

2006-15: TEACHING LEAN MANUFACTURING ON A DISTANCE LEARNING PLATFORM USING VIRTUAL SIMULATION

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Teaching Lean Manufacturing on a Distance Learning Platform Using Virtual Simulation

Abstract

Simulation is the most common tool to introduce basic concepts of lean manufacturing. The vast deployment of simulation in industry to train workers and at universities to educate students attests to this fact. However, as companies with employees scattered in different states, or universities with students logging in from several countries try to teach principles of lean manufacturing using conventional simulation, the results are less than expected. This is due to the fact that the involvement of distance students in such simulations is limited to merely viewing the action being conducted by others physically present in the classroom setting. Being restricted to the sidelines, distance students are not enthused by the potential of lean manufacturing to eliminate waste and reduce lead-time for manufacturing and non-manufacturing processes.

In this paper a method is presented which is being proposed to be implemented to create a virtual simulation to involve distance students in a hand-on manner in learning lean manufacturing principles. As this virtual simulation is conducted entirely on the computer, it can also be a good tool to train non-manufacturing process operators in optimizing their processes where the product that flows through is merely information. Lean concepts like *Takt* time, elimination of non-value added functions, quality-at-source, reduction of processing time, point-of-use-storage, teamwork, and kanbans, can be introduced to distance students using this virtual simulation. The tool is also ideal to introduce the concept of virtual cells in non-manufacturing processes like those found in healthcare, banking, insurance, business office functions, etc.

Introduction

Lean manufacturing is one management practice that is sweeping the industry^{1,2,3}. Most educational programs in manufacturing engineering and engineering technology have created or adopted a product that can be produced in a manufacturing-simulated environment to bring home the principles of lean manufacturing in the class room and industrial training room settings. Several consulting companies have also developed products of their own. One popular program⁴ developed by the National Institute of Standards (NIST) consists of using two different circuit board assemblies to simulate two different lines of products as shown in Figure 1.

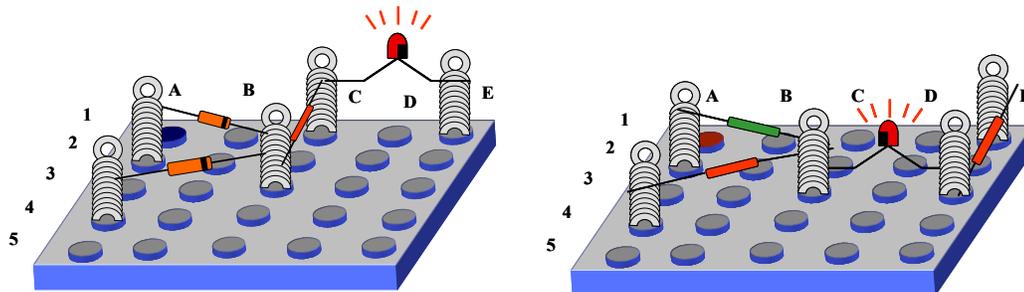


Figure 1. Lean Simulation Products—Blue Avenger and Red Devil

The NIST simulation kit requires the board for mounting of the electronic components and the springs used for holding the components in place to be procured as custom parts. To alleviate the problems encountered in procuring them, the author as part of developing the Advanced Manufacturing Training Program funded by the U.S. Department of Labor⁵, created a new set of products named the Green Hornet and Red Ranger from off-the-shelf components as shown in Figure 2. Several other products to enable teaching lean manufacturing through simulation are also being employed by various educators.

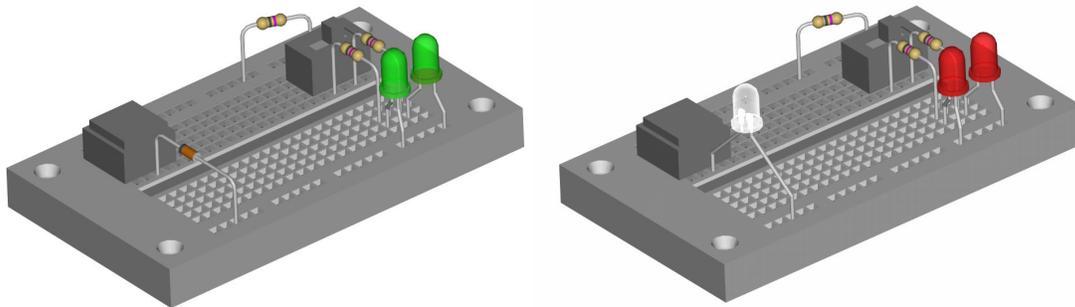


Figure 2. Lean Simulation Products—Green Hornet and Red Ranger

Lean Manufacturing Simulation

Simulation using one of the kits mentioned above is usually carried out in three or four rounds. The general pattern that has been found most practical is to let the first round be completely chaotic to reflect manufacturing conditions in non-lean manufacturing companies. This is followed by a second simulation round wherein the participants are given the leeway to make improvements based on their past learning and experience. This is then followed by a final round demonstrating how a cellular lean pull system can be instituted. In some simulation setups, an extra fourth round is included to not crowd in the introduction of all the lean principles into a single round.

In the first round of simulation, products are released for manufacturing based on a forecasted schedule in batches whereas shipping is done based on a completely different customer schedule. Although, the totals for the forecast and the actual orders to be shipped are the same, the variation amongst them creates a hoard of inventory lying between the various operations in the simulated process. A substantial amount of unnecessary production paperwork is made to be filled out in the first round, to mirror how useless data is generated on most manufacturing shop floors. This is to emphasize the effect of non-value added work on the total throughput of the system. Financial numbers like total revenues earned and the amount of profit generated are calculated to allow participants to get a monetary feel for their actions. At the end of the first round, there usually is a big loss that has been generated in the simulated factory.

In the second round, participants are given the freedom to rearrange the operation stations and improve the overall flow. Teamwork is stressed, and helping each other out is encouraged. In this

round, batch sizes are usually allowed to be halved, and a revised forecasted production schedule with half batch sizes is utilized for releasing production. Visual templates are provided to allow expediting the work operations, and the concept of standard work to maintain consistent quality is introduced. Also, unnecessary production reports are eliminated and incoming and outgoing signs are provided to allow the stations to be organized well, introducing the concept of 5-S. 5-S is a Japanese philosophy of workplace organization where the central theme is to have a place for everything and keep everything in its place, is practiced. In the second round, there is some improvement in terms of the profit numbers, however the variation in between the forecasted production schedule and the actual customer requirement still produces excess inventory in between the operations, resulting in substantial chaos within the simulated cell.

In the final round, the layout is created with kanbans in between the operations as shown in Figure 3, and the concept of *Takt* time is introduced. *Takt* time is the rate at which the customer buys the product, and the idea is to match the rate of sales to the rate of production. The processing times for each operation are determined in this round, and the number of operation stations are increased as necessary to allow the cycle time for the operation to be below the *Takt* time for each operation in the entire process. (Cycle time here is defined as the processing time for the operation divided by the number of stations in the operation.) The forecasted production schedule is eliminated in the final round, and the entire process is operated based on the pull that is created at the final shipping station based on actual customer orders.

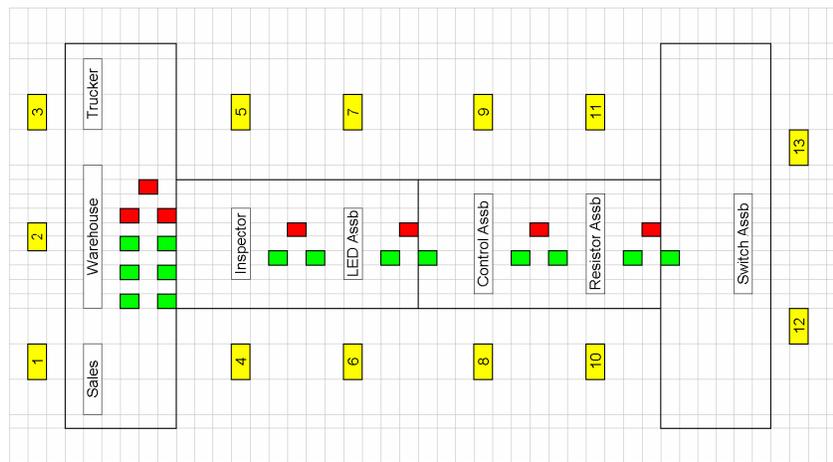


Figure 3. Simulation Layout for Final Round Utilizing Kanbans

The simulation is an eye-opener for people who have worked in industry, as one vice-president of manufacturing in Louisiana⁶ put it, “I thought it (the lean simulation) was excellent. It is one of the best seminar-type courses I have ever seen. It is a wonderful way to get people to buy into lean manufacturing and get them thinking about it.”

Need for the Virtual Simulation

Utilizing the new lean simulation kit created by the author as shown in Figure 2, it was found that the kit was well accepted by physically present students, and considerable enthusiasm was

developed by students and adult learners to take the principles of lean and apply it to real-life situations. However, when a distance education unit was added to the face-to-face class room unit, and the same simulation was conducted with the distance education students watching the simulation live, the distance learners were not very impressed. Somehow it seemed that they missed out not only on the learning of lean principles, but also were not effectively enthused to apply lean principles in their jobs.

In surveying the distance learners, the major reasons unearthed for their lack of involvement were: (1) absence of direct interaction with the facilitator during the simulation that resulted in the distance learners not getting drawn into the exercise as much as the face-to-face participants, (2) lack of camaraderie amongst the participants, that resulted in them not appreciating the importance of team-work, employee involvement and continuous improvement in applying the principles of lean manufacturing, and (3) a general feeling of boredom due to lack of empathy on the part of the distance learners during times when the simulated factory participants are busy with their functions, but the camera is capturing action that is silent and monotonous.

As most present day engineering or engineering technology programs have a face-to-face and a distance learning body of students, a method to virtually simulate a process to bring forth the principles of lean manufacturing is proposed, which is presently under consideration for implementation at the author's university.

Virtual Simulation

A pre-requisite in being able to participate in the simulation is to be able to use email, have access to an email account, be able to use software like Microsoft Paint, be knowledgeable to be able to create and save files on the computer, and use virtual meeting or virtual classroom software like BlackBoard, or Microsoft SameTime. However, with some initial training getting participants up to speed on these software to participate in this simulation is not difficult.

The virtual simulation has only two rounds of 30 minutes each. Two virtual products, the Red Card and the Blue Card are used in the simulation and the final completed cards are shown in Figure 4. The products consist of operators coloring specific colored dots in the right places. Three colors, red, blue and green are used in creating both the products. The circles with R, B, G and F are for obtaining approvals from managers after each coloring operation is over (R, B and G are for the three color approvers and F is for the final approval). In the first round, both the products will be made in batches of four.

All operators, along with having access to their email accounts, need to be logged on to a virtual class room in BlackBoard, or on a chat program like Microsoft SameTime, or any website created for instant messaging along with the means to have a common whiteboard area to allow for the creation of virtual kanbans in the second round. A minimum of thirteen participants is required to be able to run the simulation, with job duties as shown in Table 1.

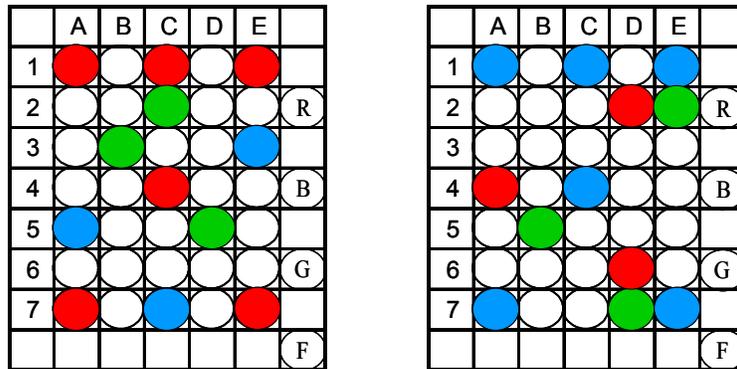


Figure 4. Virtual Simulation Products

Simulation Round 1

The material and information flow for the first round is as shown in Figure 5. Note that the files to be moved from one station to another are designated as material (or products) and instructions to coordinate the process are designated as information flow for the process. The process for the round begins with the Production Controller releasing orders to the Supervisor for the two products as specified in a forecasted order sheet provided to him/her. This is simply done by the Production Controller sending an email to the Supervisor stating that the specific number of pieces should be released for processing. The Supervisor then sends an email to the Material Releaser to go ahead and send the required number of attached drawing files which have the blank template of the product to the first operator in the process, which is the Red Painter. The drawing files can be in a commonly available software format like Microsoft Paint.

	Job Description	Job Duties	Names of Participant	Email Addresses of Participants
1	Supervisor	Coordination of the operators		
2	Material dispatcher	Releases product files to the first operator		
3	Production controller	Releases orders to supervisor		
4	Customer	Orders product from the sales department		
5	Sales department	Releases orders to the supervisor		
6	Red painter	Colors the dots red		
7	Blue painter	Colors the dots blue		
8	Green painter	Colors the dots green		
9	Red approver	Approves the red dots are good		
10	Blue approver	Approves the blue dots are good		
11	Green approver	Approves the green dots are good		
12	Final approver	Approves the entire product		
13	Shipping warehouse	Ships the products to the customer		

Table 1. Participants Needed for Virtual Simulation

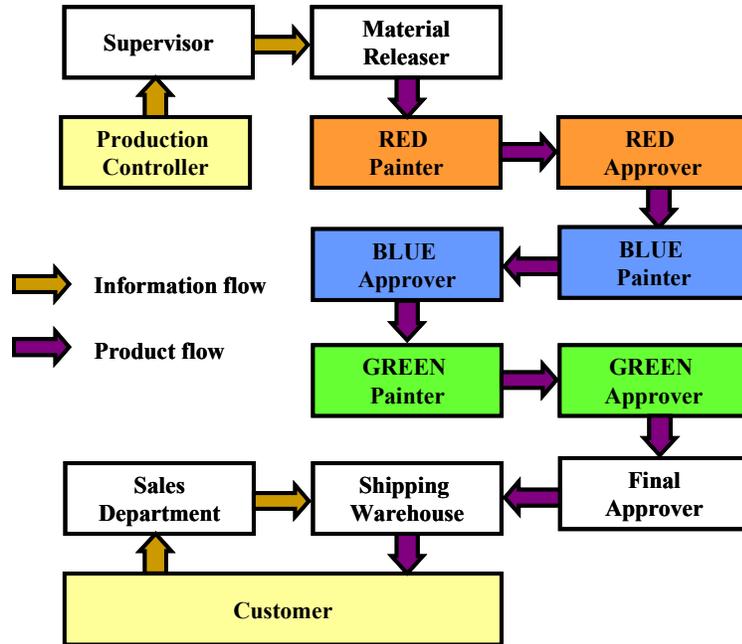


Figure 5. Flow of Information and Product in Round 1

On receiving the email from the Material Releaser, the Red Painter opens the product template files one-by-one, and begins to fill in the circles which have to have the red color in them, and goes ahead and saves it as a different file name. These are then forwarded on to the Red Approver as an attachment to an email. The Red Approver on receiving the files, opens them, checks the work, and fills in the circle that is a signature that he/she has approved it, and forwards it to the Blue Painter. All of the approvers keep a log of how many products they had to rework before forwarding to the next station to allow calculation of the percentage first pass yield of good product. This process keeps moving forward until the entire batch of all the files ends up with the Shipping Warehouse.

On the product shipping side of the simulation, the Customer releases orders as per a pre-defined schedule of orders, to the Shipping Warehouse. This is done by the Customer by sending an email to the Shipping Warehouse. On availability of the required number of product files to satisfy an order, the Shipping Warehouse dispatches the order as an email with the required number of file attachments to the Customer.

The number of orders released and the timing sequence in which they are released is kept consistent for both rounds. One hundred orders are released in an entire round. After the completion of the 30-minute round, the number of files stuck at each operation station which the operator was not able to forward to the next station are counted and the total work in process inventory is calculated. Collecting data on the products, the first pass yield pass, the number of products shipped late, and the profit or loss resulting from the round is determined which is similar to how it is done in the face-to-face simulation. A spreadsheet maintained on a common

platform that allows all participants to view it is used to carry out the calculation of these metrics.

Simulation Round 2

After completing the first round of simulation, lean principles are presented to the participants, and how these should be applied in the second round of simulation is discussed. The major principles that are included in this discussion are: (1) Takt time, (2) elimination of non-value added functions, (3) point of use storage, (4) quality at source, (5) use of templates, and (6) kanbans. The process for the second round is setup as shown in Figure 6. Details of how the products move through the simulation is explained in the next sections.

Takt Time

Assuming that the total products to be shipped are 100 units in a 30 minute period, the Takt time is calculated as 30 minutes divided by 100, which is equal to 0.3 minutes per product, or 18 seconds per unit. In applying the concept of Takt time, we now can determine whether each station is able to complete the entire operation in 18 seconds or not. If not, we assign two stations for that particular operation. The operators are now timed to see how long it takes them to complete each operation on the product, and this is used to make the determination whether to increase the number of stations.

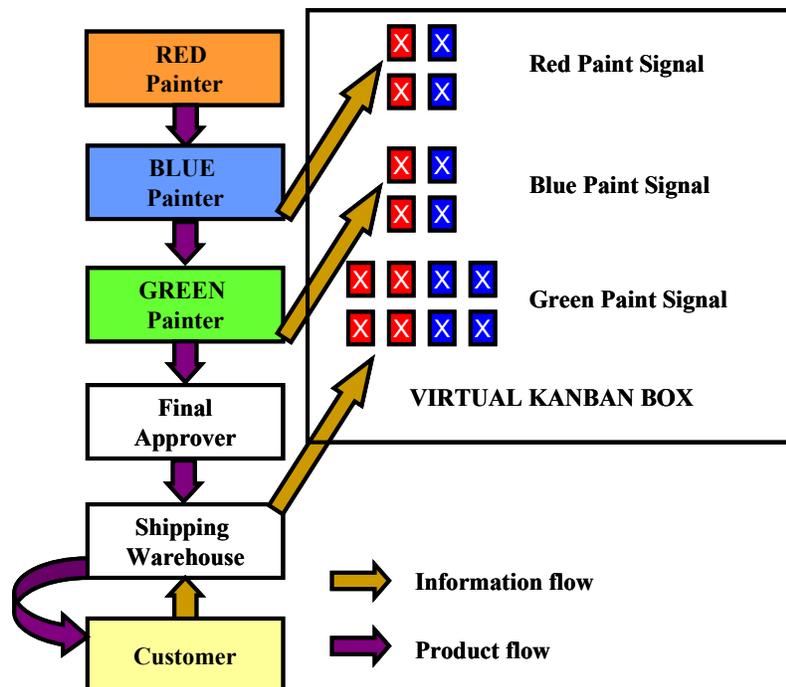


Figure 6. Flow of Information and Product in Round 2

Elimination of Non-Value Added Functions and Point of Use Storage

Of the participants in the first round, the Production Controller, Material Releaser, the Sales Department and the three approvers are not needed in the second round. The justification for doing so is explained to the participants, which is as follow:

The Production Controller is eliminated since forecasts are not needed in a pull system, and since orders are directly transferred to the Warehouse from the Customer. The Material Releaser is not needed since in lean, point-of-use-storage is implemented. In doing so, the Red Painter (the first operator) is provided with both templates of the product to directly begin the process without the need for the Material Releaser to send him/her the templates. The Sales Department was simply transferring orders from the Customer to the Shipping Warehouse in the first round, and removing the Sales Department from this process should theoretically allow them to concentrate fully on the selling function.

Quality at Source

The three approvers are adding expense without providing much benefit to the entire process as they have to make corrections to the mistakes created by the operators. Committing the operators to produce quality products using the concept of quality-at-source of lean manufacturing, and not allowing any bad product to leave the operator station in the first place, eliminates the need to have approvers after each operation. Assuming that the nature of the product is such that it requires someone from the company to certify that the final product is good, the final approver is retained.

Use of Templates

Templates to eliminate the need to read instructions to fill out the colors for each operation are provided to allow the operators to avoid filling the color in the wrong circle in the second round. This is done by including the letter R, B or G right where the colors red, blue and green are to be filled. This is shown in Figure 7.

	A	B	C	D	E	
1	R		R		R	
2			G			
3		G			B	
4			R			
5	B			G		
6						
7	R		B		R	
			RED			F

	A	B	C	D	E	
1	B		B		B	
2				R	G	
3						
4	R		B			
5		G				
6				R		
7	B			G	B	
			BLUE			F

Figure 7. Products With Template Notations Used in Round 2

Kanbans

Kanbans to institute a pull system tied into customer orders is incorporated in this round. Kanbans are created and maintained in the “Virtual Kanban Box,” which is available live on all operators’ screens in the simulation. The process begins in a similar manner to Round 1 with the Customer releasing an order, which is sent directly to the Shipping Warehouse as shown in Figure 6. The Shipping Warehouse has a set number of products already available as shown by the “X”s shown in the kanban squares in the Virtual Kanban Box. In this case four each of red and blue products are maintained in inventory. The goal is to begin with a higher number of products that will initially keep the products flowing, and which can be gradually reduced over time. Each operator is given the number of file templates as shown in the Virtual Kanban Box as semi-processed inventory to begin processing on getting their kanban signal.

The moment a product is shipped by the Shipping Warehouse, the Shipping Warehouse removes the X from one of the boxes in the warehouse kanbans, which is the Green Paint kanban signal. On seeing that one box is empty, the Green Painter takes the respective semi-processed file from his/her inventory and begins to process it. However, before starting to process the file, the Green Painter removes the cross from the respective box on the Blue Paint Signal, in essence signaling to the Blue Painter to begin his/her operation. This is how a single signal pulls the product through the entire process without the need to schedule any upstream operations in a virtual manner.

Similar to Round 1, after the completion of the 30-minute round, the number of boxes in the Virtual Kanban Box that has an X in them are counted and the total work in process inventory is calculated. Data from the Final Approver is also collected to see how many products he/she had to rework before forwarding to the next station. Based on the same metrics used in Round 1, a profit number for Round 2 is calculated to compare with results from Round 1. Due to the implementation of various lean principles and the introduction of the Virtual Kanban Box, substantial improvement should be noted in Round 2 over Round 1.

Virtual Cells

The virtual simulation is also well suited to demonstrate how non-manufacturing related processes should be optimized. In lean manufacturing, major thrust is given to the creation and implementation of work cells to improve throughput through the elimination of waste. This is true because work cells allow balancing of various value streams to satisfy fluctuating Takt times for product families.

In adapting lean principles to non-manufacturing processes by creating work cells, it is not possible, or even logical to physically locate subsequent operations close to each other, similar to the ones deployed for manufacturing processes. However, by not tying discrete operations together in non-manufacturing processes considerable delay is introduced and tolerated in between the operations in the process.

Through the creation of virtual cells, in which the completion of one operation automatically notifies the next operation station that immediate action is needed so as not to introduce time

delay into the process, a substantial reduction in the total lead time for completing the entire process can be achieved. And the presented virtual simulation is a great way to introduce the concept of virtual cells.

Summary and Conclusions

Face-to-face simulations have been good for demonstrating lean principles in a class room setting. However, doing a virtual simulation can not only allow distance education students to participate in the exercise in a hands-on manner, but also be a useful tool to demonstrate to non-manufacturing employees how the principles of lean manufacturing can be applied to processes in which the product transferred from one operation to another is merely information.

Using computers to move a simple product like a file attached to an email in cyber-space, we can successfully demonstrate the application of lean principles including Takt time, elimination of non-value added functions, quality at source, use of templates, point of use storage, and kanbans, to participants who need not be in the same room.

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