

Teaching Lean Principles through Simulation Games

Dr. Faisal Aqlan, Penn State Behrend

Dr. Faisal Aqlan is an assistant professor of industrial engineering at Penn State Behrend. He earned the B.S. and M.S. in industrial engineering from Jordan University of Science and Technology in 2007 and 2010, respectively and the Ph.D. in Industrial and Systems Engineering from the State University of New York at Binghamton in 2013. Prior to joining the faculty at Behrend, Dr. Aqlan was a faculty member in industrial and system engineering at the University of New Haven where he taught undergraduate and graduate courses. Dr. Aqlan has also worked on industry projects with Innovation Associates Company and IBM Corporation. His work has resulted in both business value and intellectual property. He has published several papers in reputed journals and conferences. Dr. Aqlan is a senior member of the Institute of Industrial and Systems Engineers (IISE) and has received numerous awards and honors including the IBM Vice President award for innovation excellence.

Dr. E. George Walters III P.E., Penn State Behrend

Dr. George Walters is an associate professor of Electrical and Computer Engineering at Penn State Erie, The Behrend College. He earned a B.S. in Electrical Engineering Technology from Penn State Harrisburg, an M.S. in Electrical Engineering and a Ph.D. in Computer Engineering, both from Lehigh University. He has been a licensed Professional Engineer in Pennsylvania since 1998.

Dr. Walters worked in industry as a controls and automation engineer for eighteen years prior to joining the faculty at Behrend in 2010. Most of his experience is in the design, development, and commissioning of PLC-based control systems for the food & beverage and cement industries. He has developed and teaches a course on PLC-based control systems for engineers. He also teaches a course on advanced digital design using FPGAs, a course on embedded systems using 8- and 32-bit microcontrollers, and the two-semester capstone project sequence for electrical and computer engineers at Behrend.

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Abstract

In recent years, several training simulation games have been developed by academic and industry experts to support the teaching and learning activities of Lean philosophy. Using simulation games to teach Lean philosophy is an effective tool to convey the concepts to students. This paper discusses the teaching of Lean manufacturing principles to high school and undergraduate students through hands-on simulation experiments. Several Lean workshops and simulation games are offered to the students. Lean workshops aim to teach students the basics of Lean manufacturing as well as different Lean tools and techniques. Lean factory simulations include a set of hands-on experiments to teach students about manufacturing systems and Lean process improvement. In addition, Lean projects are implemented by undergraduate students in partnership with local industry. For each Lean activity, qualitative and quantitative data are collected and analyzed to assess the outcomes of the simulations, projects, and workshops.

Introduction

Lean manufacturing is a continuous improvement approach that focuses on elimination of non-value added activities. The concept of Lean manufacturing was originated at Toyota Motor Company. According to John Shook, Toyota's first (and still only) American manager in Japan, Lean manufacturing is defined as "a manufacturing philosophy that shortens the time line between the customer order and the shipment by eliminating waste"¹. There are eight types of Lean wastes: defects, over-production, waiting, non-utilized talent, transportation, inventory, motion, and extra-processing. The first letters of these eight wastes can be summarized in the word DOWNTIME. Table 1 shows the eight Lean wastes and their description.

Table 1. Eight Lean wastes

Lean Waste	Description
Defects	Products to be reworked or scrapped
Over-production	Producing more or earlier than required
Waiting	Any non-work time waiting for tools, supplies, parts, etc.
Non-utilized talent	Not using or being aware of people's talent
Transportation	Unnecessary movements of products and materials
Inventory	Excess products or material not being processed
Motion	Unnecessary movements by people
Extra-processing	More work or higher quality than is required by customer

Activities can be divided into three types: value added, non-value added, and non-value added essential⁴. A description of these is given in Table 2. Process improvement projects should focus on emphasizing value added activities, minimizing essential non-value added activities, and eliminating non-value added activities. Reducing the amount of non-value add activities reduces the production cost².

When waste in a process is reduced using Lean manufacturing, cost eventually will be dropped, since the process takes less time to produce the same or more. In other words, the process

becomes more efficient. This helps the company to maintain competitiveness over other companies in the market. Lean manufacturing also improves efficiency through reducing inventory, implementing a pull system and cellular manufacturing, reducing setup time, and by increasing process flexibility³. This can be achieved by utilizing Lean tools and techniques.

Table 2. Three main types of activities

Activity Type	Description	Action
Value Added	<ul style="list-style-type: none"> ○ Adds value to product or service ○ It is done right the first time ○ Customer wants it 	Emphasize
Non-value Added Essential	<ul style="list-style-type: none"> ○ Does not add value to product or service and is necessary for the delivery of product or service 	Minimize
Non-value Added	<ul style="list-style-type: none"> ○ Does not add value to product or service and can be totally eliminated 	Eliminate

2. Lean Simulation Games

Several training simulation games have recently been developed by academic and industry experts to support the teaching and learning activities of Lean philosophy. Using simulation games to teach Lean philosophy is an effective tool to convey the concepts to students. Moreover, simulation games can effectively be used to teach the soft and hard skills for successful Lean process improvement. A review study on simulation and games for teaching Lean manufacturing found that 75% of the Lean simulations and games focus on production lines. Other focus of the Lean simulations and games include enterprise-wide operations and non-manufacturing industry⁵. Table 3 shows some examples of Lean simulations and games⁵.

Table 3. Examples of Lean simulations and games

Name of Simulation/Game	Focus	Product
UK Paper Clip Simulation	Manufacturing	Paper Folders
Buckingham Lean Game	Supply Chain	NA
Lean Enterprise Value Simulation	Enterprise	Lego Aircraft
Lean Product Development Simulation	Product Development	K'nex Product
5S Mini-Factory Simulation	Manufacturing	Tabletop Mini Factories
Furniture Factory Simulation	Manufacturing	Wooden Furniture
Ship Repair Design Process Simulation	Design Process	Container Ship
Value Stream Mapping Board Game	Manufacturing	Board Game
Lean Lego Simulation	Manufacturing	Lego Cars

3. Teaching Lean to High School and Undergraduate Students

At Penn State Behrend, Lean manufacturing workshops and simulation games are being offered to both high school students and undergraduate students. The objective of these workshops and simulation games is to provide the students with a practical understanding of Lean principles and process improvement methodologies. Several activities have been conducted over the last two years including workshops, simulation games, and practical projects with local industry. Table 4 summarizes the different types of Lean activities and their descriptions.

Table 4. Lean activities and their descriptions

Activity Name	Activity Type	Activity Description	Target Group
Explorers Event	Workshop	Provides career exploration opportunities for young people aged 14 and up.	High School Students
Lean 101	Workshop	Teaches Lean concepts and tools to undergraduate engineering students	Undergraduate Engineering Students
Lean Factory Simulation	Simulation Game	Teaches Lean manufacturing to undergraduate by	Undergraduate IE Students
5S Simulation	Simulation Game	Teaches 5S methodology to undergraduate students by	Undergraduate IE Students
Lean Project in local industry	Industry Projects	Apply Lean to solve real life problems in a local company	Undergraduate IE Students

The Explorers Event is conducted every year in February and targets high school students. The event involves teaching the high school students Lean manufacturing concepts and it includes lectures and in-class activities. Students are also given tours to the different laboratories and participate in other laboratory experiments conducted on different topics including 3D printing, laser welding, etc. Figure 1 shows pictures from a recent Explorers Event.



Figure 1. Lean number games workshop for high school students

The Lean 101 workshop is a 3-hour course offered to all Engineering students who are interested in learning Lean manufacturing. The workshop is offered by the Institute of Industrial and Systems Engineers (IISE) Chapter at Penn State Behrend. The workshop is offered in the Spring and Fall semesters. Most of the students who attend the workshop get internship positions and apply what they learn at the workshop in their internships. A survey was developed to gather student feedback (if they already participated) and interest (if they have not) about the workshop. Student feedback on the workshop has been collected and analyzed. A sample survey is shown in Table 5, and survey results of the first seven questions are shown in Figure 2. The survey was distributed to 35 senior and junior students and 30 responses were received. From Figure 2, it is noted that most students agree that workshop was effective and helped them to understand the Lean concepts.

Table 5. Sample survey for the Lean 101 survey

No.	Question	Answer
Q1	The workshop helped me understand the Lean manufacturing concepts and techniques.	4 3 2 1 NA
Q2	Information and/or skills presented were relevant and useful.	4 3 2 1 NA
Q3	The materials provided were useful.	4 3 2 1 NA
Q4	I can now apply Lean to real life process improvement cases.	4 3 2 1 NA
Q5	The hands-on activities were useful and effectively taught.	4 3 2 1 NA
Q6	The videos were helpful and informative.	4 3 2 1 NA
Q7	Do you recommend this workshop to other students?	4 3 2 1 NA
Q8	How would you rate the presenter's knowledge of the subject? (please check one).	<input type="checkbox"/> Excellent <input type="checkbox"/> Good <input type="checkbox"/> Fair <input type="checkbox"/> Poor
Q9	How do you rate the overall quality of the presenter?	<input type="checkbox"/> Excellent <input type="checkbox"/> Good <input type="checkbox"/> Fair <input type="checkbox"/> Poor
Q10	How would you rate the overall quality of this workshop?	<input type="checkbox"/> Excellent <input type="checkbox"/> Good <input type="checkbox"/> Fair <input type="checkbox"/> Poor

4= Strongly Agree 3= Agree 2= Disagree 1= Strongly Disagree NA: Not Applicable

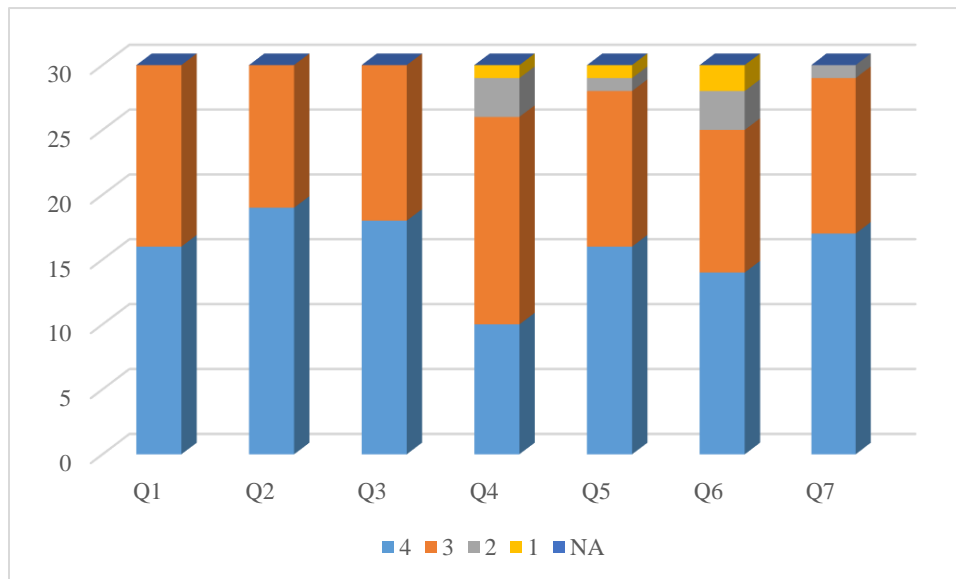


Figure 2. Survey results for Lean 101 workshop (questions 1-7)

For questions 8-10, most of the respondents rated the quality of the presenter and the course as excellent (see Figure 3).



Figure 3. Survey results for Lean 101 workshop (questions 8-10)

Out of the 35 surveyed students who took the Lean 101 workshop, 19 indicated that they had an internship during the summer. Of those 19 students, 16 had their internship in a manufacturing environment, and 15 students had an internship related to Lean manufacturing and/or process improvement. Students who had an internship were asked to answer questions related to the workshop (see Table 6).

Table 6. Internship-related survey for the Lean 101 workshop

Number	Question	Answer
Q1	The workshop was helpful and relevant to your internship.	4 3 2 1 NA
Q2	Has the workshop inspired you to seek out an internship?	4 3 2 1 NA
Q3	The workshop helped me find an internship.	4 3 2 1 NA
Q4	I anticipate career advancement as a result of completing the internship.	4 3 2 1 NA
Q5	I will prefer to get a job in Lean manufacturing and/or process improvement.	4 3 2 1 NA

4= Strongly Agree 3= Agree 2= Disagree 1= Strongly Disagree NA: Not Applicable

The survey results of the internship questions are shown in Figure 4. Most students think that the workshop was helpful and relevant to their internships. Some students, however, have an internship that is not related to process improvement and they don't agree that the workshop was relevant to their internship. For question 2, most students who had no internships indicated that the workshop inspired them to seek one, while many students who already had internships answered the question with "Disagree or Strongly Disagree". Students also did not agree that the workshop helped them to find an internship, especially those who already had one. However,

students prefer to find a job in Lean manufacturing and/or process improvement after they learned about these topics in the workshop.

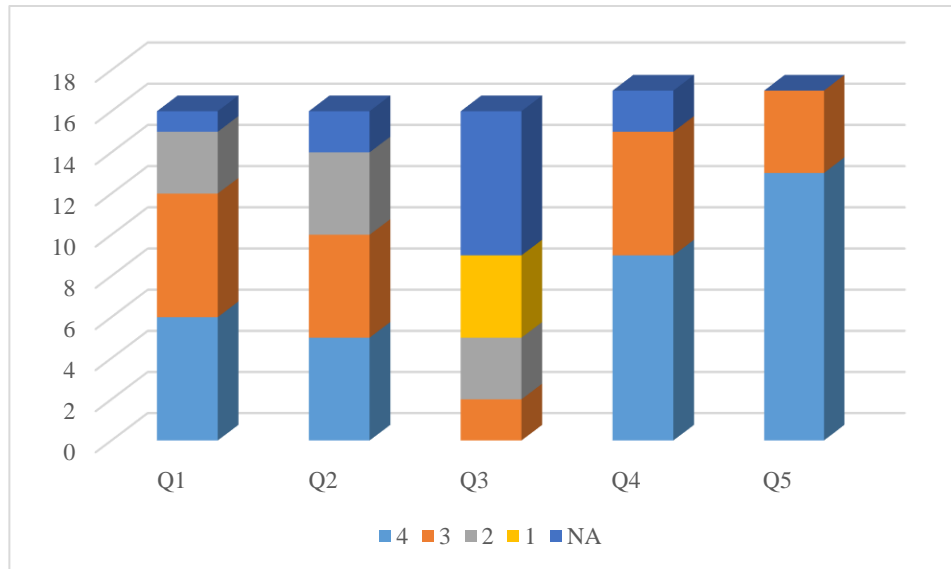


Figure 4. Survey results for questions related to internships

The last part of the survey includes 5 qualitative questions to gather student feedback on the workshop. The five qualitative questions are:

- Q1: What skills did you learn that may help prepare you for working in industry?
- Q2: What did you like best or find most useful about the workshop?
- Q3: Things you did not like about the workshop.
- Q4: Suggestions for improving the workshop.
- Q5: Areas/topics about which you would like to receive further training.

Students' answers to the five questions, which are qualitative statements, were analyzed using word clustering as shown in Figure 5. For question 1, students' responses indicate that the skills they learned are Lean, Lean thinking, and Lean waste elimination. Responses to the second question indicate that students like the Lean activities and videos. However, some students think that the videos were long as indicated by the responses to question 3. Suggestions for improvement include shortening the workshop or including short breaks and having more activities during the workshop. It should be noted that all the classes that the students are taking are only 50 minutes and the workshop is the first 3-hour long lecture they attend. This may explain why the students think the workshop was long. Students also would like to receive more workshops on Six Sigma as indicated by their response to question 5.

The factory simulation experiments are designed to teach students the basics of manufacturing systems. Four simulation experiments were conducted: Batch and Queue production, Cellular Flow Push production, Cellular Flow Pull production, and Lean Flow production. The layouts of the Batch and Queue and the Lean Flow Productions experiments are shown in Figures 6 and 7, respectively. Table 7 shows sample results of the car factory simulations. It can be seen that the Lean Flow has the highest values for profit and production rate. Simulation time was set to 10 minutes.



Figure 5. Word clustering for qualitative survey questions

Table 7. Sample results of the car factory simulations

Simulation Experiment		Batch and Queue		Cellular Flow Push		Cellular Flow Pull		Lean Flow	
		Number	\$	Number	\$	Number	\$	Number	\$
Revenue	Sales (\$500/car)	18	9,000	24	12,000	26	13,000	29	14,500
Total Sales		\$9,000		\$12,000		\$13,000		\$14,500	
Costs of Goods Sold	Raw Material (\$100/car)	18	1,800	24	2,400	26	2,600	29	2,900
	Labor (\$165/worker)	6	990	6	990	6	990	3	495
	Overtime (\$40/minute)	0.65	25.6	0	0	0	0	0	0
	Overhead (\$10/chair)	5	50	6	60	5	50	3	30
	Scrap (\$100/car)	0	0	0	0	0	0	0	0
Total Cost of Goods Sold		\$2,865.6		\$3,450		\$3,640		\$3,425	
Capital Charge	WIP (\$60/car)	0	0	0	0	0	0	1	60
	Facilities (\$15/Table)	6	90	3	45	6	90	2	30
	Facilities (\$10/Fixture)	5	50	2	20	3	30	0	0
Total Capital Charge		\$140		\$65		\$120		\$90	
Sales – Costs of Goods Sold – Capital Charges		\$5,994.4		\$8,485		\$9,240		\$10,985	
Production Rate (car/minute)		1.69		2.40		2.60		2.90	

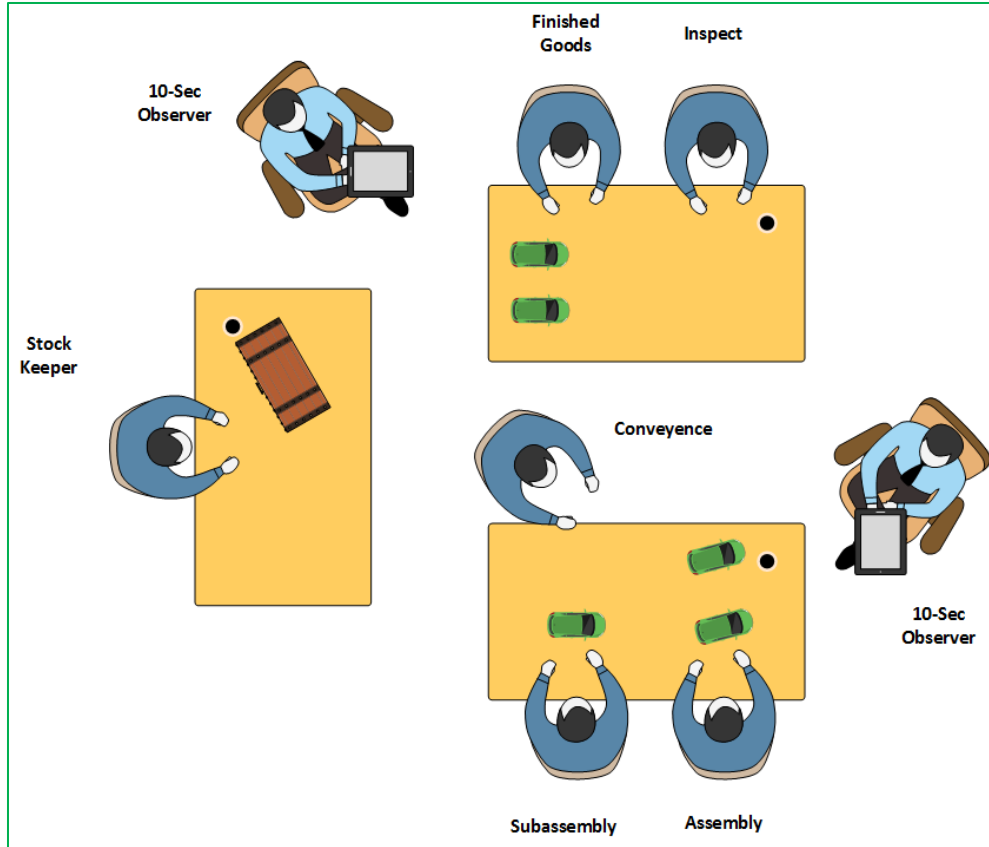


Figure 6. Factory layout for batch production simulation

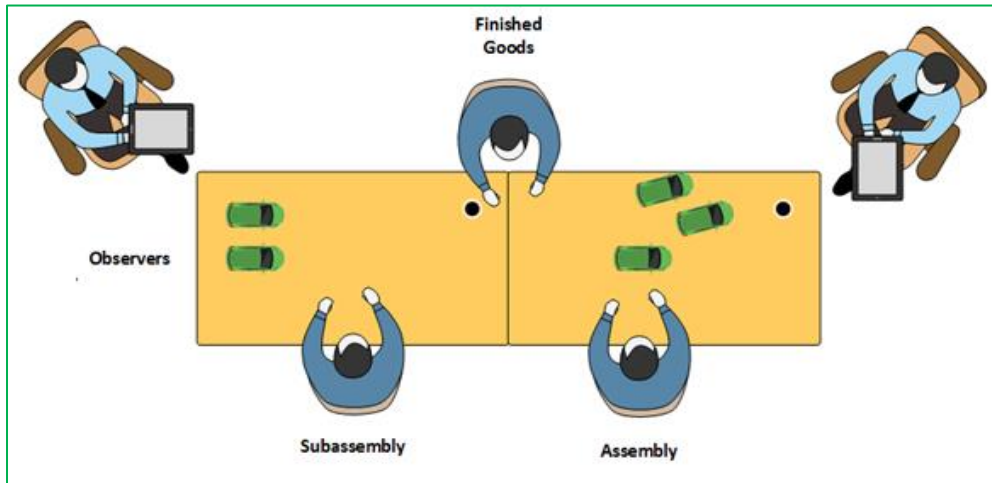


Figure 7. Factory layout for Lean production simulation

The 5S simulation experiment involves two activities, Before and After, where students are asked to assemble a product. The Before activity, shown in Figure 8, involves students performing an assembly of a plane where the parts and tools are randomly placed on the tables. Students were given two hours to finish the activity and they spent the first 40 minutes trying to find the tools and parts used in the assembly process.



Figure 8. Lean simulation game for 5S methodology (Before)

In the After activity, students implemented 5S to remove the parts and tools they don't need and reorganize the workplace as shown in Figure 9. Students were able to complete the process with 50% less time.



Figure 9. Lean simulation game for 5S methodology (After)

One of the main factors that the current Lean simulations and games do not consider is the cognitive skills and cultural aspects which are important for Lean manufacturing sustainability. In future work, we plan to integrate the cognitive and cultural factors into the Lean simulation games. This will also require the development of assessment measures for the learning outcomes.

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