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HOUSE OF CARDS – A SIMULATION OF LEAN CONSTRUCTION PRINCIPLES

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Abstract: The "House of Cards" simulation was developed to stimulate discussion and improve the application of lean production concepts (5S, flow, waste, kaizen, transparency, and collaboration) to construction engineering and management. It is a simple, scalable, hands-on exercise that enables a facilitator to lead teams to intuitively grasp lean concepts and their benefits to construction processes. The simulation requires minimal resources for each team: 3-4 players, a deck of playing cards, a timer, and a playing surface. "House of Cards" presents six phases of gameplay, and progresses from a worst-case scenario to an optimized ideal. The objective is to play the cards as quickly as possible to construct a 13-story building. As in construction, there is a logical sequence of work required. Lower floors must be built before upper floors, structural work must precede mechanical, and mechanical must precede finish work. This simulation was developed with a construction project context, but can easily be adapted to other industries. The analogies can be tailored to meet other industrial processes, and the floors can be changed to different parts of assembly or production lines.

Keywords: Lean construction, simulation, continuous improvement, 5S, flow improvement.

1 INTRODUCTION

This paper presents a simulation to introduce students or workers in the architectural, engineering, and construction (AEC) industry to lean principles, as applied to construction engineering and management. The goal was to develop a simple, scalable, repeatable, hands-on group exercise that would enable a facilitator to lead groups to intuitively understand the benefits of lean concepts applied to construction processes. Basic lean concept definitions are included so that participants unfamiliar with lean production, and without the guidance of a facilitator, can still benefit from the simulation whether as an observer or watching the video developed by the authors.

Simulations have become one of the most important ways to teach lean concepts over the years. Academics, practitioners, and consultants use simulations to engage people and enhance the learning experience in an applied setting. Tsao et al. (2012) identified the use of simulations across academic curricula in three different universities. Simulations help bridge the gap in conceptual understanding when paired with readings and cases that provide additional background to the implementation of lean in real

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construction projects. Simulations are constantly being created and re-invented to support lean education. Mitropoulos et al. (2014) developed a simulation to automate the 'Parade of Trades', which was originally developed by Tommelein et al. (1999) to evaluate the effects of variability on a sequence of interdependent construction activities. Rybkoswki et al. (2016) have upgraded the "marshmallow simulation" to teach concepts related to target value design. Similarly, teams of practitioners have developed the Villego simulation to mimic the implementation of the Last Planner System in the construction of houses (Villego 2016).

The 'House of Cards' simulation was developed at San Diego State University, where students were challenged to develop new forms of teaching lean principles. This paper describes basic aspects considered by the first three authors while developing the simulation, how it was implemented, and how they collected feedback and identified areas for improvement along the way.

2 Lean Principles Used in the Simulation

The "House of Cards" simulation exposes participants to the following lean concepts: waste reduction, flow improvement, continuous improvement (*kaizen*), and 5S. Additionally, collaborative teamwork, which is also related to the lean principle 'improving transparency', is used in phases 3-6 to improve performance. After starting the game in Phase 1 with the worst-case scenario, phases 2-6 introduce one improvement at a time to demonstrate how that one change can improve team performance. Players will observe that cycle times are reduced as a result of the continuous improvement made from phase to phase.

The simulation was developed to demonstrate performance gains realized by improving flow and reducing waste. Continuously improving flow and reducing wastes are important principles of lean thinking (Womack and Jones 2003), and have been applied to construction (Koskela 1992). The first of Koskela's eleven lean construction principles applied to production system design is the 'reduction of non-value-adding activities'. This principle is tightly related to the other principles due to their symbiotic relationships. For example, 'simplify by reducing the number of steps, parts, and linkages' contributes to 'reducing waste', 'reducing variability', and 'increasing process transparency'.

There are many ways to eliminate waste in production processes. Improving process transparency is a key principle that improves understanding of the production system, the ability to identify and mitigate wastes, and the ability of team members to effectively collaborate. Visual representation and management of transparent processes allow system wastes to be more readily exposed and eliminated (Galsworth 2005). The 'House of Cards' simulation uses multiple steps to gradually improve process organization and improve flow. This effort is very much related to the 5S process (Sort, Set in order, Shine, Standardize, and Sustain), in which the goal is to promote an uncluttered and disciplined environment (Galsworth 2005). The use of 5S in this simulation improves transparency through process simplification and by reduction of waste. Monitoring and recording team cycle times for each of the six phases leads participants to predict, evaluate, and discuss the improvements realized through application of lean principles.

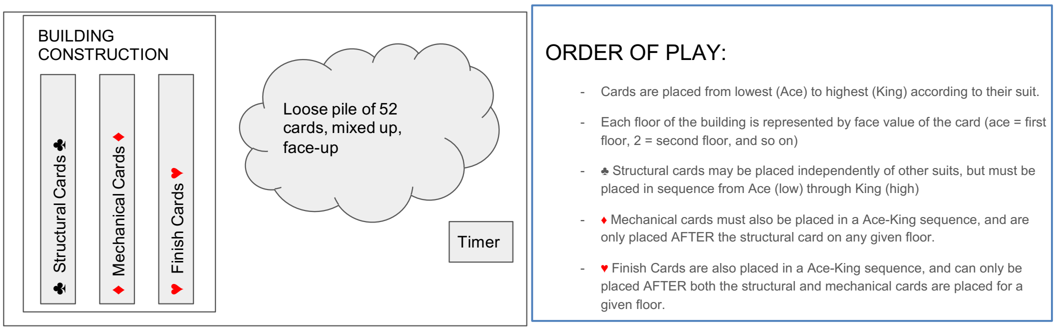
Collaborative teamwork is another principle used in the simulation. In the AEC industry, short-term teams are assigned to individual projects, and seldom have the advantage of long-term relationships to foster alignment, trust, and collaboration. Each project team must make efforts to quickly align the various stakeholders and build the trust needed for true collaboration. Design-build (DB) contracts and integrated project delivery (IPD) projects have contributed to improving collaboration among project stakeholders. IPD projects provide an operational system to enhance collaboration, such as physical collocation in 'big rooms', pain- and gain-sharing, pull planning sessions, etc. (Lichtig 2005). Integrated forms of agreement (IFOA) replace the traditional construction contract on IPD projects and make participants accountable to each other for the success of the project. Successful collaboration supports achieving target goals, boosting profits, and improving flows.

3 THE HOUSE OF CARDS SIMULATION

"House of Cards" presents six phases of gameplay, and progresses from a worst-case scenario to an optimized quick process. The objective is to play the cards as quickly as possible to construct a 13-story building. The three players represent three trade contractors, each responsible for different construction activities: structural, mechanical, and finish work. As in construction, there is a logical sequence of work required. Lower floors must be built before upper floors, structural work must precede mechanical, and mechanical must precede finish work. The game is complete when the finish contractor plays the last card (King of Hearts) representing completion of the finish work on the 13th floor. Each floor of the building, visualized by a row of cards, is represented by face value of the card, e.g., ace = first floor, 2 = second floor, and so on, with the king = 13th floor (Figure 1). If desired, the analogies can be tailored to represent processes and context of other industries, such as an assembly line.

The simulation can be used for a small team of 3 people, or multiple teams of 3-4 members each. The set-up for each team includes: 3-4 players, one table or playing surface, a standard deck of 52 playing cards, 30-60 minutes to complete all six phases, and a timer or stopwatch. The timer is used to monitor cycle time for each phase of play. Cycle time is the main indicator in this simulation, and is the basis for evaluating performance improvements. The simulation is easily scalable, from a small group of 3 players, to large groups of 50, 100, or more. Large groups need only additional decks of cards and playing surfaces. The simulation uses the standard 52-card deck of playing cards, separated as follows: Player 1 structural contractor (clubs); Player 2 mechanical contractor (diamonds); Player 3 finishes contractor (hearts); spades are considered as waste or non-value-adding activities.

<u>Phase 1</u> is a worst-case scenario that demonstrates a complete lack of organization and order on a construction site. Cards are shuffled in a loose pile, face up, on the table. The material laydown area is a complete mess, unsorted, and contains 25% waste represented by the spades cards, which are not needed but are mixed with the other cards in the deck (Figure 1). Players select their cards from the loose pile, and then place the cards from lowest (ace) to highest (king) within their assigned construction area. The game is complete when the king of hearts is placed as the last card. Screenshots of the videotaped simulation are shown in Figure 2.



a) b)

Figure 1: a) Phase 1 set up; b) Order of Play

In phase 1, players are not allowed to gather or sort the cards. Rather, they are restricted to finding and using only the one card that they can play from the pile. Additionally, the players may not talk, or work together in any way. This phase should easily prove to be the slowest, and is designed to frustrate the players so that they consider how to improve performance time. Players play phase 1 twice, once to practice and get familiar with the simulation and the second time to go for the best time possible, which will become the baseline cycle time.

After Phase 1, the post-play discussion includes the following questions:

- How long did your team take to complete Phase 1?
  - Did you do better the second time? | Is this faster/slower than expected?
- Where there any QC problems?
- What are some suggestions to improve performance (time)?

During Phase 2 (improved site laydown) all the cards are facing up in a loose, mixed pile. Now players may gather all of their cards and sort their cards during play. No talking, collaboration, or teamwork is allowed in this phase. After Phase 2 (and all remaining phases) the following post-play discussion questions are asked alongside those used in Phase 1:

- Was your team performance faster or slower?
- Which lean concepts were used to improve performance?
- What might you change to further improve performance?

In Phase 3 (collaboration) all cards are facing up in a loose, mixed pile. As in phase 2, players may gather and sort their cards during play. Now, they may also talk and collaborate with each other. The same post-play questions are used to analyse Phase 3.

During Phase 4 (reducing waste), all spades are set aside to the edge of the playing area. The remaining cards are set face-up in a loose, mixed pile. As before, players may gather and sort their cards and collaborate to help each other. The same post-play questions are used to analyse Phase 4.

Phase 5 (improved material management) involves setting aside the spades as in Phase 4. This time though, play starts with three separate piles (sorted by suit, but not rank). Players may gather and sort their cards and collaborate to help each other. The post-play questions are used to analyse Phase 5.

Finally, in Phase 6 (optimized resource management), all the rules of Phase 5 apply with the additional organization of the three same-suit piles in order of face value, that is, they are pre-ordered in the sequence in which they will be used. The post-play questions are used to analyse Phase 6. Table 1 shows a summary of the principles used in each phase.

Figure 2: Views of the simulation in different phases

Table 1: Lean principles used in phase.

Principle	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
5S		X	X	X	XX	XXX
Collaboration			X	X	X	X
Waste Reduction				X	X	X
Reducing Cycle Time		X	X	X	X	X
Kaizen		X	X	X	X	X

In phases 4, 5, and 6 the principles used are the same, but the level of application is increased - as described above. Higher levels of 5S are applied in phases 5 and 6 to reduce waste and improve cycle times.

4 Comparing Theory and Simulation Results

Throughout the six phases, players are progressively enabled to work more quickly and orderly, resulting in improved performance times from Phase 1 to Phase 6. In recorded sample gameplay, Phase 1 took an average of two full minutes, whereas the optimized process in Phase 6 took only 15 seconds. Average cycle times and percent improvement from the baseline are based on a small sample size of 3 iterations per phase, as played by the authors and recorded in Table 2.

Table 2: Simulation results (data based on 3 iterations)

Iteration	Average Cycle Time (seconds)	Improvement from previous phase	Improvement from baseline
1	120	N/A	N/A
2	74	38%	38%
3	58	22%	52%
4	52	10%	57%
5	31	40%	74%
6	15	52%	88%

The above data (Table 2) supports the hypothesis that the application of lean principles (Table 1) will improve performance (cycle time) between phases of play. Some of the changes between phases are quite noticeable, and the overall improvement of each phase over the baseline (phase 1) is significant. In phase 6, players start with all suits and cards in order, which may be equated to near-perfect execution of a perfect plan (e.g., schedule, logistics, prefabrication) with perfect resource management (labor, resources, equipment). Arguably, this is unlikely to be achieved in the real-world, but is the goal and objective of *kaizen*.

The authors had expected improvements in collaboration to result in a larger performance gains than was observed. In phases 1-2, players act primarily in self-interest and fight to find and employ their own resources, without regard to success of the overall project team (local vs. global optimization). This lack of collaboration could result in hindering the work of other players struggling with mixed resources in a tight workspace. However, increasing collaboration resulted in less performance gain than application of 5S.

Site preparation, organization, and optimized resource management were the biggest factors for improvement in this lean simulation. 5S reduced waste and contributed to improved performance in each phase. The significant amount of disorder and chaos (mixed resource pile) with which players start in phases 1-4, causes the players to waste time on non-value-adding activities to sort and order the resources prior to placing them. However, even this 'wasted time' of gathering and sorting the cards (instead of finding them individually) improves the production flow. This same principle (5S applied to resource management) is important to management of construction sites - starting with something as basic as daily housekeeping.

The best workflows are realized when tasks and resources are organized and ordered before work begins. Unnecessary resource waste (spades) is present in the first three phases of play, and slows production due to players needing to filter it out of the construction process. In phases 4-6, the non-value-added, unnecessary materials (spades) are eliminated from the simulation. The remaining wastes in phases 4 and 5 are of the “non-value-added, but necessary type”, such as sorting (double-handling) and transportation of the value-adding resources. Only in phase 6 are wastes completely eliminated due to starting with an optimized system (optimized supply system).

5 Simulation Testing and Feedback

Social media provided the primary means to share the simulation and solicit feedback. The "House of Cards" simulation video was uploaded to YouTube (https://www.youtube.com/watch?v=cL60KAm0K-I) and then shared with peers and professional social networks to solicit feedback. Specific attempts were made to engage professionals in the lean and construction industries, such as members of the Lean Construction Institute, ASCE: Construction Engineering, and the US Navy's Civil Engineer Corps. Feedback to date has been promising, and several suggestions have already been implemented in the current version of the simulation.

One commenter familiar with teaching lean construction approved of the simulation's structure, and recommended several modifications for larger groups. He noted that each team could have a fourth member to serve as observer, recorder, and timekeeper, and that another volunteer could consolidate teams' performance times for comparison. This will help keep each team competitively engaged in the simulation for larger groups (e.g. 30, 50, 100 people).

When presented to people unfamiliar with lean concepts in a small group setting, players commented on needing clarification of the rules, and a basic definition of the lean concepts. They noted that it was easier to play through the phases after watching the video simulation. Review of gameplay also indicated the need for a poka-yoke in the game to prevent players from building ahead of where they were allowed to build (such as completing finish work before structural work on a given floor). A potential idea for a poka-yoke is to use a "grid system" in place on the table to maintain an higher level of organization, and prevent one suit from "getting ahead" of another suit.

5.1 Feedback Analysis and Recommendations for Future Use

This simulation is intended for use by a facilitator, experienced in lean construction principles, who will guide group discussions and explore concepts between phases of play. The original concept was for teams of 3 players. For larger, or more competitive settings, the team size may be increased to 4 players (as recommended), with the 4th member being the official observer, timer, and recorder. In addition to the group facilitator, an assistant or designated volunteer may consolidate group performance times using a computer and spreadsheet application. This will facilitate quick compilation of times to keep groups competitively engaged, enable comparison of fastest, slowest, and average times, and serve to document the 'pursuit of perfection' as the game progresses.

Finally, simple lean principle definitions were added to the video to help those who do not have any lean experience. If the simulation proves popular, a customized 'lean construction' card deck and playing mat could be designed. Based on the feedback received, this simulation can be applied in facilitated group environment, with minimal investment costs (a deck of cards for each team).

6 Conclusions

This paper presented a new simulation to teach lean construction principles. The simulation is simple, yet easily able to convey the application of lean principles to the AEC community. Organization, collaboration, and the implementation of small changes (kaizen) lead to waste reduction and promote continuous improvement.

The entire simulation takes between 30 to 60 minutes to play, depending on how much discussion is held between rounds. It may be used as an ice-breaker in meetings or classes to educate participants about the power of lean principles. Readers are invited to visualize the simulation on YouTube as a complement to this paper, put it in practice, and improve it as they see fit. The authors welcome constructive feedback for future improvements.

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