4
	# 45	5		# 102	5
	# 46	3		# 103	6
	# 47	6		# 104	5
	# 48	5		# 105	4
	# 49	5		# 106	6
	# 50	5		# 107	5
	# 51	6		# 108	5
	# 52	6		# 109	6
	# 53	5		# 110	5
	# 54	6		# 111	5
	# 55	5		# 112	5
	# 56	4		# 113	5
	# 57	6		# 114	5

How helpful do you feel the lowering of time was in finding scope for improvement?

	Participant	Rating (1-6)		Participant	Rating (1-6)
Session I	# 1	5		# 58	6
	# 2	4		# 59	6
	# 3	6		# 60	5
	# 4	6	Session IV	# 61	5
	# 5	5		# 62	5
	# 6	5		# 63	5
	# 7	6		# 64	5
	# 8	6		# 65	5
	# 9	6		# 66	5
	# 10	5		# 67	6
	# 11	5		# 68	5
	# 12	6		# 69	4
Session II	# 13	6		# 70	5
	# 14	5		# 71	6
	# 15	6		# 72	6
	# 16	6		# 73	5
	# 17	5		# 74	4
	# 18	6		# 75	5
	# 19	4		# 76	5
	# 20	6		# 77	6
	# 21	5		# 78	3
	# 22	5		# 79	6
	# 23	5		# 80	6
	# 24	4		# 81	5
	# 25	6		# 82	5
	# 26	6		# 83	6
	# 27	6		# 84	5
	# 28	5		# 85	5
	# 29	6		# 86	4
	# 30	6		# 87	5
Session III	# 31	4		# 88	3
	# 32	5		# 89	6
	# 33	5		# 90	3
	# 34	6	Session V	# 91	6
	# 35	5		# 92	4
	# 36	5		# 93	6
	# 37	4		# 94	5
	# 38	5		# 95	4
	# 39	2		# 96	5
	# 40	5		# 97	5
	# 41	5		# 98	6
	# 42	5		# 99	5
	# 43	5		# 100	4
	# 44	6		# 101	5
	# 45	6		# 102	6
	# 46	5		# 103	6
	# 47	6		# 104	6
	# 48	5		# 105	4
	# 49	5		# 106	6
	# 50	6		# 107	5
	# 51	6		# 108	5
	# 52	5		# 109	5
	# 53	5		# 110	6
	# 54	3		# 111	5
	# 55	5		# 112	6
	# 56	5		# 113	5
	# 57	6		# 114	5

APPENDIX E

The Hacky Sack Game

Lean Concept Illustrated:

- Innovation vs. Continuous Improvements
- Stretch goals to enable behavior change
- Solving a problem without a solution in mind
- Collaboration

Learning Objective

- Change the system

Target Audience

- Anyone in the industry

Scale of Difficulty (Audience, Facilitator)

(1 = easy to 5 = hard)

- Audience: 2
- Facilitator: 3

Number of players per facilitator

- 1 facilitator per 3 groups

- Minimum: 5 mins
- Ideal: 10 mins
- Maximum: 15 mins

Duration

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

Materials required

- Ball or Hacky Sack

Instructions

- Get into groups of 5 or more people
- Create a process to move the ball through the hands of every person in your group
- You cannot pass the ball to someone next to you
- The ball must return to the person who it started with
- The ball must travel through the air
- The ball cannot be rolled across any surface e.g. floors, walls, tables, etc.
- You are now going to create a product
- **One product is equal to 8 rounds of passing the ball in the correct sequence**

- If you go out of sequence or drop the ball you must start over
- This is a timed event.