AC 2009-23: HANDS-ON SIMULATION TO DEMONSTRATE KEY METRICS FOR CONTROL OF ANY PROCESS UTILIZING LEAN AND SIX SIGMA PRINCIPLES

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Hands-on Simulation to Demonstrate Key Metrics for Control of Processes Utilizing Lean and Six Sigma Principles

Abstract:

Great emphasis is placed these days by private businesses and government agencies on quickly improving manufacturing and administrative processes through waste elimination and variation control. Lean manufacturing and six-sigma are two tools which allow substantial wasted effort to be eliminated and provide a statistical means to control variation in processes.

Classroom simulation utilizing a simple product made from Lego® blocks was used to show how a process becomes inefficient through large batch processing and unbalanced operations, and is discussed in this paper. Also, how metrics to control a process should be defined and calculated are covered in the paper. These metrics include Lean six-sigma metrics of lead time, inventory efficiency, percentage value added time (%VAT), first pass yield (FPY) and rolled throughput yield (RTY).

The concept of measuring the efficiency of a process utilizing operator efficiency is then presented and how it can be used to balance a process is discussed. Operator efficiency allows the simultaneous determination of evaluating how balanced the operations are in a process and how well the operators are performing. Utilizing examples of primed and un-primed processes, how the metric of operator efficiency can be calculated is shown in this paper.

Introduction:

Every company wants to cut costs and provide outstanding value and service to their customers. Two philosophies and tools to produce the needed results are lean manufacturing and six-sigma. Lean manufacturing has been defined as "a systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection," [1]. Six-sigma methodologies are a business philosophy and initiative that enables achievement of world-class quality and continuous improvement, along with the highest level of customer satisfaction [2].

Principles of Lean processes were first identified by Womack and Jones [3] [4], when they conducted their five-year, five-million dollar study on the differences between American and Japanese automobile manufacturing companies. In the report that they compiled for the study, that later was published as the book titled "The Machine That Changed The World," they elaborated on how automobile manufacturers in Japan seem to be using less resources to produce the same output compared to American manufacturers. In the report they first coined the term, "Lean manufacturing," by saying that the Japanese seem to be really lean in the consumption of resources to produce automobiles, and it seems that they are pursuing what can be called *lean* manufacturing [5].

Together, lean and six-sigma present a powerful array of business tools that can be utilized by companies in their pursuit of waste elimination and reduction of variation in products and processes.

Simulation Tools:

Simulation is widely used to introduce basic concepts of lean manufacturing, especially to operators from the shop floor who are more hands-on. Principles of Lean manufacturing were originated first by Toyota to eliminate waste and reduce lead-time for manufacturing and non-manufacturing processes. 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 firms have also developed products of their own. One popular program [6] developed by the National Institute of Standards and Technology (NIST) consists of using two circuit board assemblies to simulate two different lines of products as shown in Figure 1.

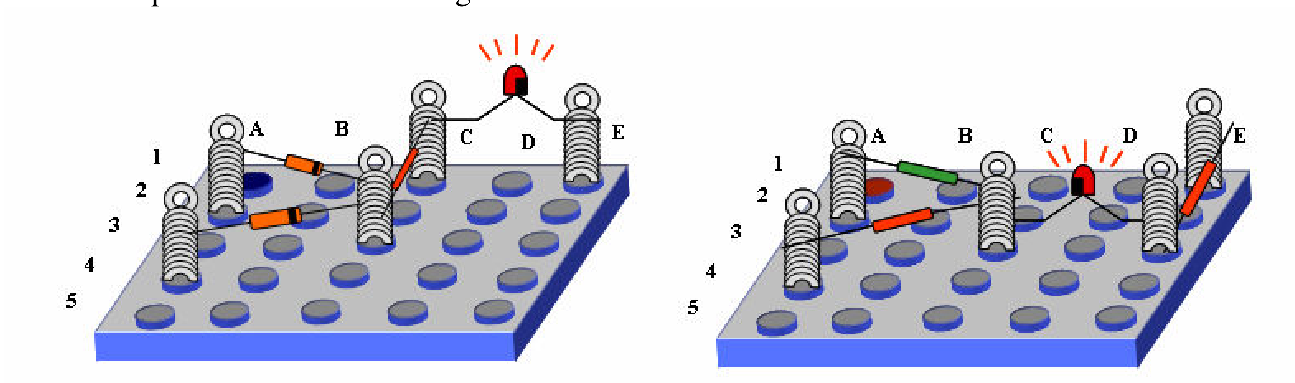

Figure 1. Simulation Kit Developed By NIST

Simulation using one of the readily available kits 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. A table of metrics as shown in Figures 2 is used to capture the production and quality details of the simulation output, and these are then transformed into financial metrics as shown in Figure 3.

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 as shown in Figure 3. At the end of the first round, there usually is a big loss that has been generated in the simulated factory.

Scenario 1	Round 1			Round 2			Round 3			Round 4		
Average Cycle Time (min.)	>20	>20		7.53	15.35		7.3	6.3		1.28	1.58	
# Units in Ending WIP	54	20		54	24		42	16		6	6	
# Units on Time	0	0		3	2		4	11		78	70	
# Units Shipped Late	7	4		7	12		48	18		0	0	
# Units in Finished Goods Warehouse	0	0		0	1		0	0		0	0	
# of Employees	17			17			17			17		
# of Tables	12			11			10			7		
# Ft. Traveled	165			75			42			30		
# Failed	5			8			8			6		
# Passed	4			30			72			142		

Figure 2. Production and Quality Metrics

Buzz Electronics Financial Report

	Round 1	Round 2	Round 3	Round 4
Sales Revenue	$ 260.00	$ 620.00	$ 1,910.00	$ 3,660.00
Operating Costs				
Facility	$ 120.00	$ 110.00	$ 100.00	$ 70.00
Labor	$ 127.50	$ 127.50	$ 127.50	$ 127.50
Materials	$ 532.50	$ 660.00	$ 810.00	$ 947.50
(Total Operating Costs)	$ 780.00	$ 897.50	$ 1,037.50	$ 1,145.00
Net Income	$ (520.00)	$ (277.50)	$ 872.50	$ 2,515.00

Figure 3. Financial Metrics

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 well organized, 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. 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 4, 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.

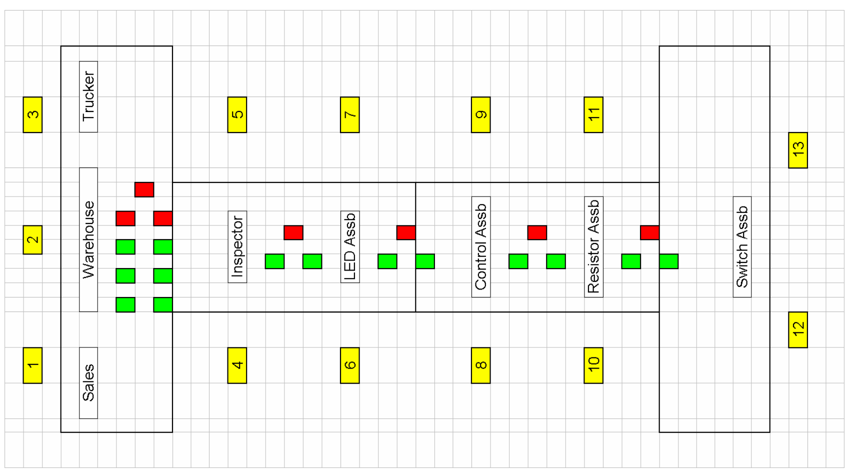

Figure 4. Simulation Layout for Final Round Utilizing Kanbans

The simulation is an eye-opener for people who have worked in industry for many years, as one vice-president of manufacturing in Louisiana put it, "I thought it (the lean simulation) was excellent. It is a wonderful way to get people to buy into lean manufacturing and get them thinking about it." [8].

Operator Efficiency:

Though the simulation is a good learning experience, lessons from this simulation are not directly applicable to people working in a cell on the factory floor since no calculations as to the efficiency for the cell is done. Utilizing the concept of operator efficiency helps participants learn how to balance the process to flow the product with the greatest throughput.

Operator efficiency also allows the operators to see how well they are performing in the process. In the simulation, primed and un-primed processes are demonstrated. An unprimed process is one which begins with absolutely no inventory of work-in-progress in the line. This is what happens when we start to manufacture a new product after a changeover. A primed process is one where the process has been stopped with inventory in between each operation like at the end of the shift. Operators then come back the next day to a primed process and start where the process was stopped. A primed process is often called a "wet" process and an unprimed process is called a "dry" process.

Figure 5. Simple Process With Three Operations

To understand the concept of operator efficiency, let us assume a simple process as shown in Figure 5. The sum of operation times for the three operations is equal to 15 + 25 + 50 = 90 minutes. Now say there are 3 operators in the process, and the process is operated for an 8-hour shift with 2, 10 minute breaks. This makes the available time for the operation of the process to be equal to (8 hrs x 60 minutes) – (2 x 10) = 460 minutes. The total person-minutes in the cell will be equal to 3 x 460 or 1380 minutes. Based on this if we are to calculate the ideal expected output it will be 1380 / 90 = 15.33 units.

Now once the cell begins to operate, the first unit will be done in 90 minutes as it will go through the three operations A, B and C. The cycle time C/T for the entire process consisting of the three operations A, B and C, will be 50 minutes because Operation C is the bottleneck operation. Hence, in the remaining (460 – 90) = 370 minutes in the shift, we can get (370 / 50) or 7.4 units. Hence, in the entire 8-hour shift we will get (1 + 7.4) or 8.4 units. In this scenario, we started with no inventory in between operations or with an un-primed line.

Now, say you keep the line filled with an available unit at start of shift or have a primed line. In such a case, the first unit will be done instantly after the production begins since a unit is ready after Operation C. Hence, in the 460 minutes of the shift, we can get (460 / 50) which is 9.2 units. Adding the one unit that we got at the very start of the shift, in 8 hours we will get (1 + 9.2) units or 10.2 units. Hence, the expected output for a primed line for our scenario will be 10.2 units.

Doing these calculations, we have three numbers: (1) Ideal Expected Output = 15.33 units, (2) Expected Output (un-primed line) = 8.4 units, and (3) Expected Output (primed line) = 10.2 units. We can now use these numbers to calculate operator efficiencies.

For our scenario, if the process produces 15.33 units we can say that the work-cell is running at an ideal efficiency of 100%. This can only happen if the operations are perfectly balanced, and if the operators are working to maintain the balance by working at 100% efficiency. With the imbalance arising from differences in the operation times for the three operations though, the efficiency that can be achieved in the un-primed cell can only be equal to 8.4 / 15.33 or 0.548 or 54.8%. Hence we say that the Operator Efficiency (un-primed line) = 54.8%. Similarly, the Operator Efficiency (primed line) will be 10.2 / 15.33 or 0.665 or 66.5%. The summary of the results for the example are shown in Figure 6 below.

	Expected Output Units	Expected Operator Efficiency
Ideal	15.33	100.0%
Un-primed	8.4	54.8%
Primed	10.2	66.5%

Figure 6. Summary of Results of Operator Efficiency Results

Using these, we can see that the loss of efficiency from 100% to 66.5% is due to the imbalance in the process even when the process is run primed, and the loss of efficiency from 66.5% to 54.8% is due to running the line un-primed. Processes that are infrequently done can be considered un-primed processes, whereas repetitive processes that are constantly being carried out can be considered primed processes. Naturally, if a process can be kept primed, the efficiency of the process will be higher as shown by our example. Production and transactional business processes can both be primed or un-primed processes depending on the application.

Lean Simulation For Operator Efficiency:

In teaching lean simulation to allow participants and students to learn about operator efficiency, Lego® blocks are used to build a toy airplane as shown in Figure 7. The topside and the bottom-side of the plane are shown in the left-hand and right-hand pictures respectively.

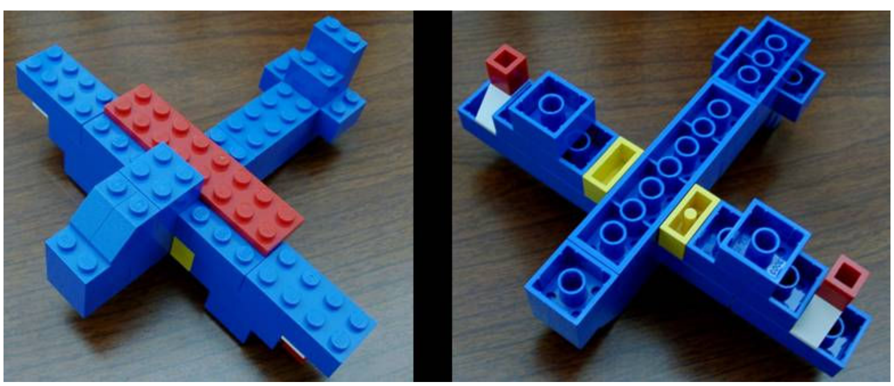

Figure 7. Lego® Airplane to Demonstrate the Concept of Operator Efficiency

Station #	Job Description	Required
WS-1	Wings Assembly	2
WS-2	Extension Assembly	1
WS-3	Tail Assembly	1
WS-4	Wheel Assembly	1
WS-5	Rudder Assembly	1
WS-6	Aerolon Assembly	2
WS-7	Cockpit Assembly	1
WS-8	Engine Assembly	1
WS-9	Tank Assembly	1
WS-10	Inspection	1

Production Planners / Material Handlers	
1	
2	
3	
Production Planning Manager	
Plant Manager	
Industrial Engineers	
1	
2	
3	
Sales Manager	
Customer	

Figure 8. Operations and Jobs Required to Perform the Lego® Simulation

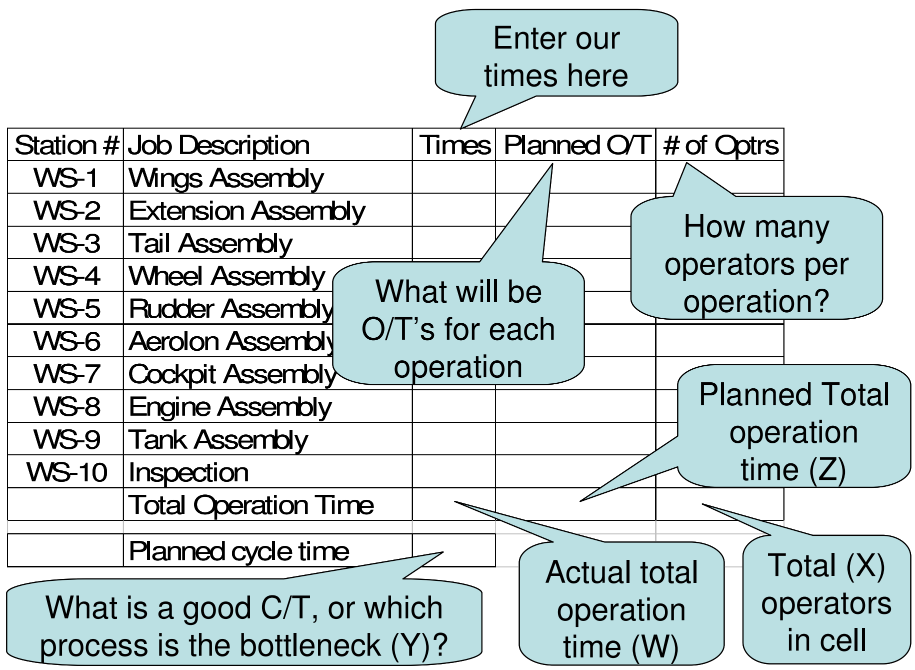

Figure 9. Chart Used to Balance the Operations in the Lego® Simulation

The list of participants that can take part in the simulation exercise are shown in Figure 8. A total of 22 people that include 12 operators can be accommodated. Depending on the availability of the people, some staff functions can be eliminated. Figure 9 shows the chart utilized for balancing the operations in the simulation and calculate the operator efficiency. Once the work-cell is balanced as best as possible, metrics are collected to allow the operators to view how efficiently they are performing as shown in Figure 10. Figure 11 shows the final chart that is used to make comparisons between the various metrics and bring home the concept of operator efficiency. Figure 12 shows participants engaging in the airplane simulation exercise.

	Round 1	Round 2	Round 3
Time to make one airplane:	425	186	132
Airplanes made in 6 minutes:	1	8	27
Total inventory in system:	45	23	9
Airplanes rejected:	5	4	2
Number of people in cell:	16	14	9
Productivity: airplanes / person	0.06	0.57	3
		Improvement Round 1 to 2	Improvement Round 2 to 3
Time to make one airplane:		-56%	-29%
Airplanes made in 6 minutes:		700%	238%
Total inventory in system:		-49%	-61%
Airplanes rejected:		-20%	-50%
Number of people in cell:		-13%	-36%
Productivity: airplanes / person		814%	425%

Figure 10. Metrics Collected in the Three Simulation Rounds

	Expected output units	Expected operator efficiency	Actual operator efficiency
Ideal			
Un-primed			
Primed			
	Round 2	Round 3	Improvement
%VAT			

Figure 11. Final Chart Showing Improvement in the Metrics

Figure 12. Participants Engaged in the Lean Simulation

Conclusions:

Simulation is a great tool for demonstrating the principles of lean manufacturing, but without letting the operators know how much actual waste in terms of loss time is cushioned in their process, the potential of lean ideas is lost. Utilizing the concept of operator efficiency and calculating the ideal efficiency, the expected efficiency for an unprimed line, and the expected efficiency for a primed line allows us to be able to estimate how much loss of efficiency can be expected to occur due to the imbalance of the processes. Once the process is run and the actual numbers derived, the operators can then be shown how much further waste is incurring in their process or work-cell due to their lack of teamwork and coordination.

The simulation using toy Lego® airplanes is very replicable and the results of the exercise can be immediately taken to the shop floor work-cell and can immediately allow management and operators to see the extent of waste in their setup.

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