Teaching Strategic Lean Thinking Through Simulation Gaming

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***Abstract*— Lean production is the cornerstone of modern manufacturing. Training all employees in lean thinking is critical to the successful implementation of lean production. Training should include basic lean tools plus strategic lean thinking. Several training methods and physical simulations exist for teaching single lean tools, but few methods exist to teach strategic lean thinking, even though it is much harder to master. This paper describes a computer simulation game which teaches lean strategic thinking. The player manages a manufacturing facility with nine processes to manufacture a single product. They have one year to transform the factory from a series of problems and operating losses to profitability. At their disposal are 13 lean tools, of which they select some to implement each month. Students must diagnose the problems, separate root causes from symptoms, and select lean tools which best resolve the root causes of the problems. User-friendly interfaces allow the students to review process and inventory data and select their lean tools. Then the month's factory performance is presented through animation and numeric results. The game is scored by monthly and year-to-date profit. Learning is demonstrated through improved game scores on different scenarios. The game is housed on a website, making it easy to play in an on-line environment. The game has been used in upper-level engineering courses, but is also suitable for industrial training.**

***Index Terms*— Lean manufacturing; strategic thinking; simulation; game.**

I. Introduction

Lean production systems are essential to the survival of modern production facilities. At the tactical level, lean production is accomplished by implementing lean tools, such as 5-S, pull systems, quick changeover, preventive maintenance, etc. But these production facilities are very complex and tightly coordinated systems with multiple operational objectives. The selection and sequencing of the lean tools is critical for successful lean implementation.

One key element of all lean systems is the training of all employees. Operators need to understand how lean tool implementations in their work areas impact the entire facility. Engineers, team leaders, and managers need to understand the strategic implications of implementing various lean tools. It is difficult for these professionals to understand how lean tools impact the overall system performance measures. Typically, individual lean tools are taught through traditional training classes and simple Lego® physical simulations. The strategic concepts are typically not taught.

To teach strategic lean concepts, the newly developed training method animates and simulates a production facility. The simulation has the graphics of a commercial simulation package, but runs as a video game. The game player operates the factory for a year, making monthly decisions on which of various lean tools to implement. Their decisions are animated and the financial results of their decisions are displayed as their game score. The game is available on a web site, so it can be played on individual computers anywhere. In a class setting, the game has been played in a competitive environment with rewards to the best team score.

II. Literature review

A. Simulation Gaming

Simulation games are used for education and training purposes in all academic disciplines and many industrial training situations. Simulation is a small, simplified model of a problem. A game contains roles, rules, decisions, and results, usually in a visual and competitive environment [1]. There are several advantages to gaming over traditional academic lecture or industrial training methods. Games engage players, permit players to fail on the way to success, provide feedback and rewards, and provide a friendly competitive environment [1, 2]. Nearly 200 engineering education games have been reported since 2000. When results are reported, most games demonstrate positive learning outcomes [3]. For industrial training, games have advantages in economics and safety. It is obviously much cheaper, safer, and faster to experiment with a computer simulation than an actual factory setting [4]. Even students who prefer traditional learning are neutral about playing games [5].

B. Strategic Gaming

Games can teach strategic and systems thinking [1, 4]. In business settings, strategic simulations such as The Business Strategy Game are designed at the organizational level, where players manage research, marketing, and finance, and operations departments [6]. Business strategy games do not focus solely on the operations area.

C. Tactical and Lean Gaming

Many simulation games exist for operations management tactics. The classic Beer Game models the bullwhip effect in a multi-channel distribution system [7]. It can be run as a physical simulation or a computer game. Many companies and universities use Legos® or other simple products to compare and contrast mass production and lean production in serial assembly lines [1, 8, 9]. These physical simulations have been be extended to multi-product systems and parallel processes in the NIST-MEP developed Buzz Electronics simulation. Buzz Electronics has been programmed in the Arena® simulation language, but for demonstration and not participant play [10]. Most operations games emphasize quantitative scheduling and ordering decisions [1]. For example, the Littlefield Technologies game is used in many MBA programs to teach forecasting, lead time, inventory, and queueing concepts [11]. The Federal-Mogul game uses Legos® to teach production control, but introduces setup, layout, and kan-ban [12]. It uses two rounds of game play to reinforce learning objectives. Free software games to teach 5-S, one piece flow, setup reduction, and small batch sizes can be found across the Internet [13]. However, these games and simulations focus on one or a few tactics, and do not deal with strategic aspects of lean manufacturing.

III. Simulation Game Description

A. Game Premise

The All-World Wheelchair game simulates a wheelchair manufacturing facility. At the start of the game, the company is losing money fast. The players have one year to return the company to profitability, saving the jobs of hundreds of workers, and providing quality, affordable wheelchairs to those in need! The players select from a vast array of lean manufacturing tools, trying to find a good strategy which provides much benefit to the company.

The target audiences for the game are students and industry employees who have previously been trained in basic knowledge of a variety of lean manufacturing tools. No particular academic experience is required. However, the player should have a basic knowledge of a wide variety of manufacturing terms and data. The game can be played by college students, engineers, managers, supervisors and line workers.

Games are played independently, one team to a computer. The game has 12 monthly stages. Monthly production and inventory status reports are available for each part and process. All problems encountered during the month are presented visually and in tables. A profit-loss statement is generated each month, along with the year-to-date profit (loss). The team who generates the largest year-to-date profit at the end of 12 months is the winner.

Players experience how to strategically evaluate a manufacturing system, sort through and find relevant data, recognize bottleneck processes, identify root causes to problems, select, and sequence the best combination of lean tools to solve the problems. There are many simulations which deal with the mechanics of individual lean manufacturing tools, but no known simulation of strategic lean manufacturing.

B. Product and Processes

All-World Wheelchair company produces a single model of manually-powered wheelchair, designed for global distribution. Demand is constant at 200 chairs per month, with no finished goods inventory or backorders allowed. There are a total of 32 materials, parts, and assemblies in the wheelchair bill of materials. Three types of steel tubes are formed into 14 tubular parts and then welded into 5 frame subassemblies. One fabric material is cut into and sewn into two fabric subassemblies. Six other purchased components (wheels, fenders, etc.) are added to the subassemblies to produce one completed wheelchair.

All-World Wheelchair uses nine processes to make wheelchairs. A saw, drill, and tube bender create the tubular parts. Welding, grinding, and painting are used to create frame subassemblies. A fabric cutter and sewing machines create fabric subassemblies. Final assembly stations produce the finished product. A simple production flowchart is shown in Figure 1, and is presented to the player in the game instructions. At the start of the game, there are one or two of each station.

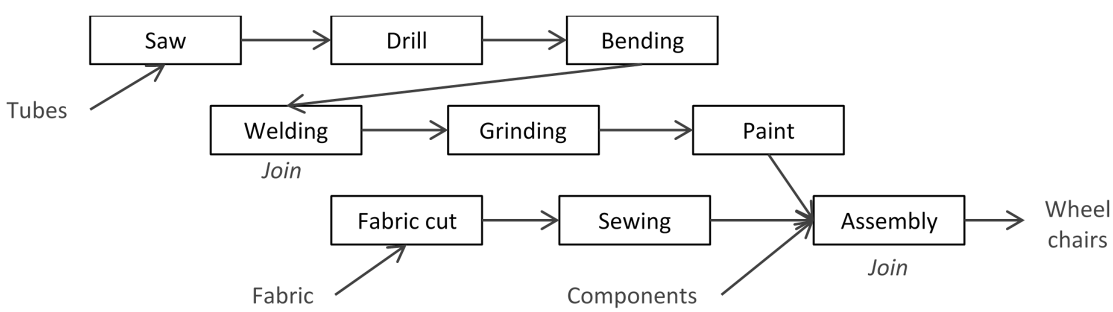

Figure 1. Game process flowchart

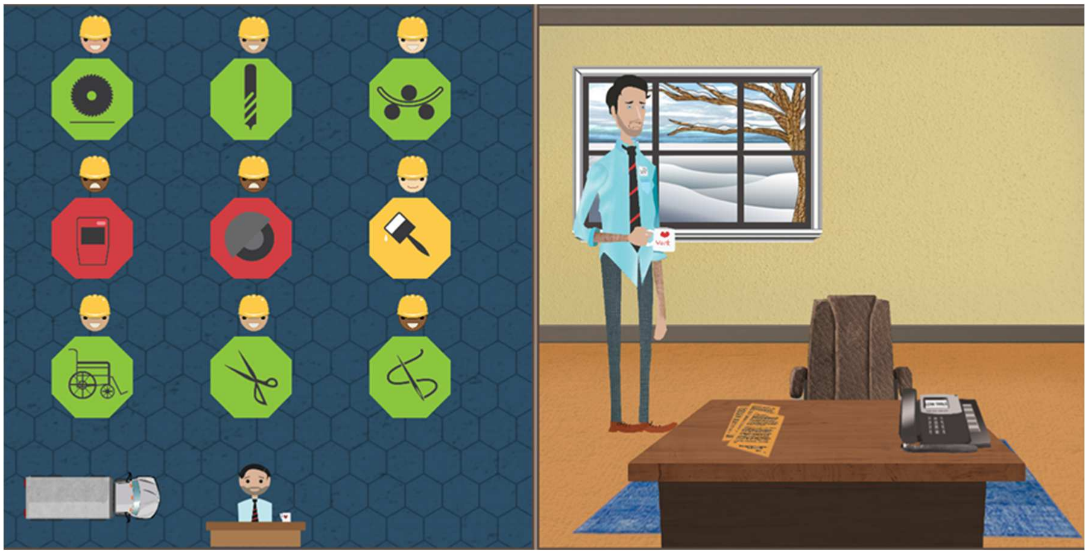

Figure 2. Initial game screen

C. Art Design

The player initially sees the game screen shown in Figure 2. The simple graphics and animations have been acceptable to students in other educational games [4]. At the start, the player may view animated instructions which walk through all of the screens. The left side of the screen represents the factory floor as nine icons and workers, representing the processes on the factory floor, as shown in Figure 3. The colors of the process icons and expressions of the workers represent the performance of that station in the last month. Selecting the truck icon brings up information on suppliers and the last month's purchase orders. Mousing over any icon gives a summary on the monthly production, lost time, and overtime. Clicking on one of the station icons brings up a detailed animation of the machine, as shown in Figure 4.

Figure 3. Factory floor graphic

Clicking on the clipboard in front of the machine brings up details about the machine. Details include current process specifications, current inventory, current expected number of required machines, and problems encountered in the last month, as shown in Figure 5.

The right side of the initial game screen shows the boss's office, as shown earlier in Figure 2. His expression and mannerisms change as the factory profit/loss changes. He starts the game jittery and with a worried expression. Selecting the folder on the left of the desk brings up two tabs. The first tab displays the problems for the month. For example, in the first month, the five welder problems at the bottom of Figure 5 are included with the problems at all of the other processes. The second tab displays the monthly profit and loss statement and the year-to-date profit or loss, as shown in Figure 6.

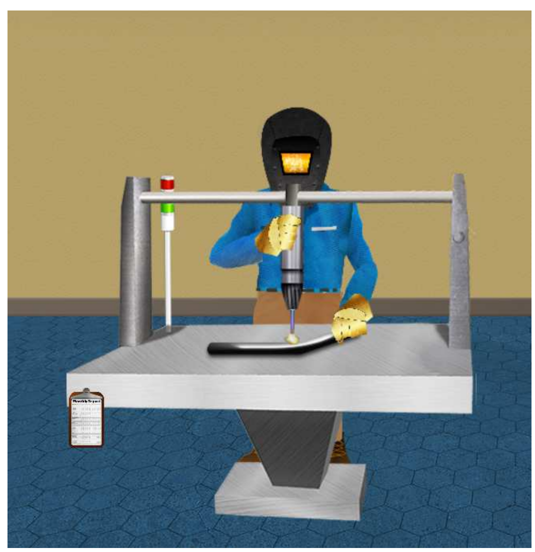

Figure 4. Example animation: welding station

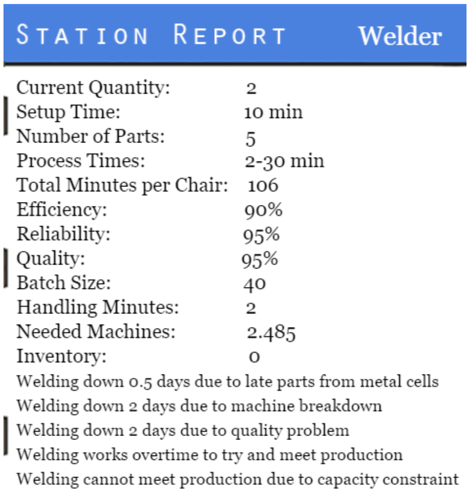

Figure 5. Example machine details:
Welding machine at end of month one, scenario one

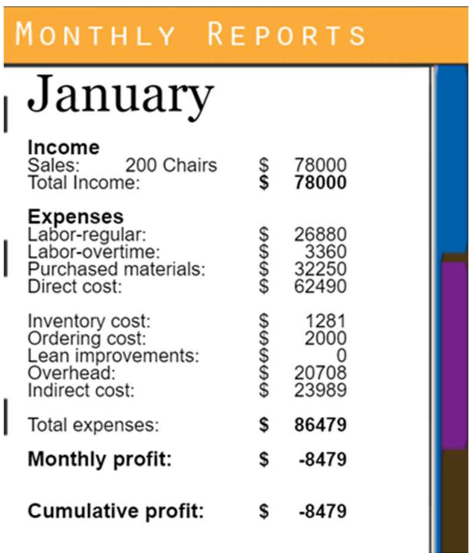

Figure 6. Example profit and loss statement:
End of first month, scenario one

The player clicks on the phone on the right of the desk to bring up a dialog box of lean tools to implement. Tools that have previously been implemented are greyed out and not available for selection. If cells have not been implemented, tools that require cells are also greyed out.

D. Program logic

The game is coded in HTML5 and JavaScript, making heavy use of the canvas element. It can be played directly from the program webpage, or the code can be played locally by opening the main file with any browser that supports HTML5.

The player makes decisions at the end of each month, and then the monthly production occurs automatically and is animated. No production system modifications are allowed during a month. When the month is completed, the new factory screen and current year-to-date profit are displayed. Deterministic problem sets permits fair competition between teams, and permits an instructor to quickly assess and comment on team progress and decisions during the game session. By selecting the appropriate lean tool can a player avoid incurring a problem. For example, if preventive maintenance on the drill has been selected, 80% of future drill breakdown problems will not occur.

After monthly problems have been identified, forward logic is used to determine the production and inventory at each machine. Purchase orders are automatically sent and delivered for any raw material whose inventory is below the re-order point. Machine capacity is calculated based on process parameters and monthly problems. All problems are converted to days of downtime. Overtime is automatically and incrementally incurred if capacity is above 80%. The full monthly production quota is produced unless capacity exceeds 100%. Updated inventory quantities are calculated, and inventory shortages will be listed as an additional problem at the succeeding process. Finally, monthly sales and the monthly costs for parts, purchasing, labor, inventory, and overhead are calculated and totaled as the game score.

E. Game Play

The game starts in January. The first month plays automatically, and the player starts the game with a long list of problems to resolve and an operating loss. Station status is shown by color: red indicates that a station did not meet production, yellow indicates that a station worked overtime or had at least 2 problems, and green indicates that the station met production without overtime or multiple problems.

To make improvements to the production system, the player selects from 57 individual options in the 13 types of lean tools listed in Table 1. Lean tools can improve process parameters (5-S, Preventive maintenance, etc.), reduce costs (Cells, Vendor certification, etc.), or reduce inventory (Kanban, Supermarket, etc.). The impacts of each tool are precisely given. The player is restricted to two types of lean tools per month. They can implement the selected tools on as many machines/cells/vendors as desired. Each lean tool has a one-time cost and the player is also restricted by a $1000 per month budget. Lean tools are implemented immediately. When all tools for the month have been selected, the player selects the "Play Month" button and the month's production is animated and the results calculated.

Play continues for 6 months (February through July). Most lean tools require several months to justify their initial expense. So to prevent "end gaming" of the system, no lean tools may be implemented from August to December. The players simply play these months and see the results of their decisions. The game ends with a certificate screen, showing the total (hopefully) profit at the end of the year.

TABLE I.
AVAILABLE LEAN TOOLS AND THEIR IMPACTS

Lean Tool	Where Used	Cost	Impact
Kanban	2 cells	$100 each	Less work-in-process inventory, less rework
Supermarket	2 processes	$200 each	Less work-in-process inventory
Small lot sizes	Any cell	$100 each	Reduce production lot size by 50%
5-S / housekeeping	Any process	$100 each	Improve efficiency 6%
Single-minute exchange of dies	6 processes	$300 each	Reduce setup time by 80%
Quality at the source	5 processes	$200 each	Reduce rework, scrap by 80%
Cells	Overall	$700 total	Eliminate handling time; reduce overhead $700
Cross training	Any cell	$200 each	Reduce number of workers
Self-directed teams	Any cell	$200 each	Overhead down $500, efficiency down 3%
Preventive maintenance	6 processes	$200 each	Reduce downtime 80%
Vendor certification	Any vendor	$200 each	Reduce order costs 75%; reduce late orders 80%
Small purchase lot sizes	Any vendor	$100 each	Reduce order size by 75%; set re-order point to 0
New equipment	Any process	$1000 each	Additional capacity; overhead up $300; more labor

F. Scenarios

Currently, the game has two scenarios. Each scenario has different starting conditions, process parameters, and costs. Therefore, different lean tools are needed to improve the system. Scenario one has a single significant bottleneck machine. As a consequence, the scenario starts with too little inventory to meet production despite excess capacity at several stations. Scenario two has multiple smaller bottleneck stations and a larger January operating loss. Inventory costs are much higher, but large setup costs make it difficult to reduce work-in-process inventory.

IV. RESULTS

The game has been run in an on-campus Lean Manufacturing class of 20 to 30 engineering students for eight semesters. For five semesters scenario one of the game was played on a pilot macro-based Excel version, and in the most recent semesters the animated video game version was introduced. Although the game itself did not change, the animated version was more engaging and allowed the students to identify problem areas and relevant data much more quickly.

The game is played simultaneously by 8 to 12 teams on individual PCs. After reviewing the tutorial and demonstrating game play and data, the instructor moves between teams, reviewing decisions, reviewing individual lean tools as necessary, and encouraging systems thinking and root-cause analysis. To encourage serious play, extra credit is awarded to the teams with the best scores. The entire session usually takes about one hour.

In the first round, half of each class plays scenario one, the other half plays scenario two. For the second round, the scenarios are reversed. Average scores improve in the second round, demonstrating that learning has occurred. Specifically, 46 teams played both scenarios of the game, with 23 teams playing scenarios one and two each in the first round. Although designed to be equally difficult, the average score for scenario one is significantly higher than scenario two, as shown in Table 2. On the first round 14 of the teams achieved large profits ($50,000 to $100,000 for the year), 22 achieved smaller profits, and 10 ended with losses for the year. After normalizing the scores, 27 of 46 teams achieved larger profits in the second round. In general, teams with lower first round scores showed large improvement in their second round scores. Nine of 10 teams which showed a loss the first round made a profit the second round. But teams with large profits in the first round played around with various strategies on the second round and ended with slightly normalized scores, sometimes significantly lower.

The normalized difference in scores between round 1 and round 2 is subject to a hypothesis test. The calculated paired t-statistic is 1.44. The one-tailed critical t-statistic with alpha = 0.05 and 45 degrees of freedom is 1.71 and the p-value is 0.0779. The game scores increased, but only at a 90% confidence. There were some outlier data points which skewed the results. Five of the top 10 game scores were achieved by teams in the first round. These teams already understood lean strategic thinking. There was little opportunity for additional learning, and as the teams changed strategies, they incurred some of the largest decreases in scores.

TABLE II.
GAME SCORES IN DOLLARS BY SCENARIO AND ROUND

	Scenario 1	**Scenario 2**	
Average score	39048	28444	
Minimum	-56362	-54245	
Maximum	92000	87788	
Standard deviation	32236	36041	
Normalized average	0	0	
	Round 1	**Round 2**	**Normalized Round 2 – Round 1**
Average score	29322	38169	8847
Minimum	-56362	-54245	-91594
Maximum	86020	92000	103822
Standard deviation	37745	30511	41565
Normalized average	-4423	4423	

On the other end, some of the lowest score was recorded in the second round. It appears that the team gave up, although there is no way to be sure. The five outliers at the top were removed from the data set, but the outlier at the bottom was kept in the data set. The paired t-test was re-run with the remaining 41 teams. The new paired t-statistic is 2.28, generating a p-value of .0139. After removing five outliers, with 95% confidence, it is shown that the average game score increased between rounds one and two, indicating that learning took place through the game playing.

Empirical observations and conversations with players also validate that the players learn strategic lean thinking. For example, in scenario one, there is not enough capacity at the Welding station at the start, resulting in the entire Welding cell being emptied of parts by the end of January. Significant sales revenue will be lost if the Welding station capacity is not increased. Once the emergency is stabilized, a player can proceed along several lines of action. At that point, the Welding and Paint stations are potential bottlenecks, but the Grinding and Assembly stations part shortages are only symptoms of problems at the bottlenecks. If a player attacks symptoms rather than the bottlenecks, little improvement will be seen. Also, if they chase problems rather than take a systems perspective, little improvement is seen. For example, in scenario 2, the Saw is down 5 days in January due to late parts and a breakdown, even though the vendor has relatively high on-time deliveries and the saw is generally reliable. Additionally, the process is only 15% utilized, so it had no trouble meeting production despite these problems. When players chase these minor problems rather than addressing less reliable suppliers and processes, they will not see any cost savings. In either scenario, if they try to reduce inventory before reducing disruptions (late deliveries, breakdowns, quality problems, etc.) there will be more overtime and lost sales. Similar results occur if they reduce costs (via cells, self-directed teams, etc.) before reducing disruptions. If they order or produce smaller lot sizes without setup reduction (via Single-minute exchange of dies or Vendor certification), net profit will decrease. If players fail to address the largest cost items of labor and inventory, their net profit will be small.

There are several ways an instructor could interact with players. In this case, the instructor questioned decisions but did not offer suggestions for 3 or 4 months. After it becomes clear to players that there are flaws in their strategic thinking, the instructor more directly guides the players into bottleneck identification, root-cause analysis, and systems thinking. Debriefing at the end of the second round reinforces the learning objectives.

The game has been tested with individual working adults in remote locations. In this setup, the individual played an entire scenario without instructor input. Discussion in a chat format followed, and the individual had the option to try the second scenario if they desired. There has not been an opportunity to play the game with an entire class in a fully on-line setting.

V. Conclusion and Future Work

An animated simulation game of a factory has been created to teach players about strategic lean thinking. The game covers 13 typical and important lean tools. Simulation games are known as effective means for players to learn strategic thinking and decision making. Through success and/or failure players experience how to strategically evaluate a manufacturing system, diagnose the problems, separate root causes from symptoms, and select lean tools which best resolve the root causes of the problems. Improved game scores between rounds demonstrate that key learning objectives are achieved. The game has been used in upper-level engineering courses, but is also suitable for industrial training.

Future work includes enhancements to the game and expansion to other scenarios and products. Background bills of materials and route sheets exist, and could be presented for display. Improved animations could be made for individual machines. Visual representations of selected lean tools could be made on the factory floor or individual machine animations. Animation of finished goods leaving the factory could show monthly sales. The monthly play could be more animated, with machine icons changing colors as play progresses through the month.

More scenarios could be made for the wheelchair product. A second way to create new scenarios is to produce a similar product, such as a go-cart. This could be done within the existing program, but would require more art and coding changes. Finally, the game could be modified to match a given industry's products and processes, providing learning for a specific audience. In this case conversion to more object-oriented code in the program would be required.

Finally, the game can be tested in a fully on-line class. Depending on the synchronous or asynchronous nature of the course and discussion capabilities, the instructor will need to develop various methods to coach, interact with, and debrief the class on the learning objectives. Note: the game can be access and played online at www.allworldleangame.com.

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