Designing Effective Simulation Games for Active Learning in Systems Engineering

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Abstract

Simulation games have been an effective method of teaching, especially for Systems Engineering concepts. The hands-on activities facilitate active, experiential, and collaborative learning with fun elements. Many simulation games have been developed in the past, but not all are equally effective. How to design a simulation game that is effective and easy to implement? This paper attempts to identify the key design factors that affect the performance of simulation games for teaching systems engineering concepts. By reviewing designs of several existing simulation games, important design factors were identified and verified. With these factors, a more effective way to design new simulation games has been suggested.

1. Introduction

With the growing demand of Lean and Six Sigma training in both higher education and industry, hands-on simulation games have been widely used as an effective teaching tool to demonstrate Lean concepts. The interactive role-playing simulation games are especially useful for teaching Systems Engineering concepts, such as pull system, workload balancing, visual standards, and cross-training. Due to the game-playing nature, this teaching method facilitates active, experiential, and collaborative learning within a controlled environment inside a classroom. To learn the concepts to be taught, students gain first-hand experience by actively participating in the staged activities and witnessing the effects of certain concepts or techniques being applied. For example, a popular 5S Number Game [1] demonstrates how the simple Lean tool "5S" (i.e., Sort, Set in order, Shine, Standardized, and Sustain) improves work efficiency in stages within a 20 minute duration. It is fun to play and shows the 5S concepts very effectively.

Many simulation games have been developed and reported in literature. Some of them are simple and effective, while others are not. Therefore, an important question is raised here: *How to design a simulation game that is effective and easy to implement?*

This paper aims at identifying the key design factors that affect the performance of simulation games for teaching systems engineering concepts. By reviewing designs of several existing simulation games, the analysis of strength and weaknesses of these games reveals important design factors to be considered. These design factors are further analyzed to verify their impacts. With the identified design factors, a more effective way to design new simulation games has been suggested to assist educators teach systems engineering concepts more efficiently.

2. Literature Review

In a search of better ways to teach systems engineering concepts, especially process improvement methods, it becomes evident that active project-based learning is very effective. It allows students to apply theoretical knowledge in solving real-world problems [2]. Using collaborative activities and physical laboratory simulations, students can develop more solid comprehension [3]. Simulation game is actually a way of project-based learning in a controlled classroom environment, where students learn by experiencing the impact of improvement skills [4].

The benefits of lean simulation games have been discussed widely in literature. Verma [5] reviewed 17 popular lean simulation games, such as the TimeWise Simulation of the Lean 101 training program, Aircraft Simulation developed by Lean Aerospace Initiative (LAI), and some games designed by the National Institute of Standards and Technology (NIST). Badurdeen et al. [6] and Mirehei et al. [7] extended the list of existing games and categorized them into production line, office, academic setting, and so on. Gupta [8] summarized 20 games of shop floor setting, 2 games of product development, 5 games of administrative process, and 5 games of enterprise and supply chain levels.

The vast amount of previously developed simulation games shed lights on the design factors affecting the effectiveness of the games. In the review of Badurdeen et al. [6], the gaps of existing simulation games as (1) lack of stress on soft skills, (2) a mistaken focus on "linear lean," (3) misunderstanding of the key role of the facilitator, and (4) lack of realism. Based on practical experience, Wan et al. [9] pinpointed issue of implementation, such as game time longer than allocated class time, number of students not matching with number of roles in game, and significant preparation efforts. The success stories, gaps, and issues help to shape the design factors of effective games reported in the following sections.

3. Effectiveness of Existing Games

One of the authors of this paper has been teaching Lean Six Sigma courses and training workshops regularly, which leads to many chances of running simulation games. The other author also gained experience while assisting training workshops. With these experiences, the authors analyzed the effectiveness of some simulation games to explore the critical design factors. Four games are compared here.

3.1 A Visual Aid Number Game – Not A Good Design

In a Lean Manufacturing class in fall 2015 at the authors' university, several student teams attempted to use simulation games to demonstrate the Lean concepts they were assigned to present. As a result, the authors witnessed some successful cases and failure cases. The "Visual Aid Number Game" was one of the ineffective ones.

The game uses two pictures full of numbers to demonstrate the impact of "color code." Figure 1 shows the idea of the game. Before using visual aid, all numbers were black on a printed sheet. Player's time of scratching off odd numbers were measured. After using visual aid, the odd numbers are colored in red. Player's time of scratching off odd numbers were measured again to demonstrate the impact of visual aid on work efficiency.

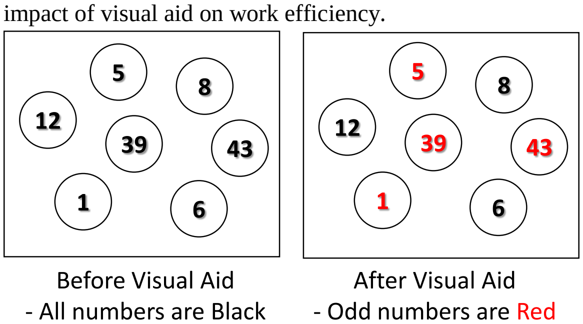

Fig. 1 The Visual Aid Number Game

It turned out that the "before" and "after" performance of several players were almost the same, because the graduate students were able to recognize odd numbers easily without any visual aid. This case shows that the contrast of the "before" and "after" phases in a simulation game has to be significant enough to demonstrate the concept to be taught.

3.2 The LEGO Airplane Game – A Good Design

Next, a very well designed game is reviewed, the LEGO Airplane Game [10]. This game has been widely used in lean training, and we use it regularly at the university as shown in Figure 1.

Fig. 2 The LEGO Airplane Assembly Game

The game demonstrates lean concepts, such as cellular layout, one-piece flow, pull, and workload balancing. It is a successful design for the following reasons.

- The performance metrics (e.g., throughput and work in process) clearly shows the impact of lean tools with enough contrast between phases.
- The metrics can be linked with lean concepts easily.
- It is easy to implement and fun, especially with multiple teams competing.

Some drawbacks of the game are also identified.

- It requires 5 people per team, 10 for 2 teams, etc.
- It requires about 1.5 to 2 hours to run all phases.

Facing these drawbacks, the authors had to modify the game to fit in 75-minute classroom setting and make it more flexible for different numbers of attendees. Nonetheless, the game is effective and enjoyable.

3.3 The 5S Number Game – A Good Design

As mentioned in Introduction, this is another popular game in lean training workshops. The game uses a few sheets of carefully arranged numbers to guide the players through a 5S implementation process [1]. The metric is time to scratch off the numbers in correct sequence. In the phases of sort, set in order, shine, standardize, and sustain, the performance improves step by step, showing the impact of the lean tool, 5S, being taught.

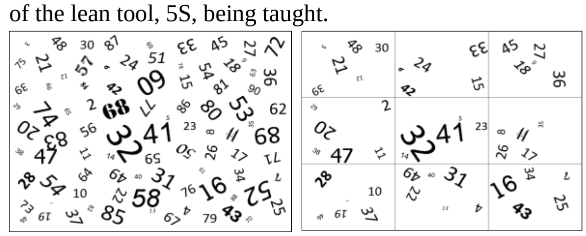

Fig. 3 The 5S Number Game

This game is favorable due to the following reasons.

- It is easy to prepare (just need to print out a few pieces of paper) and easy to run.
- The metrics shows impact of lean tools clearly.
- The single player game is not constrained by number of participants.
- It requires only about 20 minutes to complete.

One major drawback was identified:

- The setting is disconnected with real world.

Due to the identified drawback, the authors made additional efforts to connect the number sheets with a real-world scenario everyone can relate with, i.e., the office desks. As a result, the game becomes more effective.

3.4 The Lean Office Game – An Improved Design

The last game to be reviewed in this paper is a game developed by the authors' team in the past, the Lean Office Game [9]. This game simulates operations of a scheduling team as an office setting with two different job types. It demonstrates impact of lean tools successfully through metrics like throughput and lead time.

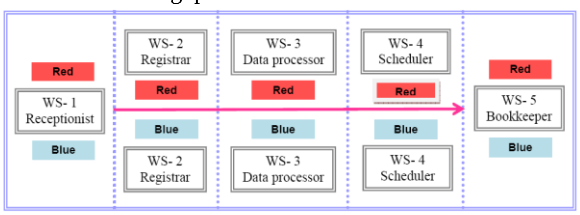

Fig. 4 The Lean Office Game [9]

However, several drawbacks were identified while using the game in training workshops at the authors' university. The game was too rigid (e.g., requires 10 players in each team), required too much time (2 hours), and was not fun. With these identified drawbacks, the team improved the game with the following efforts [9].

- The run time was reduced from originally 2 hours down to 45 minutes, which makes it more feasible for 75-minute class time and shorter workshops.
- Originally, it required 10 players to run the game. After modularizing, it accommodates 6 to 11 players.
- The tasks in the game were redesigned. Some tedious work (e.g., filling out bubble forms) was replaced.

As a result, the game became easier to implement, more flexible, and more interesting for the participants.

4. A Five-Step Design Method for Creating Good Simulation Games

Summarizing the lessons learned in Section 3, it is clear that a good simulation game should possess the following characteristics: (1) be able to demonstrate the concepts to be learned, (2) requires reasonable effort from the facilitator, (3) be feasible within certain constraints, such as time and space, and (4) be interesting with fun interaction and healthy competition. Based on these, the authors of this paper have identified three Design Aspects of Lean Simulation Games in an earlier effort [4]:

- Objectives and Constraints
- Dynamics of Simulated System
- Learning and Teaching Experiences

The three design aspects include all factors that should be considered while designing a new simulation game. It also helps educators review and improve existing games if any weakness is identified.

In this paper, we take one step further to materialize the design concepts into a five-step design method for simulation games. The steps are:

1. Theme: Define main concepts to be demonstrated.
2. Metrics: Identify performance metrics to be tracked.
3. Effectiveness: Design game contents to show significant contrast of metrics in "before" and "after" settings while keeping the game interesting.
4 Feasibility: Review feasibility in terms constraints of time, cost, efforts, etc.
5. Design: Finalize the design with proper documentation including instructions and supporting slides.

Figure 5 illustrates the procedure graphically. As shown, steps 3 and 4 form a loop before finalizing the design. When feasibility is in doubt, the game contents should be revised until the game meets the constraints. Once the game design is effective and feasible, the design is documented to be reproduced for future use.

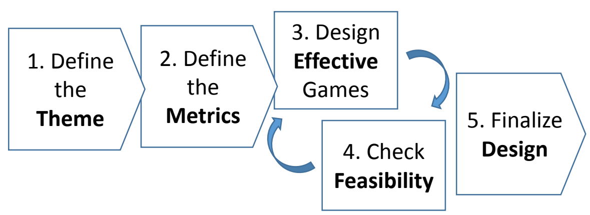

Fig. 5 The Proposed Five-Step Design Method

In the design process, step 3 "Design Effective Games" is a critical step that requires creativity and knowledge of systems engineering. The dynamics of the system to be simulated (i.e., the "before" and "after") play a critical role in the students' learning experience. Simulation games often use simple tasks such as paper folding, number recognition, etc., to form a series of tasks. The way the tasks are put together determines if an improvement can be demonstrated within a reasonable timeframe or amount of effort. Therefore, the feasibility check in step 4 helps to improve the game before it is finalized.

Another factor to be considered in step 3 is whether the games tasks are "interesting" or not. However, unlike the dynamics of the system, "how fun is it" can be quantified or analyzed easily. The creators of the Lean Office Game (see section 3.4) thought that filling out bubble forms seems to be an interesting resemblance of office tasks. Nonetheless, feedbacks from most players consistently say that bubble forms should be removed from the game. Even though “how fun is it” is not readily quantifiable, some suggestions are listed below for reference.

- The game tasks should not be too long and tedious, too complicated, or too challenging.
- Use simple physical activities, such as folding paper, searching, simple math, building something, etc., to keep participants actively engaged.
- Use simple devices or materials, such as dice, LEGO, color note paper, marker, coins, etc., to relate with fun experiences.
- The results of the tasks should be measurable, which allows competition among players.

In summary, the proposed five-step design method provides a framework for systematic design of new simulation games for teaching systems engineering concepts. The use of the framework is illustrated in the next section with a few examples.

5. Examples of Simulation Game Design

In this section the design of three simulation games are introduced based on the five-step design process.

5.1 Paper Airplane Game for “Pull System”

Step 1: Define the Theme

This game is to demonstrate a very important concept in lean manufacturing, i.e., the Pull System.

Step 2: Define the Metrics

The typical performance metrics associated with implementation of Pull Systems are work in process (WIP) and lead time. While running a simulation game, WIP level is often easier to identify (just by counting) than lead time of production flow. Therefore, WIP is selected to be the main metric.

Step 3: Design Effective Game Contents

In order to illustrate the concept of Pull System, a series of operations have to be defined. It is preferred to be a job with many small tasks, so the system can be reconfigured in different ways. In this game, a 10-step paper airplane folding process (Fig. 6) is selected to be the game tasks.

The main purpose of step 3 is to ensure the effectiveness of the game tasks and setting, which means that the difference in performance measures before and after Pull System has to be significant enough. This requires careful design of the system so that the dynamics of the system will behave in a desired way. The following few scenarios shows some good and bad designs.

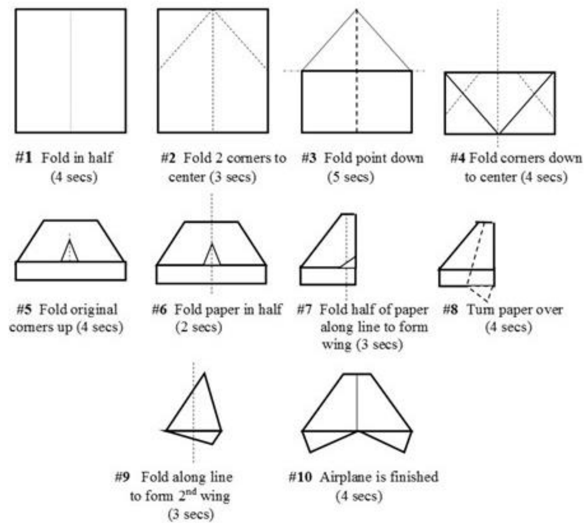

Fig. 6 Ten Tasks of Paper Airplane Folding

Figure 7 shows a system suitable for showing the impact of Pull System. The figure shows a production line with cycle times associated with each station as well as the Yamazumi chart (i.e., bar chart of workloads). In a Push system setting (as a “before” scenario), a new job is picked up by station #1 about every 4 seconds, while the system throughput is one job every 16 seconds determined by the bottleneck station #4. Therefore, using this setting, WIP level increases by 3 units in every 16 seconds (i.e., increment ΔWIP = (1/4 – 1/16)(60 sec) = 11.25 jobs/min). As a result, WIP level can reach 22.5 jobs within 2 minutes, which is an ideal length for an in-class activity to perform hands-on task with visible results before getting bored.

When Pull system is implemented as the “after” scenario, the WIP level can be controlled at 4 jobs (with no buffers between stations) or 7 jobs (with buffers between stations) while maintaining the same throughput. Therefore, this system is capable of showing the impact of Pull.

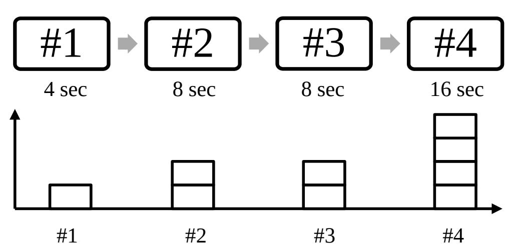

Fig. 7 A Good Design to Show Impact of Pull System

On the contrary, the following two game settings would not satisfy the purpose, even if we use the same airplane folding tasks. In Figure 8, the tasks were distributed quite evenly in four stations. The differences among cycle times are not significant enough (i.e., from 10 seconds to 12 seconds). As a result, the WIP increment rate is merely ΔWIP= (1/10 – 1/12)(60) = 1 jobs/min. With this setting, it would take 22 minutes to show a similar level of WIP build up like the system in Figure 7.

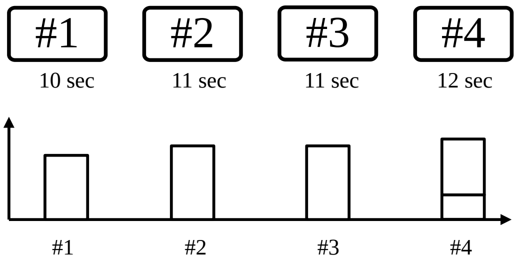

Fig. 8 Cycle Time Difference Not Significant Enough

In Figure 9, the bottleneck is placed at the beginning of the line. This results in no WIP build-up when running as a Push system. Therefore, it fails to show the impact of Pull system as a simulation game.

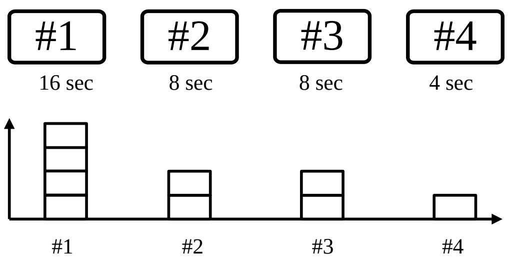

Fig. 9 Bottleneck Position Located Incorrectly

Step 4: Check the Feasibility

This step checks feasibility against constraints in time, cost, etc. With this game design we only need to prepare scrap paper from offices, which is economical. The run time is very short, so some other lean concepts, such as workload balancing and value stream mapping can be added to this game.

Step 5: Finalize the Design

After the game is fully designed and validated, it is important to document what to prepare, how to run the game, what to discuss with students, and how to wrap up.

5.2 Peg Placing Game for Standardized Work

Step 1: Define the Theme

This game is to demonstrate the effect of Standardized Work and the concept of Motion Study.

Step 2: Define the Metrics

The typical performance metrics associated with Standardization are cycle time and quality. In this game, we have determined to select Time as the main metric.

Step 3: Design Effective Game Contents

For demonstrating impact of Standardized Work, we have selected the Peg Board game (Figure 10) as the game tasks, since similar boards can be found or made easily and the tasks are easy to implement.

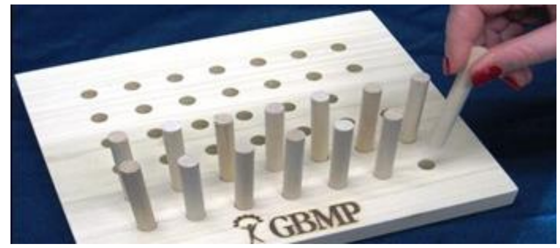

Fig. 10 Peg Board Game for Standardized Work

To demonstrate the concepts effectively, we should create a "before" scenario that performs poorly in terms of time, the main metrics. Then, improved phases are introduced to demonstrate the impact of standardization. For this purpose, three phases are created as follows.

- Phase 1 – No Standard: In this phase, players are asked to randomly place the pegs onto the board until it is filled. Players are not specifically told what to do or what performance metric is being measured. The result is expected to be chaotic; some players may perform well, while others lag behind. Some may even miss some places without pegs. Our experiments resulted in an average of 61 seconds.
- Phase 2 – Poor Standard: In this phase, a standardized work procedure is introduced. Players are instructed to pick and place the pegs in sequence (starting from one corner) by one hand. This procedure ensures no holes are missed, but it is not very efficient. Our experiments resulted in an average of 57 seconds.
- Phase 3 – Improved Standard: In this phase, a carefully designed work procedure is implemented. Players are asked to first keep the pegs equally distributed on both sides of the board, then start from the middle point on the top, with both hands to place the pegs in sequence toward the sides, and continue with the second row and so on. Our experiments resulted in average of 32 seconds and good quality.

With this game design, the impact of Standardized Work can be demonstrated clearly as the performance metric improved from 61 seconds to 32 seconds. Meanwhile, the concepts of Motion Study and Continuous Improvement can be introduced. If time is allowed, a fourth phase with open-ended discussion to allow players to create further improved standards.

Step 4: Check the Feasibility

With this game, the main concern is to have enough boards for all players if the class size is not small.

Step 5: Finalize the Design

Again, proper documentation is needed to allow reproduction of this game in future and by others.

5.3 Standard Pig Game for Quality Improvement

Step 1: Define the Theme

This game is to demonstrate the use of visual aids and standardized work procedures to improve quality.

Step 2: Define the Metrics

Obviously, the major metric of this game is quality.

Step 3: Design Effective Game Contents

For this purpose, we have adopted modified an existing game named the Standard Pig Game [11]. Similar to the peg board game, we have created three phases to demonstrate the improvement of quality standards.

- Phase 1 – Free Drawing: In this phase, players are asked to draw a pig without clear instruction, while the quality is inspected against a set of rules. As a result, many (if not all) of the drawings will be disqualified.
- Phase 2 – Side of A Pig: In this phase, players are instructed to draw the side of a pig. Players can ask for clues, such as how long the pig should be. With verbal instructions, not all the drawings will pass the quality inspection.
- Phase 3 –Standardized Work: In this phase, players are given a grid paper and a list of detailed instruction. The instructions are easy to follow, such as “draw an M at location (1)” and “draw a W at location (2).” With the standardized procedure, the quality of work will be dramatically improved. The results of most participants are expected to be similar to the drawing in Figure 11.

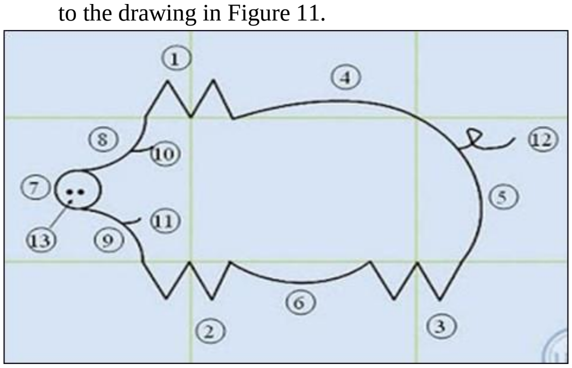

Fig. 11 Standard Pig Game for Quality [11]

Step 4: Check the Feasibility

This game is also economical and easily repeatable. The only consumable is the blank paper and grid paper. The run time can be adjusted easily. If time is a constraint, the first or second phase can be ignored.

Step 5: Finalize the Design

Again, document the details of the game operation is important. For this game, the detailed instructions used in Phase 3 can be printed out on paper or shown on screen.

6. Summary

Simulation games have been the favorite teaching tool of the authors of this paper while teaching systems engineering concepts. A well designed game can accommodate active learning with project-like experience within a controlled environment. It is a natural fit for demonstrating process improvement concepts and techniques, and that is exactly why most Lean Six Sigma training workshops include some simulation games. While being popular, not all simulation games are effective. Some games are long, complex, and hard to reproduce, and some others cannot demonstrate the desired effects visibly.

In this paper, the effectiveness of simulation games has been discussed in detail. Some existing games were reviewed and analyzed in order to identify the critical design factors. As a result, a five-step simulation game design process is proposed to help educators design new games or improve existing games. A few examples are included in this paper to illustrate the use of the five-step design process.

Although the examples of game designs in Section 5 may seem straightforward, the game tasks selection and design requires creative thinking, analysis of dynamics of the system (especially “before” and “after” contrasts), and careful planning. It also requires experiences of game facilitation and preparation. Ultimately, the simulation games should be effective in showing the concept, easy to implement, and enjoyable by participants. Hopefully the proposed five-step game design process stimulate more effective game designs in the community.

Acknowledgement

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References

[1] “The 5S Numbers Game,” (https://www.lean.org/FuseTalk/Forum/Attachments/5S%20GAME.PPT, accessed 1/15/2018).

[2] Kanigolla, D., Cudney, E.A., and Corns, S.M., “Enhancing Engineering Education Using Project-based Learning for Lean and Six Sigma,” International Journal of Lean Six Sigma, 5(1), 45-61 (2014).

[3] Doolen, T.L. and Choomlucksana, J., “Using Collaborative-Learning Activities to Introduce Lean Principles and Methods in the Higher Education Classroom,” Industrial Engineering Research Conference, May 30-June3, Miami, FL (2009).
[4] Wan and Gupta, “The Design Aspects of Role-playing Lean Simulation Games,” Industrial Engineering Research Conference, May 21-24, Anaheim, CA (2016).
[5] Verma, A.K., “Simulation Tools and Training Programs in Lean Manufacturing – Current Status,” A Technical Report submitted to NSRP-ASE, National Shipbuilding Research Program (2003).
[6] Badurdeen, F., Marksberry, P., Hall, A., and Gregory, B., “Teaching Lean Manufacturing with Simulations and Games: A Survey and Future Directions,” Simulation & Gaming, 41(4), 465-486 (2010).
[7] Mirehei, S. M., Kuriger, G., Wan, H., and Chen, F.F., “Enhancing Lean Training for the Office Environment through Simulation and Gaming,” International Journal of Learning and Intellectual Capital, 8(2), 206-221 (2011).
[8] Gupta, N., “The Desired Dynamics of Selected Lean Tools and Framework for Effective Design of Lean Simulation Games,” Master’s Thesis, University of Texas at San Antonio (2016).
[9] Wan, H., Liao, Y., and Kuriger, G., “Redesigning a Lean Simulation Game for More Flexibility and Higher Efficiency,” ASEE Annual Conference & Exposition, June 10-13, San Antonio, TX (2012).
[10] Visionary Products, “Lego® Airplane Game,” (http://www.visionaryproducts.biz, accessed 1/15/2018).
[11] Shmula, “Standard Pig Game,” (http://www.shmula.com/standard-pig-game/12385/, accessed 1/15/2018).