A Comparative Study of Teaching Lean Manufacturing via Hands-On and Computer-Aided Simulation

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Abstract

Lean manufacturing concepts have become more and more prevalent and important to understand and to be utilized by engineers in manufacturing and service industries. Many industrial organizations are mostly focused on increasing their process responsiveness and thereby creating a need for the emerging workforce to understand and apply the principles of Lean engineering. Several academic courses are currently in place to increase the exposure on the application and practice of Lean engineering principles. Though focused on teaching the same concepts, teaching methodologies being adopted span across several horizons.

One of the most common hands-on simulation techniques for teaching Lean principles is observed to be the "Airplane assembly line" simulation. Towards the effort of identifying an effective teaching methodology for imparting Lean Engineering principles, this study intends to explore on if there is a significant difference observed on teaching Lean principles using hands-on simulation technique versus a computer aided simulation. The only difference among the methodologies explored here is based on the fact that, one is based on a hands-on simulated assembly line, and the other is a computer-aided simulation using Arena software.

Keywords: Arena; Gamification; Lean, Engineering; Lean Principles; Lean Teaching; Simulation

Introduction

Nowadays, the concept of Lean manufacturing is widely used in industries and so it is imperative for the current emerging Industrial engineering workforce to understand and be able to apply lean manufacturing concepts. Implementing Lean principles in real time manufacturing settings has increased significantly since 1990's [1] and the application in service [2] industries for the last 10 years. This observed increase in the application of lean principles could be easily narrowed down towards the effectiveness of lean methodology in reducing waste, creating savings and increasing value in organizations and industries across several domains. The main objective of Lean is to eliminate waste in manufacturing (and service) systems [3]. A rapid increase in the use of lean methodology in several industries created the need for academic settings to educate and train students to be able to apply lean manufacturing principles in real time.

Several teaching methodologies have been analyzed towards increasing the effectiveness and understanding of lean concepts. One of the widely adopted approaches for imparting the knowledge is the use of physical simulation [4]. This method though proven to be effective, it still has opportunity scope of improvement in the areas such as: the lack of realism in the simulation process in academic settings[5]. To create a more realistic simulation on the application of lean principles, the authors believe that the use of computer simulations would help towards increasing effectiveness for teaching lean principles.

Computer simulation allows the facilitator(s) to create systems with more realistic constrains when compared to physical simulations that are conducted at seminars and courses on Lean. It is widely observed that, in order to re-create hand-on simulated manufacturing and service systems (including healthcare) Legos are commonly used. This method helps to better transmit the knowledge of lean principles and thereby to increase student understanding. The challenge of creating simulations that allow students to understand real scenarios, or creating scenarios for practitioners to reflect upon their required application is very complicated; however using Lego based physical simulations increase the effectiveness [6]. Creating these simulations allows the concepts of Lean to be thought in a "game" based scenario called Gamification[7]. The concept of Gamification is applied in order to use a set of games in a series of contexts to transmit knowledge more effectively to any type of audience, from kids to technical experts in specific areas.

Here, the authors explore on the comparison of teaching effectiveness in Lean principles using physical hands-on simulation and computer based simulation. Both the techniques used are based on Lean and Gamification in order to effectively convey the knowledge. These two approaches have their own pros and cons that will be discussed in the sections.

Basic concepts

In order to better understand how the concepts of Lean, Gamification and Simulation are related in this study, they must first be clearly understood. Each one of these concepts is very broad and a defined scope must be identified in order to create an un-bias comparison of the physical hands-on simulation and computer-based simulation.

Lean

The idea of waste elimination was observed in manufacturing settings for a long time especially in rapid mass production settings. The main pioneer of these concepts was Henry Ford [8] when he implemented the concepts of mass manufacturing through manufacturing lines. Back then, the concept was not known as lean, but an emphasis on waste elimination was introduced to the automotive industry. The concept of Lean was pioneered years later by Toyota motor company, when they created the Toyota Production System (TPS) where many lean tools where created such as Just In Time (JIT) and Kaizen events [9]. Since then Lean has continuously evolved around the concept of reducing waste in a system. Mentioned below are the wastes that Lean currently considers [10]:

- Inventory: Excess inventory goes against the idea of JIT and requires space in warehouse that can be eliminated or reduced.
- Talent: Added in the more recent years, company talent can be easily wasted if there is no systematic structure in order to promote and generate innovative ideas form talented personnel at all levels of an organization.
- Waiting: Any time that is wasted by waiting for parts, documents or any non-value added activity is considered a waste.
- Motion: When motion of parts or personnel is required in excess, the system becomes more and more inefficient over a period of time.
- Transportation: This refers to unnecessary movement of material and/or products using material handling equipment or major transportation sources such as trucks, train, boat, etc.
- Defects: Every time a defect is created, waste is generated. This includes scrapping product, reworking or repairing it.
- Overproduction: When a push system is used, more products that are required, or at the time that it is not required can be generated and this is not efficient.
- Over-processing: Refers to the creation of extra processes that are not required by the customer, either due to defects or a higher quality standard that the customer does not demand.

All of these defects can be identified in manufacturing and service industries. Lean philosophy uses the following tools to identify, reduce and even eliminate the previously mentioned wastes [11]: Value Stream Mapping (VSM), Kaizen events, Flow cells, Standard Work, 5S's, Visual Management, Pulls and Kanban systems, Brainstorming, Prioritization, Spaghetti diagrams, Poka-Yokes, Single Minute Exchange Dies (SMED), Total Productive Maintenance (TPM), Change Management, Quality at Source, Batch reduction and Plant layouts.

Gamification

Gamification was introduced in 2003 in order to engage and motivate people to achieve their goals with the help of concepts: Playing and Gaming [14]. Playing refers the participating in a game without a necessary intention of learning a concept. Gamming on the other hand is intended to transmit knowledge. This is where the concept of serious games is developed where, Serious games are not indented to be played merely with the intent of entertainment; they are thought-out games with an educational purpose behind them [15].

The main benefits of Gamification are that the participants are motivated during the process and thereby improving their retention levels along with understanding complicated concepts [16]. In order to create effective gamified experience among the participants, seven steps are proposed that include: Creating an elaborate game strategy, Visualizing what, why and who of the game, creating a suitable environment, increasing the game mechanics in different levels, using user appealing graphics and repeated iteration of the game for improvement.

Simulation

Simulation refers to the process of creating a physical or computational controlled environment that allows the application of different scenarios in order to understand the outcomes [15]. In most cases, computer based simulations are commonly used, but not necessarily the most effective. Computer based simulations allow the user to change factors mimicking Lean improvements in a controlled and fast environment without incurred high costs. Dynamic simulation is commonly found on any manufacturing or service operation because time plays an inherent role in this simulation. Stochastic simulations have random inputs through out the process for times, failures, etc. Discrete simulation occurs when changes in a given system occur at given points of time. The authors use Arena® software to create a system simulation for the Lean activity.
When creating computer based simulations, the two main benefits observed when compared to physical hands-on simulations are that: it almost always very cost efficient, and that computer based simulation is very detailed in portraying interdependence and their influence. The main disadvantage here is that there can be simulation errors that are sometimes not detected by the user. Also, this approach doesn’t allow the users to interact directly with the system and “feel” and live the changes being made.

Methodology

The main objective here is the comparison of effectiveness in Lean knowledge transfer using physical hands-on and computer-based simulations. The concept of Gamification is used for both approaches used. In order to create the most un-bias comparison possible, a set of undergraduate students varying across junior and senior levels pursuing their bachelor’s degree in the Industrial, Manufacturing and Systems engineering department at the University of Texas at El Paso were selected. A pre-survey was initially conducted in order to assess the student perception and knowledge on the concepts of Simulation, Lean Principles and the use of Arena Simulation software.

The selected groups of students were provided with a problem (Appendix 1) that describes in detail a manufacturing process of 12 different Lego products that require assembly. The process consisted of a warehouse that receives the parts, sends them to a Raw Material Inspection (RMI) area where they are quality inspected, then sent back to warehouse for kitting, kits are then sent to manufacturing that consist of 5 assembly areas, a final quality inspection is performed, and finally finished products sent back to the warehouse where they are batched together and shipped. Figure 1 illustrates the process flow of the simulation. Work instructions for assembly at each of the stations were also provided to the students. Data for the computer simulation was provided, however the tables of finished quality products, Order entry records in order to calculate Inter-arrival times and Bill of Material (BOM) that had to be created by the students.

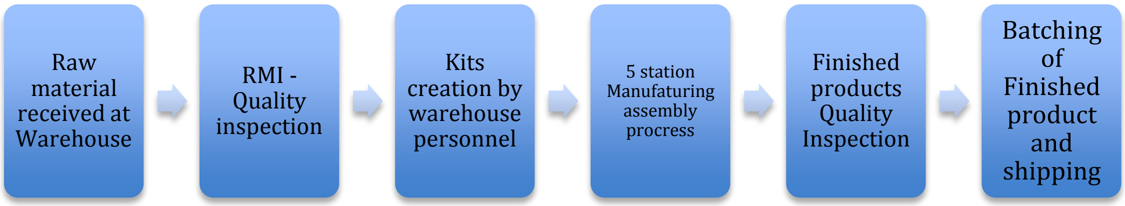

Figure 1: Simulation process flow

Once the process was understood the selected group was randomly divided into two different unbiased sections. One of the groups was asked to create the simulation using Arena software, while the other group was asked to create the simulation physically, the most close to how it was explained in the problem as possible. Figure 2 shows Lean Lego products used for Hands-on simulation (physical model), and a computer based model created in Arena (Simulation model).

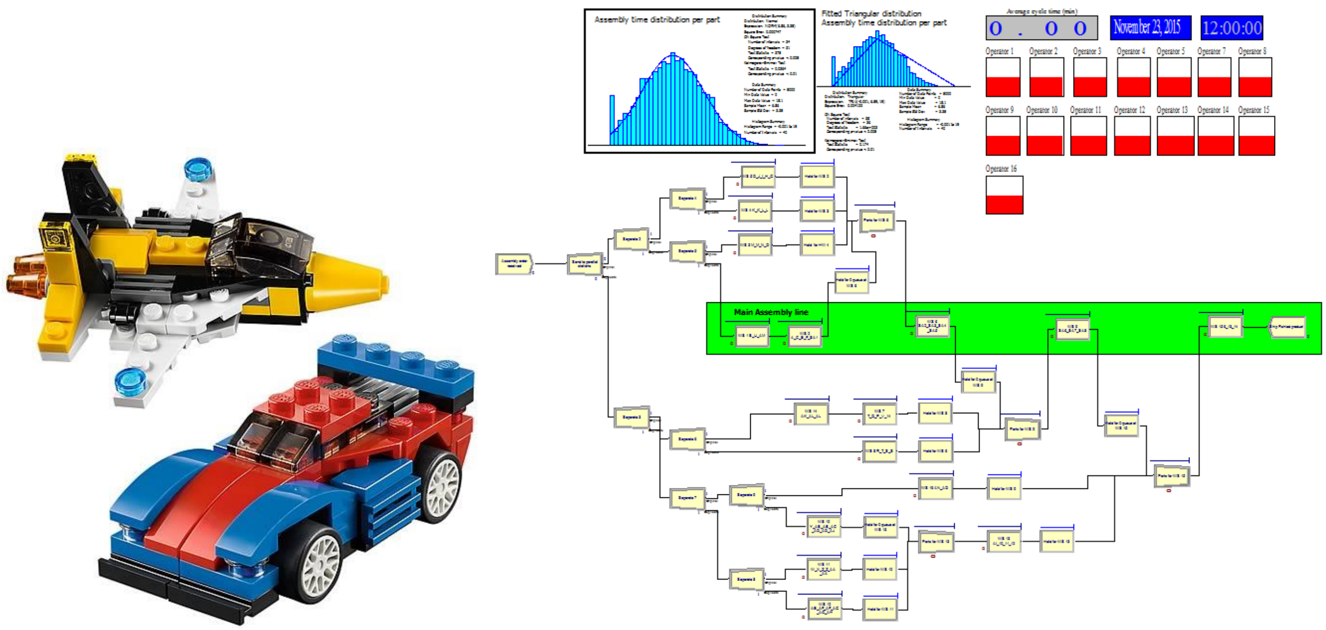

Figure 2: Products used for hands-on simulation [17] (left), Computer based simulation (right)

Once both simulations were created the groups went through several iterations of improvements on their process using Lean tools. Different tools were used in different ways depending on the type of simulation that was being used. Some of these differences are identified in table 1.

Table 1: Lean tools difference for both types of simulation

Lean Tool applied	**Physical Hands-on Simulation**	**Computer aided Simulation**
5 S	Arrangement of kits step-by-step sections was performed.	Assumption of time reduction was used to simulate 5S's improvement.
1 piece flow	Assembly operators had to wait to pass their product until the next station was free.	Restriction of resource seizing was used in avoid having the software create queues between stations.
Poka-yoke	Physical simple Poka-yoke's were created and implemented in the stations.	The concept was explained but only the scrap percentages changed to reflect the implementation of a Poka-yoke.

Value Stream Mapping	The VSM was not created but a small discussion on what it would look like was promoted.	The VSM was created when the simulation was created. The final report provided Value added and Non Value added times for analysis of improvements.
Total Productive Maintenance	Was explained and included in the simulation, but not improved on.	Was explained, included and improved on in the Simulation with the use of different resource failure times.

At the end of several rounds of improvements, a small 30 min discussion on Lean tools was held along with gathering student comments. The students were then requested to fill a post-survey to assess their understanding. The pre-survey was used as the baseline, and the post-survey was used in order to evaluate any statistical differences regarding knowledge and perception of Lean tools between the two groups. The results section presents the data analysis performed on all surveys received.

Results

The pre and post surveys, shown in appendix 2 given to the students mainly focused upon:

- Identifying students Proficiency on the use of Arena software
- Concepts of Discrete event simulation & probability density functions
- Scheduling rules of arena
- Understanding of the concept Bottleneck
- Use and Application of Lean principles
- Selection of appropriate lean tools

Figures 3 illustrates graphically the percentage of students before and after hands-on and computer aided simulation sessions on their perception of correct lean tools among the choices given to them. It can be observed that the students after the sessions were able to correctly identify the lean tools from the given choices. However, if closely observed, the students were not able to correctly identify the tools that are not a part of lean philosophy. It is believed by the authors that this is because; the emphasis was on student's learning the lean tools but not necessarily on identifying the wrong tools of lean philosophy.

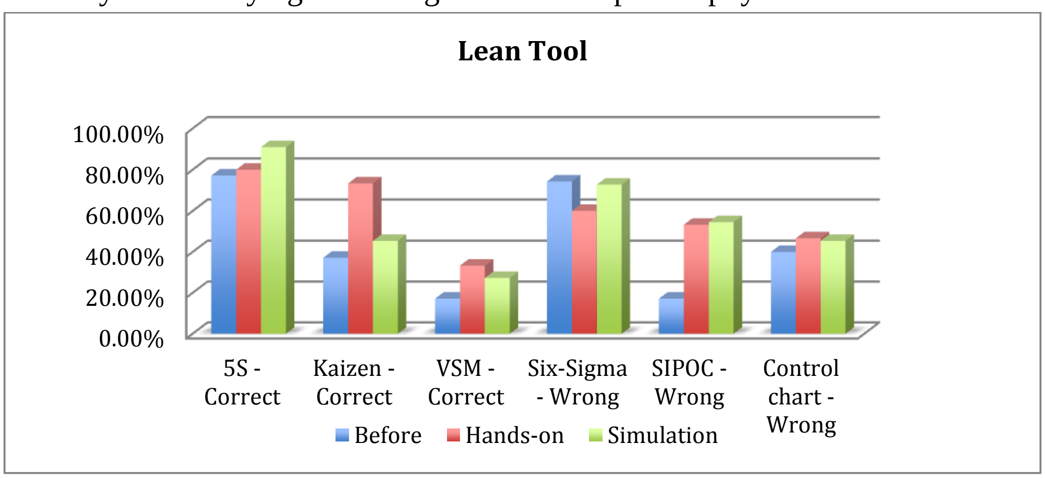

Figure 3: Lean tool identification survey question

Figure 4 illustrates student self-perceived view on the level of understanding they have on Lean principles. It can be seen that there is a significant shift observed towards a higher self-perceived view on the level of understanding. Statistically, most of the student's perceived themselves to have an "average level" (on a scale of "very low" to "expert") of understanding on lean thereby creating a significant skew in the graph.

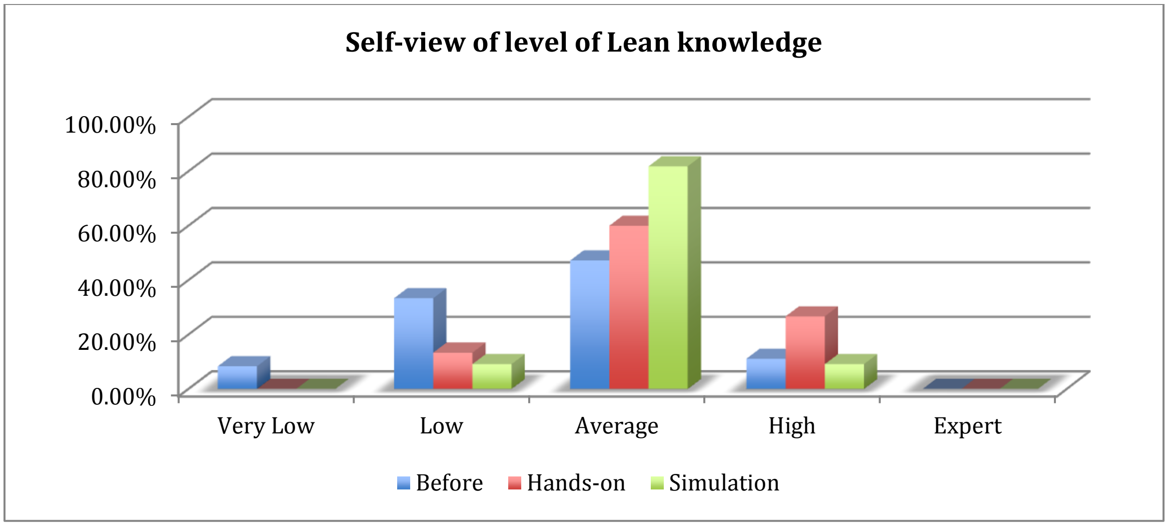

Figure 4: Self-view of Lean knowledge level

The main conclusions that can be drawn from the pre-survey were:

- Only 33% of the students were able to define the concept of bottleneck correctly before the simulations.
- 65.71% of students already could define what Lean is.
- The percentage of students that thought that the following tools are Lean tools were:
    - 5S's: 77.14% (Correct)
    - Kaizen: 37.14% (Correct)
    - Six-Sigma: 74.29% (Incorrect)
    - SIPOC: 17.14% (Incorrect)
    - Control charts: 40% (Incorrect)
    - VSM: 17.14% (Correct)
- Only 35.29% of students could identify correctly an example of Poka-yoke.
- 47.22% of students feel they have an average knowledge on Lean.

The conclusions that can be drawn from the post-survey given to the students involved with hands on simulation experience are:

- Only 13.33% of the students were able to define the concept of bottleneck correctly after the hands on simulation.
- 64.29% of students could define what Lean is.
- The percentage of students that thought that the following tools are Lean tools were:
    - 5S's: 80% (Correct)
    - Kaizen: 73.33% (Correct)
    - Six-Sigma: 60% (Incorrect)
    - SIPOC: 53.33% (Incorrect)
    - Control charts: 46.67% (Incorrect)
    - VSM: 33.33% (Correct)
- Only 13.33% of students could identify correctly an example of Poka-yoke.
- 60% of students feel they have an average knowledge on Lean.

The conclusions that can be drawn from the post-survey given to the students involved with Arena software simulation experience are:

- 45.45% of the students were able to define the concept of bottleneck correctly after the computer-aided simulation.
- 80% of students could define what Lean is.

- The percentage of students that thought that the following tools are Lean tools were:
  - 5S's: 90.91% (Correct)
  - Kaizen: 45.45% (Correct)
  - Six-Sigma: 72.73% (Incorrect)
  - SIPOC: 54.55% (Incorrect)
  - Control charts: 45.45% (Incorrect)
  - VSM: 27.27% (Correct)
- 45.45% of students could identify correctly an example of Poka-yoke.
- 81.82% of students feel they have an average knowledge on Lean.

Conclusion

The students that were exposed to the computer simulation using the Arena software showed an improvement on the concepts of lean, and showed a significant improvement on the way they perceived their level of expertise on Lean tools. On the other hand students exposed to the on-hands simulations, showed an improvement but slightly lower than the computer based simulation. Individual gains could not be calculated because the pre and post surveys were collected anonymously; this was done with the objective of allowing the students to be completely honest. Comparing both types of teaching Lean methods for students, it can be concluded that both improve the level of knowledge. The software simulation approach showed a slightly higher improvement. This difference was identified to be due to the fact that on the hands-on simulation some students did not participate as much, but with the computer based simulation, all students created the changes personally on their simulations allowing a better understanding of the process and the improvement.

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Appendix 1

A Manufacturing facility assembles 4 different Families of products with 3 different product variations each. Table 1 specifies the Product Family, Product name, and Part Number.

Table 2: Table of products manufactured

Product Family	Product Name	Product Number
Green Car	Race Care	6910-A
	Long Truck	6910-B
	Dragster	6910-C
Emergency Vehicles	Ladder fire truck	6911-A
	Fire truck	6911-B
	Helicopter	6911-C
Red Car	Sports Car	31000-A
	Short Truck	31000-B
	Old car	31000-C
Flying vehicles	Jet	31001-A
	Space Ship	31001-B
	Airplane	31001-C

All of these products are manufactured based on a **Make To Order (MTO)** production strategy. The time and quantity of each order for the months of January to June of 2015 is presented in the "Order entry time" record. The orders are processed in a **First-In-First-Out (FIFO)** sequential rule.

One operator per station currently assembles their specific products manually (their required assembly process at each station). There are 12 workstations per each main Station (one for each PN). The current floor plan of the manufacturing facility (not to correct scale) is presented in figure 1.

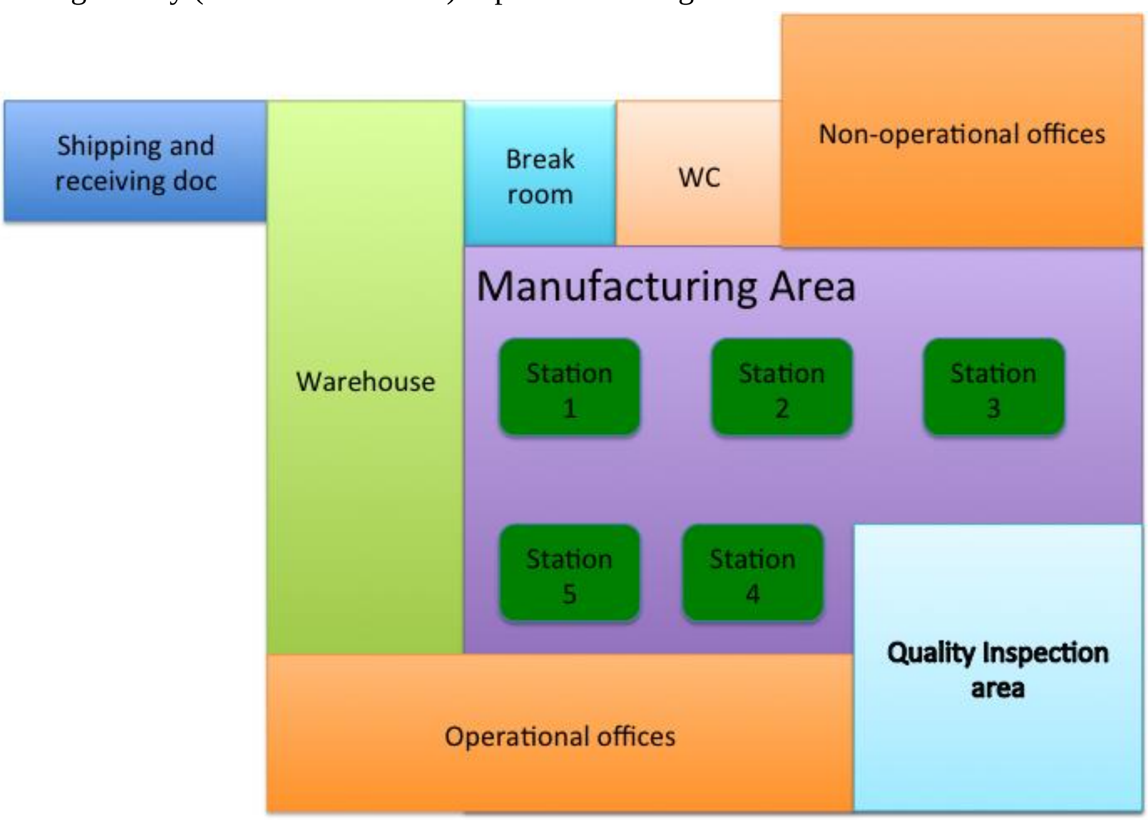

Figure 1: Facility floor plan

Once an order arrives, a purchase requisition is generated in order to buy the necessary parts required to assemble the corresponding product. The **Bill Of Materials (BOM)** and the **Lead-time** for each part can be found in the "BOM" record. Once the part has been received, all parts go through a **Raw Materials Inspection (RMI)** process where all parts are inspected visually and functionally. There are 12 quality technicians working on this inspection, the process varies between 1 and 3 minutes per part. A 99% of the parts are approved and sent back to the warehouse for normal production.

The Materials handling department has two "Kiters" that are responsible of creating the Kit with all the Parts required for a final product to be assembled. If the Kit is not complete, it is not send to production and an order is generated for the missing parts. The Kiting process (assuming all parts are available at the warehouse) takes an average of 12 ± 4 minutes per Kit. The Kits are transported by the Kiters to Station 1 in the manufacturing area using Utility Karts shown in figure 2. There are only 2 carts available and each cart can carry a maximum of 2 Kits.

Figure 2: Utility Cart on Wheels - Uline Black - 45 x 25 x 33"

Once the Kits have arrived to station 1 on the manufacturing area they go through all 5-assembly stations and finish in the Quality inspection area. An assembly of one part takes 3 to 5 seconds to be performed. If a part just needs to be selected (Ex. The first part of every product), or a realignment required; this process only takes 1 second. Each station assembles two pages (Not including title page nor BOM page) of the Work Instruction of each PN (some PN's might only requires 3 or 4 Stations). Once the assembly steps required on each station the **Work In Process (WIP)** is transported using a conveyor between stations as shown in figure 3. Even though formal Quality inspections are not established between stations, operators find wrong assemblies, missing parts or other defects on a rate of 1 per every 100 products. If any defect is detected, the entire kit is sent to an off-line rework station where the product is completely disassembled and sent back to station 1. The disassembly time depends on the amount of parts to be disassembled. It takes between normally 2 seconds to disassemble a part, but could take as less as 1 second and a maximum of 8 seconds.

Once products are at the Final Quality inspection are they go though visual inspection (done by a Quality Technician) and through a weighted inspection. The rejections of the products that reach final inspection, of the months of January to June are shown in the "Final product Quality control rejects" table. There are 8 quality technicians available that perform the Visual and weighted test, but only 4 scales are available (figure 4 shows the scales used). The visual inspection takes between 1 minute and 5 minutes and the weighted test takes 4 minutes ± 20 seconds. The scales stop working after the scale has been used for at least 300 uses. If they break a mechanic fixes them and take 4 to 5 hours to do so. They are also calibrated once every month by the metrology department, which takes 2 to 3 hours to do the calibration.

Figure 3: Automation Series AS40 and AS65 low profile belt conveyors

Figure 4: CAS MWP-300H High Accuracy Bench Scale, 300 x 0.005g

Once the final product is released from the Quality Inspection area, a batch record is generated with the PN, date, time and QC Technician that approved the product. A Material handler transports this record and the part manually to the warehouse area. There parts wait until batches of 15 parts are generated and then packaged and shipped to the distribution center for final delivery to the customer.

All personnel works an 8 hours shift (6:00am to 2:00pm). Production personnel (Assembly operators) take a lunch break at 10:00am. At break time, the operators stop what ever they are doing and go to break for their entire 30 minutes. All other personnel take their break at 10:30am. They finish the process or inspection they are performing and then go to break, they take their entire 30 minutes once they leave.

Appendix 2

1. How proficient are you with these concepts in Arena software?

	Very low	Low	Average	High	Expert
Using Basic modules	◯	◯	◯	◯	◯
Using Advance modules	◯	◯	◯	◯	◯
Entity, Queue and Resource animations	◯	◯	◯	◯	◯
Creating Plots & Graphs	◯	◯	◯	◯	◯
Understanding & Interpreting the Report	◯	◯	◯	◯	◯
Creating a Process flow	◯	◯	◯	◯	◯
Defining and identifying Entities	◯	◯	◯	◯	◯
Defining and identifying Queues	◯	◯	◯	◯	◯
Defining and identifying Resoruces	◯	◯	◯	◯	◯

2. Why does Arena have capabilities of Discrete event simulation?

◯ Because it is easy to use and simulate processes

◯ Because the processes can be divided into modules

◯ Because each event occurs at a specific time

◯ Because the flow of the processes are all connected

3. Probability Density Functions:

◯ Describe the likelihood of a random variable to take a given value

◯ Describes how the input of a process performs

◯ Describes what probability is given for random values

◯ Describes how the input of a random value affects the density function

4. The types of failures and scheduling rules that Arena uses are:

◯ Preempt, Ignore & Continue

◯ Ignore, Preempt & Wait

◯ Ignore, Wait & Continue

◯ Continue, Preempt, Ignore & Wait

5. What is a bottleneck?

- ◯ A process that reduces the amount of resources
- ◯ A process that has a big queue
- ◯ A process that has an average queue larger than 5
- ◯ A process that has the largest queue of the system

6. What is Lean?

- ◯ Short term cost reduction program
- ◯ Improvement program with an end goal
- ◯ Philosophy for reducing waste in a system
- ◯ The integration of many Kaizen events

7. Select the lean tools:

- ☐ 5S's
- ☐ Kaizen
- ☐ Six-sigma
- ☐ SIPOC
- ☐ Control charts
- ☐ VSM

8. An example of Poka-yoke is:

- ◯ Quality Inspection
- ◯ Automated quality Inspection (Ex. Vision system)
- ◯ Fixture that helps assembly process
- ◯ Fixture that prevents assembly errors

9. How proficient are you with Lean principles?

Very Low	Low	Average	High	Expert
◯	◯	◯	◯	◯