Problem Definition and Problem Solving in Lean Manufacturing Environment

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Abstract

This paper describes the use of scientific principles of Lean Manufacturing for teaching problem solving process in Lean environment. Various Lean Efficiency Factors are used to provide evaluation of production environment at various stages of improvement efforts. A particular emphasis is put on the move from qualification to quantification of waste. Based on results of quantification of the present state of environment, groups of students develop lists of solutions to be implemented. Each of the proposed solutions is then ranked and accompanied by quantification of gains expected from its implementation. Some solutions implemented by the manufacturers to guard against detrimental influence of external factors are also presented after the exercise. A preliminary evaluation of advantages and challenges encountered while teaching the topic using hands-on simulation with simple objects, as well as solutions to the problems are presented.

1. Introduction

Large scale applications of Lean Manufacturing, origin of which can be traced back to Ford Motor Co. in 1910's, have matured at Toyota Motor Co. during 1960's through 1980's [1 – 11]. Paraphrasing long known goal of designers *"the simpler the better"* into the realm of production management one could say *"do more with less"*. Baudin defines lean production as continuous pursuit of improvement in all measures of manufacturing performance by elimination of waste [12, 13]. The eight key principles of lean production according to Schniederjans [14] are:

1 production to order
2 one piece flow production
3 elimination of waste
4 continuous production flow improvement
5 perfection in product quality
6 respect for employees
7 elimination of contingencies (e.g. production buffers)
8 maintenance of long term emphasis.

Since the Lean Manufacturing is as a concept, a philosophy and a strategy for achieving excellence in production and management of related operations, the available literature treats the subject using descriptive qualification. It deals very little with numbers and measures transferable from one industrial setting to another. The five steps for implementing lean production proposed by Womack and Jones [8] are a good roadmap, but they do not provide any decision making tools. The ten steps to achieve lean production proposed by Black [15], lay out a roadmap to success, however the activities and milestones are vary vague and no specific and immediately usable performance measures are introduced. Nisanci and Nicoll [16] proposed an eleven step project planning network for investigation and implementation phases of lean manufacturing. The precise activities and evaluation-implementation sequences of the network steps need to be devised by users themselves. In all these methods, there is no exact performance measure that would point initial improvement efforts towards the biggest wastes or compare them to a standard (for example standard achievements in an industry). Obviously, such "industry standards" do not exist, or rather are kept unpublished since they are at the core of a set of competitive advantages of a manufacturer. However, inside a facility or an organization, there should be a flow of somehow standardized information about methods that help pointing out the biggest wastes. At present, such information is in a form of personal experiences of sensei or other people involved in lean improvements efforts.

A pyramid model of waste elimination and performance measures [17] suggests close to twenty measures, none of which relates to the performance of the entire production system but rather to specific aspects of production or accounting. For all of the proposed measures, equations have to be developed by users themselves.

Many case studies on lean improvements are available in literature. Very few of them show entire picture of the old and the new stage of production outcomes, largely focusing on a few big improvements achieved. One case study of a metal cutting tool manufacturer [13] reveals interesting, yet fairly common trend: value added time is a minute fraction of the product lead time, only about 0.01%. After improvements, the product lead time decreases by 72%, but this is mainly due to 78% reduction in raw material lead time (79% contribution to the product lead time decrease). All improvements inside the factory decreased time spent by the material on the floor by 56%, but that amounts only to a 21% contribution to the product lead time decrease. This raw material lead time reduction was achieved through by incorporating delivery to forecast (hence elements of push system were put in place of pull system), instead of truly reducing raw material lead time. After implementation of the improvements, the raw material lead time still accounts for 57% of lead time for finished product (versus 72% before the improvements). All these numbers, which could be used to suggest areas of immediate improvements, instead of being exposed for analysis are hidden inside a cluster of other numbers.

Lean Efficiency Factors introduced by Prusak [18], are the first approach to enumerate various aspects of entire production operation, from order reception to product delivery to a customer. Application of some of these factors for problem simulation in class exercises stemmed from the observed need of academic and industrial students for having something more than an opinion or educated guess while making decisions related to lean improvement efforts.

2. Lean Manufacturing Principles and Low Hanging Fruits

Since about 1960's in Japan and late 1980's in the USA, Lean Manufacturing principles revolutionized the approach to the entire process of fabricating a product. In its core, is a quest for elimination of waste not only on production floor level, but across an entire organization. Ten Primary Wastes in any operation, whether in manufacturing or office environment, can be described as [19]:

1. Overproduction
2. Waiting of a part or a resource for the next processing step
3. Motion – unnecessary movement of employees and other resources
4. Processing
5. Defects (products and processes)
6. Inspection
7. Inventory (too high or too low)
8. Transportation of products or resources
9. Re- (repetition, redoing, rework, etc.)
10. Disposal

Following principles of Kaizen, the emphasis should be primarily placed on wastes that are easy to eliminate and on wastes with highest contribution to the overall inefficiency. From the teaching point of view, not all of the above described wastes are easy to simulate in a classroom setting. However wastes number: 2, 3 and 5-9 (Waiting, Motion, Defects, Inspection, Inventory, Transportation, and Re-) are fairly easy to simulate and measure in a classroom. Table 1 illustrates the type of waste, its measurement type and physical unit of each measurement as used in classroom exercises. Table 2 illustrates the relationship of earlier described Schniederjans' key principles of lean production to classroom activities, namely strength of emphasis in exercises and ease of addressing each principle.

Table 1. Type of waste, type of measurement and physical units used in class exercises simulating lean manufacturing environment.

Waste	Measurement type	Physical unit
Waiting	Time	[s]
Motion	distance or time	[m or s]
Defects	number of defects	[-]
Inspection	existing or non-existing	[-]
Inventory	number of items	[part]
Transportation	distance or time or cost	[m or s or $]
Re-	necessary not necessary	[-]

Table 2. Schniederjans' eight key principles of lean production addressed in class exercises simulating lean manufacturing environment.
● substantial emphasis, ⦿ secondary emphasis, ○ no emphasis.

Principle	Emphasis	Ease of addressing
1. Production to order	●	Easy
2. One piece flow production	●	Easy
3. Elimination of waste	●	Somewhat easy
4. Continuous production flow improvement	●	Somewhat easy
5. Perfection in product quality	⦿	Somewhat easy
6. Respect for employees	○	Difficult
7. Elimination of contingencies	⦿	Easy to difficult
8. Maintenance of long term emphasis	○	Difficult

3. Lean Efficiency Factors Used

Out of 18 Lean Efficiency Time Factors introduced by Prusak [18], 6 were used in classroom exercises with goals of visualizing waste, qualifying and quantifying it, and to inspire improvement efforts. The choice of factors for the exercise is based on fulfillment of the above three goals and on simplicity of measuring their inputs. The chosen factors are:

1. Internal Movement Time factor - actual movement of raw material and parts.
   Receiving → incoming quality inspection (average per part if not 100% inspection) → storage → first machine → through all other machines → QC (average per part if not 100% inspection) → secondary operations (packaging, etc.) → finished goods stock → shipping.
   $$LET_{m,\text{int}} = \frac{T_{m,\text{int}}}{T} \quad (1)$$
2. Outside Movement Time factor - actual movement of parts for subcontracted operations.
   Packaging for shipment → shipping → processing by subcontractor and return on-site → receiving → incoming quality inspection (average per part if not 100% inspection) → storage.
   $$LET_{m,out} = \frac{T_{m,out}}{T} \quad (2)$$
3. Rework Time factor
   $$LET_{re} = \frac{T_{re}}{T} \quad (3)$$
4. Waiting for Processing Time factor
   $$LET_{wp} = \frac{T_{wp}}{T} \quad (4)$$

5. Incoming Order Fulfillment Time factor

$$LET_{raw,in} = \frac{T_{raw,in}}{T} \tag{5}$$

Where: $T_{raw,in} = 0$ if needed material is already in the inventory

6. Internal Raw Material Inventory Pull Time factor

$$LET_{inv,p} = \frac{T_{inv,p}}{T} \tag{6}$$

The nomenclature and definitions for the above equations:

LET Lean Efficiency Time factor

QC Quality Control

T Total order fulfillment time (time from the order reception to order delivery to customer's site)

$T_{m,int}$ Internal Movement time (movement time of raw material and parts inside the plant). Receiving → incoming quality inspection (average per part if not 100% inspection) → storage → first machine → through all other machines → QC (average per part if not 100% inspection) → secondary operations (packaging, etc.) → finished goods stock → shipping.

$T_{m,out}$ Outside Movement time (movement time of raw material and parts for subcontracted operations outside the plant). Packaging for shipment → shipping → processing by subcontractor and return on-site → receiving → incoming quality inspection (average per part if not 100% inspection) → storage.

T_{re} Rework time

T_{wp} Waiting for processing time

$T_{raw,in}$ Incoming Order Fulfillment time (from requesting raw material or components from a supplier to their shipment by the supplier – encompasses all order fulfillment activities at the supplier site, but does not contain the incoming shipment transportation time)

$T_{inv,p}$ Internal Raw Material Inventory Pull Time (from a request to inventory department to the start of production)

Theoretically, value for each of the above listed factors can be as small as 0 and as big as 1. The idealistic target value for each factor is 0, which would mean an infinitely fast response to a customer order. In other words, when an order is received, the items produced for that order arrive at customer's site in no time.

4. From Lean to Agile

It is very common that, while solving a problem, not only students but also seasoned engineers do not try to find the root of the problem, but concentrate efforts on optimizing existing solutions which may not be based on the most suitable principles. That may be caused by a variety of reasons, such as: managerial or group decisions, internal politics, reliance on internal or industry standards or simply by psychological inertia. Use of appropriate metrics tends to point towards the most promising solutions.

Agility in respect to manufacturing is understood to have four basic principles [20]:

- delivering value to the customer
- being ready for change
- valuing human knowledge and skills
- forming virtual partnerships

The first three principles are among the core functional fundamentals of lean manufacturing organizations [1, 3, 6 and 8]. The fourth principle is rather non-existent for Lean. It is due to quite different approaches envisioned by Lean and Agile towards partnerships with suppliers. Following Toyota's supplier model, Lean envisions long term relationships with key suppliers targeted at over 20 years, while Agile aims at shorter but flexible relationships [21]. Among various Agile Manufacturing tactics envisioned by Gunasekaran, two of them: "Decision making on functional knowledge level" and "Easy access to integrated data" [22, 23] need to be supported by relevant metrics and data. Simulation of both tactics, from building through experiments to verification, is therefore doable in a simple classroom environment as described below. From the Lean Efficiency Time factors used in the exercise, two provide information useful from the point of view of the fourth principle. They are: Outside Movement Time factor and Incoming Order Fulfillment Time factor.

5. Exercises Simulating Lean Manufacturing Environment

Exercises assigned to groups of 10 to 12 people were completed almost entirely in classroom. Some out of the classroom work was required to complete calculations and evaluate results. This type of projects gave multiple opportunities to repeat the experimental runs. Objects used are children's building blocks: Mega Blocks Mini or Lego Duplo. There is almost no limit in creation of a production facility using such simple objects as building blocks. For that reason, only an exemplary exercise is outlined in this paper. The exercise is preceded by theoretical introduction to the principles of lean production, definition of wastes, value adding activities, most common inefficiencies, Lean Efficiency factors, and numerical analysis of a hypothetical production case using the Lean Efficiency factors.

In the first run of the experiment, the production system is intentionally inefficient. Raw materials (components in form of individual blocks as shown in Figure 1) are held in storages, each type separately, situated in various places and far from the subassembly and final assembly points as shown in the layout in Figure 2. There is a "fork lift" (one person) transferring all the parts between departments and a "shipping truck" (another person) carrying the finished products to customers. Inventory personnel receive messages from subassembly about which items to deliver to the subassembly and assembly. Subassembly in turn receives requirements from the final assembly. The final assembly calls the required volume of parts needed based on a sheet containing a forecasted demand (given to the students). Although the finished parts are very similar in shape, only certain combinations of colors and shapes are produced, as required by customers, and illustrated in Figure 3 (also given to students). Figure 4 shows the finished parts aligned with their components. During the subassembly, two bottom parts of each finished product are put together, and the rest is added during the final assembly. Assembly output is verified by quality control and incorrect products are rejected, counted and repaired by the assembly. Shipping truck is called to pick up a shipment to a customer once the entire order from that customer is finished. The run time for the exercise is limited to 2 minutes. There are people with stopwatches measuring times necessary to calculate the above six LET factors. Before the first timed run, there is one dry run to allow for group members for better understanding of their tasks.

Once the experimental run is completed, on the spot brainstorming starts with the goal of producing two lists: a list of wastes and a list of improvements to the production system. It is followed by a numerical analysis using Lean Efficiency factors, then a review of previous decisions about the improvements needed. The experimental cycle is done twice.

Subsequently, ideas aiming at redesigning the system to satisfy lean principles must be generated. Two runs of the remodeled systems follow. Data is gathered and efficiency of the systems is assessed. One of the goals of the redesigned system is to run the production in silence (without verbal communication) relying on visual controls and signals only. A total of five production runs are made.

Students must perform Group Technology (GT) classification and devise their own coding system. They also design their kanban cards or kanban card / transportation bin devices. Design of a kanban card by the students becomes fairly automatic once they are told to work in silence. Initially, students are not offered any cardboard, scotch tape or color markers. They are told though to ask for whatever simple office supply they would like to use.

Figure 1. Components used to build assemblies.

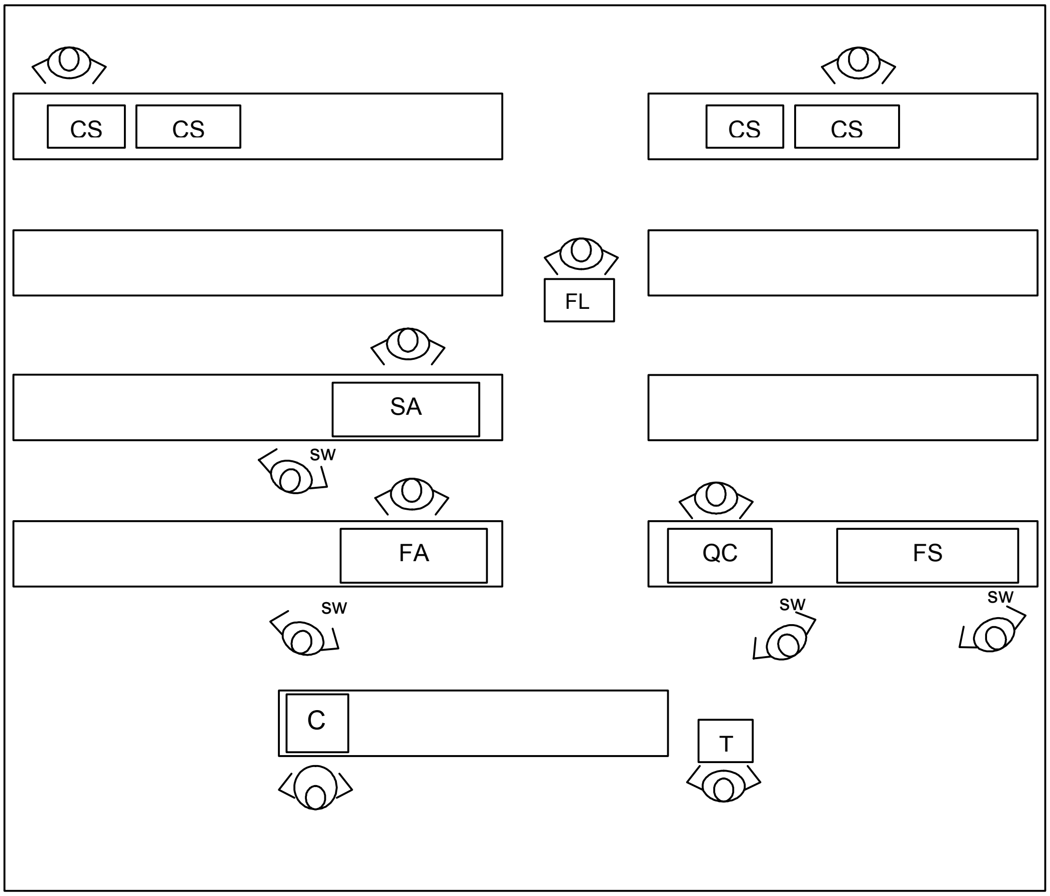

Figure 2. Layout of the initial setup of the production environment simulated during the in-class exercises.
CS = components storage, SA = subassembly, FA = final assembly, QC = quality control, FS = finished products storage, FL = "fork lift", T = "shipping truck", C = customer, sw = stop watch.

Figure 3. Eight types of finished parts required by customers.

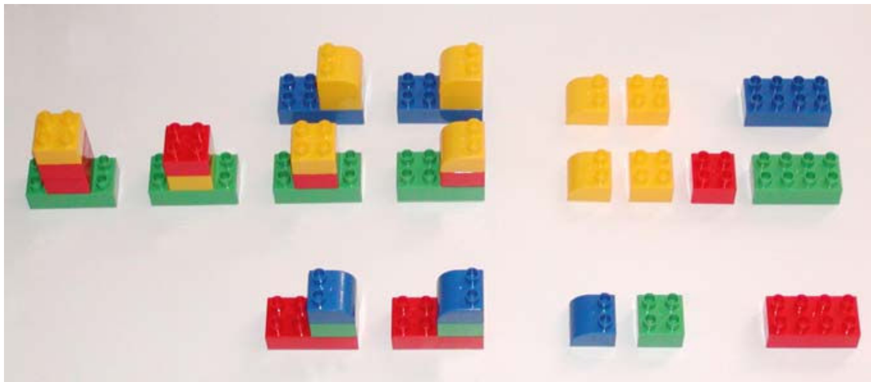

Figure 4. Eight types of assemblies and their components organized in rows (assemblies on the left, components on the right).

6. Student Learning

Group work in documentation of wastes in production system, calculations, brainstorming of improvements and evaluation of them were observed to be the best peer learning activities. Through hands-on work, students observed waste, quantified it and clarified own misunderstanding of some of the most important aspects of lean production. Work group was required to produce a brief written report containing qualitative and quantitative documentation of waste, calculations of Lean Efficiency factors and hand sketches of solutions. The documentation was then used for an in-class presentation which had to address the following aspects of each stage of development of the lean production line:

1. wastes and other problems
2. evaluation criteria used
3. constraints
4. evaluation of new solutions
5. choice of the best solution

After summary of the exercises, a brief introduction to Agile Manufacturing is given to illustrate the subtle differences in nature of Lean and Agile. Although the presented here form of the exercise was used only twice in the junior level course in Computer-Aided Planning, the surveys at the end of the exercises show two common threads:

- Like of hands-on learning
- Like of using calculations to support problem definition and subsequent decision making

Four major problems were also observed by the author of the paper:

- Poor ability in designing a pull system based on visual controls
- Marginal ability in designing the visual controls (writing was continuously preferred over sketching, words were preferred over symbols)
- Problems in designing quality control into each activity of the production
- Inability to efficiently use principles of Group Technology to simplify interaction between storage and assembly

The most successful group did not have a dominant leader with all the answers, but was able to evaluate the evidence and come to a consensus. That group also did not pretend to find the ultimate solution after the first run, but patiently immersed itself in the process of continuous improvement. However, some students were rather bored at the fourth run, acting as if they had already achieved the best possible solution. Coincidently, they were some of the lowest achievers in the class. Although after two runs of the exercise it is too early to make a definite conclusion, it seems that the multiple runs (opportunities to improve the process), increase understanding of rigors of problem solving deeply rooted in the environment of continuous improvement.

7. Summary

A negligible monetary investment is needed to equip the groups for the exercise. Although a set of plastic blocks is far from being real life equipment, it does not require maintenance, safety training or teaching how to use it (tremendous time wasting activities in traditional laboratory based exercises). The set is also very flexible in designing exercise problems, and allows for effective imbedding of principles of Group Technology into the exercise. These facts seem to help in concentrating students' efforts on the subject of the exercise – principles of lean production and creative use of them for pinpointing problems and solving them. Project groups were able to generate multiple solutions and test them very quickly.

Since combination of subassembly and final assembly was proposed by all the project groups, a follow up exercise in design of a lean production process to a given set of constraints is under development. The exercise is a mix of a multitude of open ended problems in evaluation, design and continuous improvement; all focused on rather clearly stated big goal of all the improvement efforts. The majority of students considered that type of challenge relatively unambiguous. Learning was considered very stimulating due to hands-on activities, freedom in designing improvement measures and peer interaction.

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