

# 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 players manage 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. The game has been used in upper-level engineering courses, but is also suitable for industrial training.

## Keywords

Lean manufacturing, strategic thinking, simulation game

## 1. 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 to understand how lean tools impact the overall system performance measures. Typically, individual lean tools are taught through traditional training classes and simple Lego<sup>®</sup> 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 to implement various lean tools. Their decisions are animated and the financial results of their decisions are displayed as their game score. In a classroom setting, the game has been played in a competitive environment with rewards to the best team score.

## **2. Literature review**

### **2.1 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, and provide a friendly competitive environment [1, 2]. 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 [3]. Even students who prefer traditional learning are neutral about playing games [4].

### **2.2 Strategic gaming**

Games can teach strategic and systems thinking [1, 3]. 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 [5]. Business strategy games do not focus solely on the operations area.

### **2.3 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 [6]. It can be run as a physical simulation or a computer game. Many companies and universities use Legos<sup>®</sup> or the Cuppa game to teach kan-ban concepts in serial production lines [1, 7]. These physical simulations have been extended to multi-product systems and parallel processes in the NIST-MEP developed Buzz Electronics simulation. Buzz Electronics has been programmed in the Arena<sup>®</sup> simulation language, but for demonstration and not participant play [8]. 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 [9]. The Federal-Mogul game uses Legos<sup>®</sup> to teach production control, but introduces setup, layout, and kan-ban [10]. Free software games to teach 5-S, one piece flow, setup reduction, and small batch sizes can be found across the Internet [11]. However, these games and simulations focus on one or a few tactics, and do not deal with strategic aspects of lean manufacturing.

## **3. Simulation Game Description**

### **3.1 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 audiences 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 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.

### **3.2 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 two each of the welding stations, sewing machines, and final assembly stations.

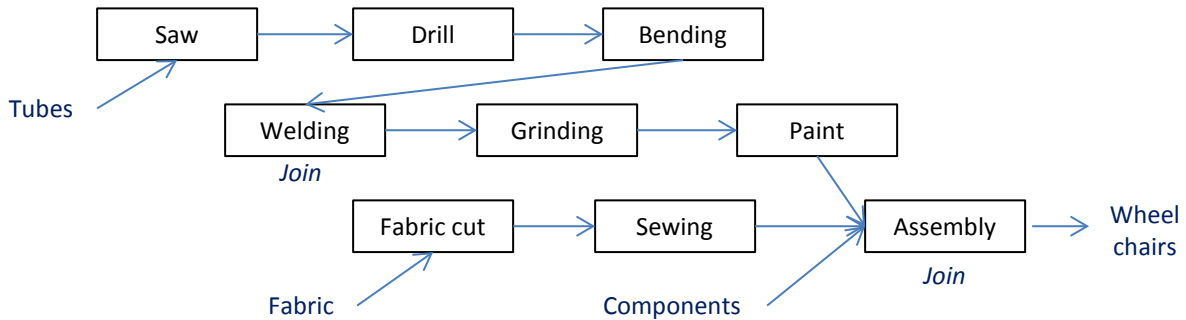


Figure 1. Game processes flowchart

### 3.3 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. 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.

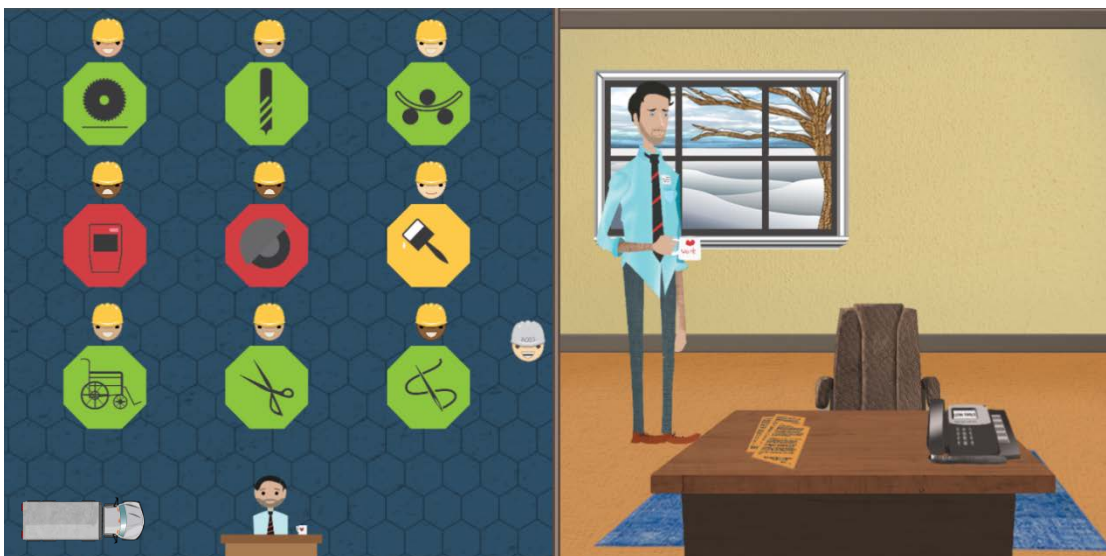


Figure 2. Initial game screen

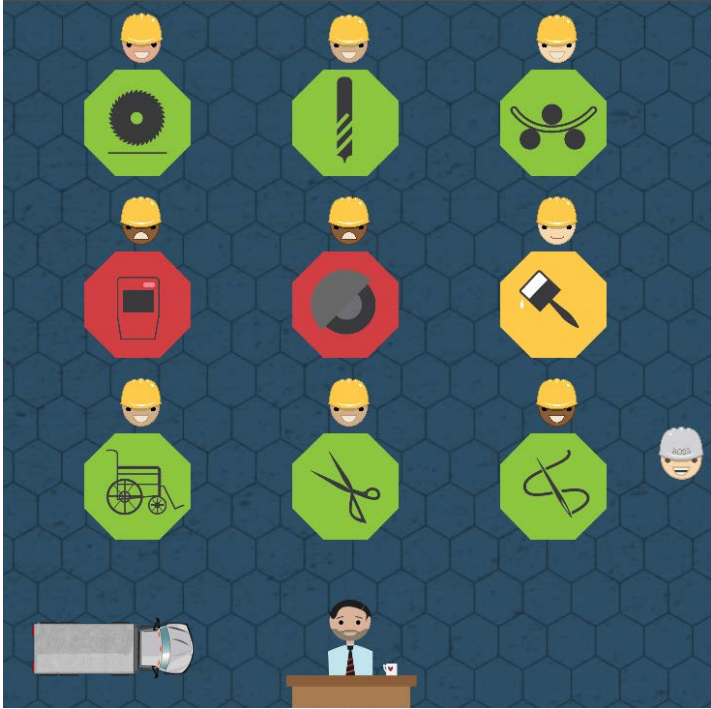


Figure 3. Factory floor graphic



Figure 4. Example animation: welding machine

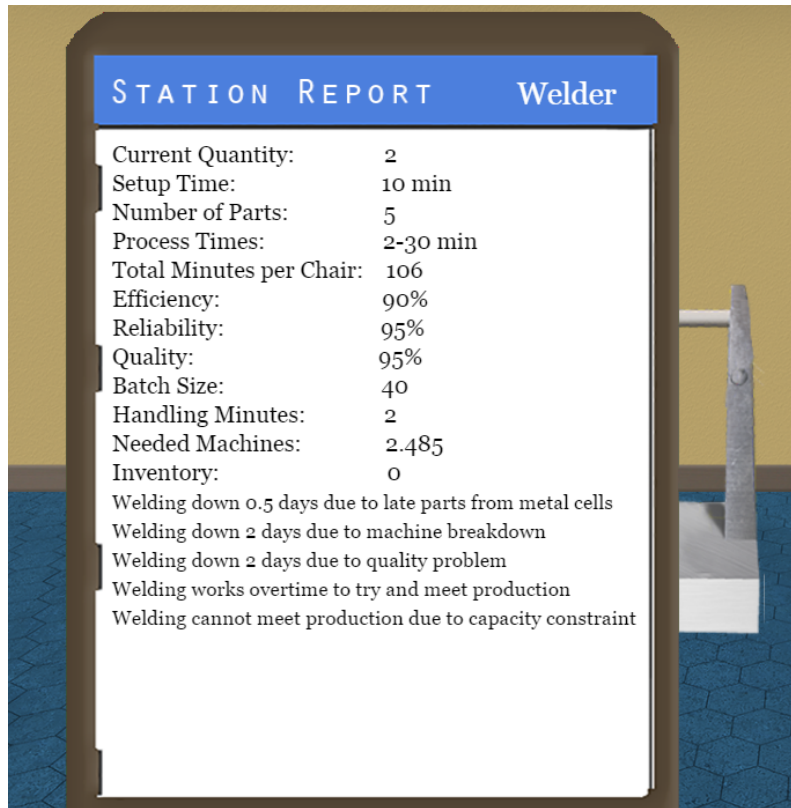


Figure 5. Example machine details: welding machine at end of month one

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. 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.

### 3.4 Program logic

The game is coded in HTML5 and JavaScript, making heavy use of the canvas element. It can be played from any server hosting the code as a webpage, or the code can be downloaded and played locally by opening the main HTML 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 player 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 lists permits fair competition between teams, and permits an instructor to quickly assess and comment on team progress and decisions during the game session. Only 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.

MONTHLY REPORTS	
January	
<b>Income</b>	
Sales:	\$ 78000
Total Income:	\$ 78000
<b>Expenses</b>	
Labor-regular:	\$ 26880
Labor-overtime:	3360
Purchased materials:	\$ 32250
Direct cost:	\$ 62490
Inventory cost:	\$ 1281
Ordering cost:	\$ 2000
Lean improvements:	0
Overhead:	\$ 20708
Indirect cost:	\$ 23989
Total expenses:	\$ 86479
<b>Monthly profit:</b>	<b>\$ -8479</b>
<b>Cumulative profit:</b>	<b>\$ -8479</b>

Figure 6. Example profit and loss statement: end of first month

Finally, monthly sales and the monthly costs for parts, purchasing, labor, inventory, and overhead are calculated and totaled as the game score.

### 3.5 Game play

The game starts in January. There is sufficient initial inventory, but there is not enough capacity at the welding process. The first month plays automatically, and the player starts the game with a long list of problems to resolve and an operating loss of \$8478. 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 known.

The player is restricted to two types of lean tools per month. But 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 February 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 1. Available lean tools and their impacts.

Lean Tool	Where Used	Cost	Impact
Kanban	2 cells	\$100 each	Less WIP inventory, less rework
Supermarket	2 processes	\$200 each	Less WIP inventory
Small lot sizes	Any cell	\$100 each	Reduce lot size by 50%
5-S	Any process	\$100 each	Improve efficiency 6%
SMED	6 processes	\$300 each	Reduce setup time by 80%
Quality at the source	5 processes	\$200 each	Reduce rework, scrap by 80%
Cells	Overall	\$1000 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 lot size by 75%; set re-order point to 0
New equipment	Any process	\$700 each	Additional capacity; overhead up \$300; more labor

#### 4. Results

The game has been run in a Lean Manufacturing class of 20 to 30 engineering students for six semesters. For five semesters the game was played on a pilot macro-based Excel version, and the most recent semester 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 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 less than one hour.

Through empirical observations and conversations with players, the players appear to learn strategic lean thinking. The simulation is realistic enough that the game scores reflect the quality of strategic decision making. For example, there are not enough Welding machines at the start of the game, resulting in the entire Welding cell being starved of parts by the end of January. Significant sales revenue will be lost if the welding capacity is not increased. Once the emergency is stabilized, players proceed along several lines of action. At that point, the Welding and Paint stations are potential bottlenecks, but problems at the Grinding and Assembly stations are symptoms of problems at the bottlenecks. If players attack symptoms rather than the bottlenecks, little improvement will be seen. If they try to eliminate 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 (cells, self-directed teams, etc.) before reducing disruptions. If they purchase or run small lot sizes without setup reduction (SMED, Vendor certification) net profit will decrease. If players fail to address the largest cost items of labor and parts, their net profit will be small. Finally, if they chase problems rather than take a systems perspective, little improvement is seen. For example, 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 relatively 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.

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.

On a first play about 25% of the teams achieve large profits (\$40,000 to \$80,000 for the year), 50% achieve smaller profits, and 25% end at a net loss for the year. But players generally want to “fail forward” and re-play the game several times to learn from their mistakes and gradually achieve good lean systems thinking.

Instructor observation and conversations with players make it clear that players learn much lean systems thinking. This is consistent with results in the literature. But, no formal attempt has been made to validate this observation.

## 5. 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. Test runs and sessions demonstrate that key learning objectives are achieved. 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. 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.

Additional scenarios would enable players to reinforce their learning and verify that the learning is transferable to new situations, similar to the two rounds of the Federal-Mogul game [10]. One new learning objective would be to resolve capacity issues solely through lean tools and not require purchasing a new machine. Another new learning objective would be to recognize how large setup times are a constraint to most inventory reduction tools. The most basic way to create new scenarios is to change the process parameters and initial conditions. This could easily be done within the existing program. 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 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 significant changes to the program would be required.

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