Improving Productivity on the Production Line of a Manufacturing Process Using Lean Model

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ABSTRACT:

In this paper, the production line of a company manufacturing metal file cabinets was under-studied with the aim of improving productivity. Lean was deployed with reference to data obtained from a case study company. Material and information flow for the current manufacturing process was studied and designed with the help of Value Stream Map (VSM). Reduction in Lead time was used as a measure for improvement in productivity. The current process had a total cycle time (time taken to process a part) of 8.45 hours and lead time (time an item spends on the floor before being shipped to clients) of 11.3 hours, average order of 240 cabinets monthly from clients. Value stream map was used to study the process flow and one of the production processes (Assembly 1) was found to impact productivity negatively. Assembly 1 was eliminated from the production line because it consumed valuable time of 2 hours and manpower energy. The efficiency of each production stage was measured by how much each impacted the production process. MATLAB and Python programming were used in running the 2k factorial analysis, studying the level of variations within the factors, and studying the effect on the entire system. A new sub-process line (comprising Shearing 1, blanking 1, stamping 1 and forming1) was designed using Value stream map to enhance material and information flow and productivity. With assembly 1 process removed and new adjustments made, the total daily lead time was reduced from 11.3 hours to 6.6 hours and total daily circle time from 8.45 hours to 5.05 hours. Production foremen were reassigned to new roles. The methods and findings of this research if implemented would enable the company to afford producing more than the monthly average of 240 cabinets, and could be used as a template for other local manufacturing companies that desire to go Lean.

Keywords: Cycle time, Lead time, Lean, Productivity, Value Stream Map.

1. INTRODUCTION:

Lean also known as the Toyota production system means doing more with less manpower, machinery, materials, time and space without compromising standard and being able to satisfy customers with what they desire. Lean model or Toyota production system was the solution to Toyota's problems; one by one the Lean model solved the problems and pushed Toyota ahead of rivals and competitors. As the global market grows at a very fast rate manufacturing Industries can remain relevant by adopting the Lean model this in turn guarantees them staying in the competition, manufacturing their products at a faster and cheaper rate (Sumit *et al*., 2014). The idea of Lean was designed to maximize the resources made available for production through minimization of waste (Sundar *et al*., 2014).

The case study company is facing similar challenges as Toyota did which includes: small and fragmented market, demanding various products in small quantities, ailing economy. There has been in recent times a decline in productivity at the case study company as a result of the traditional push production model still in use leading to delay in meeting customer demands.

The aim of this research is to improve productivity on the production line of the case study company using Lean.

Objectives of the research includes: To study the general production process of producing metal file cabinets at the case study company and evaluate current raw data, to adapt Lean model to the company's production process and to compare the Lean production model to the existing batch production model at the case study company.

The origin of the Lean concept is older than its name and reaches back to the fifties of the 20th century (Kleszcz *et al*., 2019). Lean management is a model that creates such a work culture where all Lean members of the organization are interested in constant reduction of cost, improving quality level and reducing delivery cycle. Lean emphasizes the elimination of waste.

Kleszcz *et al*. (2019) asserted that the most important Lean manufacturing rule includes: elimination of waste, reliability of equipment, reliability of machine, reliability of machine, reduction of rejects, reduction of production time, Kanban system, work visualization, production level, production cycle and short retailing time. Lean is a systematic approach to identifying and eliminating waste (non value adding activity) through continuous improvement by allowing the product flow at the pull of the customer (Vikas *et al.,* 2015). Mohanty *et al*. (2007) stated that at the beginning stages the Lean model is not very comprehensive to the practitioner, these in turn leads to a warped mindset on a journey to Lean transformation. Mohanty *et al*. (2007) also noted that a successful Lean project should include a comprehensive tutorial on Lean, lessons learned on the shoulders of those who have gone ahead and proper channel of communication. An expert experienced team should be involved in this beginning stage to ensure effectiveness. In most occasions the Lean implementing team are usually not so grounded in Lean or are new to the concept.

2. MATERIALS AND METHODS

2.1 Analytical Model
The area of concern in this research was limited to the general production process of metal file cabinets, identification of critical factors affecting productivity such as high level of lead time (total amount of time a product spends on the production floor before they are shipped to clients) and how reduce lead time to the barest minimum to improve productivity. The data used in the research work was based on a current data gotten from the company and a proposed one with respect to three

Lean factors (Production setup, Total Productive Maintenance and Quick Change over Time). The current and proposed data was analyzed using a 2k factorial experimentation executed with the MATLAB and Python software with the aim of evaluating the impact the factors have on the production process and addressing them to improve productivity.

2.2 Value Stream Map
Value stream mapping is a resource tool used in mapping the current and future proposed material and information flow on the production floor. The aim of using value stream mapping was to identify all forms of waste embedded in the current manufacturing process and apply requisite lean tools to eliminate them.

2.3 Simulation Support for VSM
Three factors were analyzed in the research, which are Production Model (PM), Total Productive Maintenance (TPM) and Quick Changeover (QCO). These three tools were analyzed using a 2k factorial experimentation with the help of MATLAB and Python 2. MATLAB and python codes were used to run the factorial analysis, equations (equation 5) and generate tables used in the research. Python code was also used to run the Anova analysis. 2 represent the current and future level while K represents the number of factors which is three (3). It should be noted that in this research, Lead time was used as the standard to measure productivity attained. The 2^k factorial simulation was used to obtain the response of the factors at 2 different levels. For example, if there are 2 factors A and B with levels '+' and '- ', a python program was developed to run these combinations as shown in the Table 1. Assume that when A is '+' then the response of using A is 'a' when B is low or '- '. The same thing applies to B when it is high and A is low the effect becomes b. but whenever A and B are positive then the response will be 'ab', also if A and B are both negative then the response is represented by '(1)'. This is illustrated in the table 1.

Table 1 2K Factorial Table

Factor A	Factor B	Response
+	-	A
-	+	B
+	+	Ab
-	-	(1)

The response of A is given as follows;
$$A = \frac{1}{2n}(ab + a - b - (1)) \qquad (1)$$
The response of B is given as;
$$B = \frac{1}{2n}(ab + b - a - (1)) \qquad (2)$$
Where n = no of replicates (the number of times the simulation is running)
A = factor 1
B = factor 2
a = response of factor 1 at positive level
b = response of factor 2 at positive level
ab = response of the interaction between factor 1 and 2 at both positive levels
1= response of the interaction between factor 1 and 2 at both negative levels

2.4   Efficiency of the Current Process
Each process or step on the production line was evaluated to ascertain their respective effectiveness in terms of general impact to the productivity. The processes that gave 100% or close to 100% were most effective while those further from 100% were less effective. The calculation was done by dividing cycle time by lead time and multiplied by 100% to obtain percent value.
$$CT/_{LT} \times 100\% \qquad (3)$$
Where:
CT = cycle time
LT = lead time

2.5   Calculation of the Effect of Factors
The three key lean factors were used in the research work they include: Production Model (PM) represented with 'a', Total Productive Maintenance (TPM) represented with 'b' and Quick Changeover (QCO) presented with 'c'.
The Effect is given as
$$Effects = \frac{1}{4n} [contrast] \qquad (4)$$
(The above equation was executed using python)
n = number of replications
While: Contrast is the difference between a factor and other factors.
$$Contrast\ A = (a + ab + ac + abc - b - c - bc - (1)) \qquad (5)$$
(The above equation was executed using python)
Sum of Squares for the First Factor
This was calculated using the formula:
$$SSF = \frac{[contrast]^2}{2^k \times n} \qquad (6)$$
Where:
K = number of factors given as 3
n = number of replications given as 3
This is the variation of the values obtained in all three repetitions or replications. There were 3 repetitions and 8 variations. Therefore, the total number of cost values is 3×8 = 24. The formula for obtaining the Sum of Squares is:
$$SSW = \frac{\sum[x - mean]^2}{2^k \times n} \qquad (7)$$

Where:
X = time value, cost value or unit value.
Mean = average mean of all 24 cost values

2.7   Analysis of Variance (ANOVA) Concept
The ANOVA concept is a tool used to analyze variability found in a set of data. ANOVA two-way variance test was used to test the hypothesis of all the factors to know which one is different from the normal variance of all 24 cost value. This is done by comparing the degree of freedom for all the factors with the degree of freedom within.
P-value is the value got by comparing the f_0 values with the f probability distribution table which is the table used to look up F Statistics in hypothesis testing. The f table is read by locating the degree of freedom (df) of any factor on the columns then the

degree of freedom (error value) on the row and where they intercept is the f-value.

F-value is compared to f_0 to get p-value:

$$f0 - fvalue = pvalue \qquad (8)$$

If p-value is greater than f-value on the table then that factor affects the production process to the extent of its positive value.

The standard deviation of all 24 cost values was calculated using the formula:

$$Std = \sqrt[2]{\frac{\sum([Effects] - Emean)^2}{7}} \qquad (9)$$

Where: Σ (Effects) is sum total of effects
Emean is the mean of the total effect values
All data concerning the research work was gathered while observing the production process on the shop floor, questioning and interacting with production foremen, taking time reading of various processes as cabinet parts moved from one station to another.

3.1 RESULTS AND DISCUSSION

The file cabinet manufacturing process begins at the shearing station where plane mild steel plates of 0.7mm thickness are sheared to specific sizes for the production of back and side panels, top covers, bottom brackets, drawers, spacers, right and left ribs, and top members with the help of a shearing machine. The steel plates are transferred to a blanking machine where a profiling operation is carried out to allow for forming. After the profiling the next stop is the engraving or embossing operation where the company's logo is embossed or engraved into the parts.

Next is the forming process which involves bending the profiled edges by a press brake machine after which the parts are assembled together using jigs to allow for welding. The assembled cabinets are inspected for any irregularities such as sharp edges which are smoothened by a grinding machine and finally sent in for painting and shipped to the store awaiting end customers. See Figure 1.
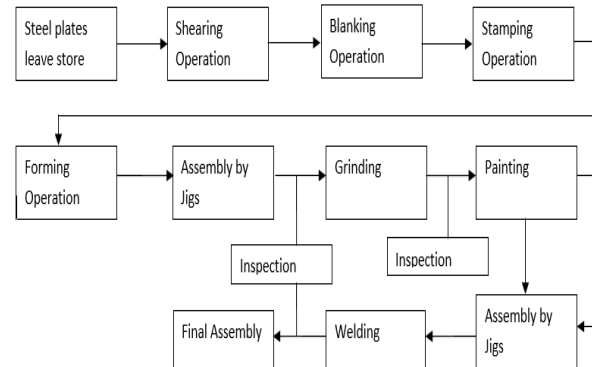

Fig 1 File Cabinet Production Flow Process
Source: Generated from the current production line

3.2 Analysis of Current Data

Current data was collected from the company and the information was carefully analyzed and reconciled before beginning the process of analysis using Excel, MATLAB and Python. From the data gathered there are currently 10 production stations with a number of operators assigned to them as seen fit by the management. The current cycle time (time taken to process a part) of 8.45 hours, machine reliability (MR), change over time and lead time (total time a product spends on the production floor before being shipped to clients) of 11.3 hours were carefully calculated and analyzed. Lead time was used as a parameter in the research work to measure improvement in productivity. The higher the lead time the lower the productivity and the lesser the lead time the higher the productivity.

3.3 Efficiency of Production Stages

Results from Table 2 indicate that some of the processes on the production line are more efficient that the others. This calculation was carried out to check which processes were more or less efficient by applying equation 3. The processes up to 100% or close to were more efficient than those not close to a 100%, for example, grinding operation which had a 50% efficiency rate.

Table 2   Individual Process Efficiency

Process	Percentage Efficiency
Shearing	90%
Blanking	100%
Stamping	60%
Forming	60%
Assembly 1	74.1%
Grinding	50%
Painting	83.3%
Assembly 2	68.2%
Welding	100%
Assembly 3	100%

3.4   Assembly 1

From the defined processes and activity ratio calculated, some problems can be noticed in the production model. An instance of a wasteful process is the assembly1 where parts are assembled and then disassembled in for the painting process. The painted part is then assembled again in assembly 2. To resolve this, the assembly1 section was removed from the production model. This means the total lead time reduced by 2.7 hours making the lead lime of 11.3 drops to 8.6 as shown:

$$11.3 - 2.7 = 8.6$$

3.5   Effect and Contrast of Factors

The contrast of each combination was derived using equations 5 and then for each contrast derived equation 4 was applied to get the effects as shown in Table 3. The importance of this was to check how each of the factor and their respective interaction (ab, ac, bc and abc) with each other affected the system positively or negatively. Factors A, B and BC have the highest values indicating that they have a strong effect on level of productivity on the process line.

Table 3   Table for Factor Contrast

FACTORS	CONTRAST	EFFECTS $\frac{1}{4n}$ [contrast]
A	301	25.083
B	243.	20.25
C	118.	9.833
AB	13.	1.083
AC	-13	-1.083
BC	-343	-28.583
ABC	-17	-1.417

Source: Python Code

3.6   Sum of Squares for the First Factor

The sum of squares is the variations between the contrasts given in Table 4

Table 4   Sum of Squares between Factors

FACTORS	CONTRAST	EFFECTS $\frac{1}{4n}$ [contrast]	SUM OF SQUARES (SSF) $\frac{[contrast]}{2^k \times n}$
A	301	25.083	3775.04
B	243.	20.25	2460.38
C	118.	9.833	580.17
AB	13.	1.083	7.04
AC	-13	-1.083	7.04
BC	-343	-28.583	4902.04
ABC	-17	-1.417	12.04

Source: Python Code

From Figure 2 factors A, B and BC are the most dominant factors in the production process and their effects were addressed to yield positive changes in the entire process. Their effects can be visualized with a line plot of effects versus factors and also plotting the Upper Control Limit (UCL) and Lower Control Limit (LCL) of the standard deviation of all 24 cost values. The standard deviation given below was derived applying equation 9.

$$Std = \pm 16.33$$

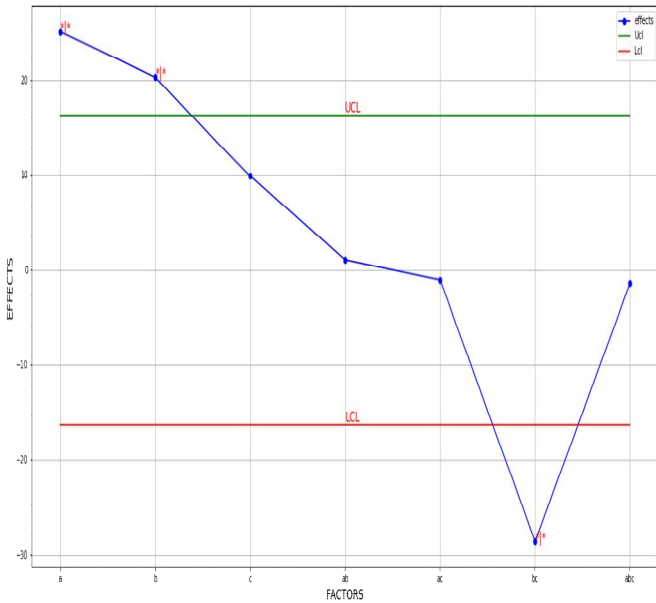Standard deviation obtained from equation 9

Fig 2 Effects of Factors on the Current Process

3.7   Current and Proposed Process Charts

Assembly1 in Figure 3 towers every other process having the most lead time and cycle time. In addition, assembly1 is a redundant process since it adds no value to the produced cabinet thus, changes were made to correct the problem by eliminating assembly1 the total lead time dropped to 6.6 hours

Fig 3 Current Process Chart

In the chart below assembly1 was removed after being identified as a wasteful process as stated earlier. Also, CT and LT of the proposed model showed a reduction for shearing, blanking, stamping and forming, as a result of the use of Lean.
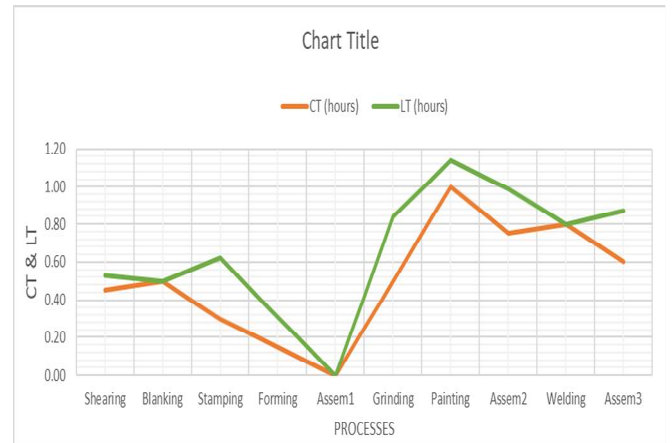

Fig 4 Proposed Process Chart

3.8   Value Stream Map for Current and Proposed Process

Looking at the production process there are a number of inventories preceding each process. Also, the timeline below for each process has two quantities which are the production lead time (LT) and cycle time (CT). The value on the upper level is the LT while CT is the lower step. Following the timeline towards the right shows a table-like box with two rows, the first row is total lead time and the second row is the total cycle Time.
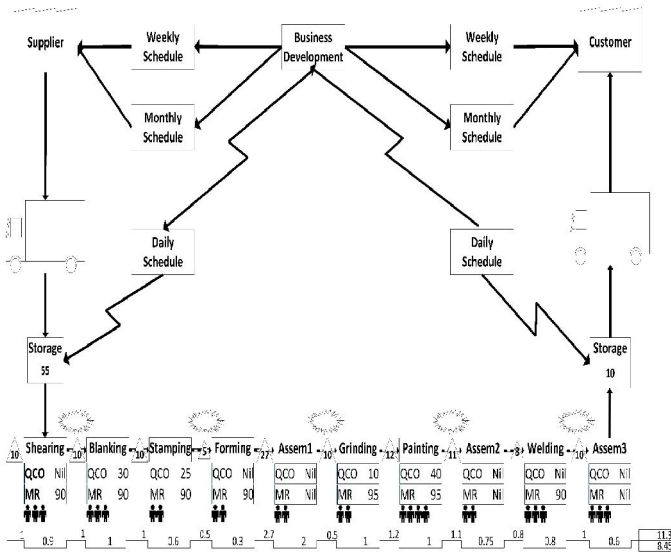
Fig 5 Current Process Value Stream Map
Source: value stream map designed from the current process.

In the proposed VSM below some previous processes were subdivided into two, the frame and the body. This is to enable the system to adopt a Lean manufacturing method in processes like shearing, blanking, forming and stamping. This reduced the time for this process by half and also reduced the time values in the optimized factor sheets. Workers were reassigned new processes from painting, welding, assembly 3 and assembly 1 giving way for the proposed assembly line.
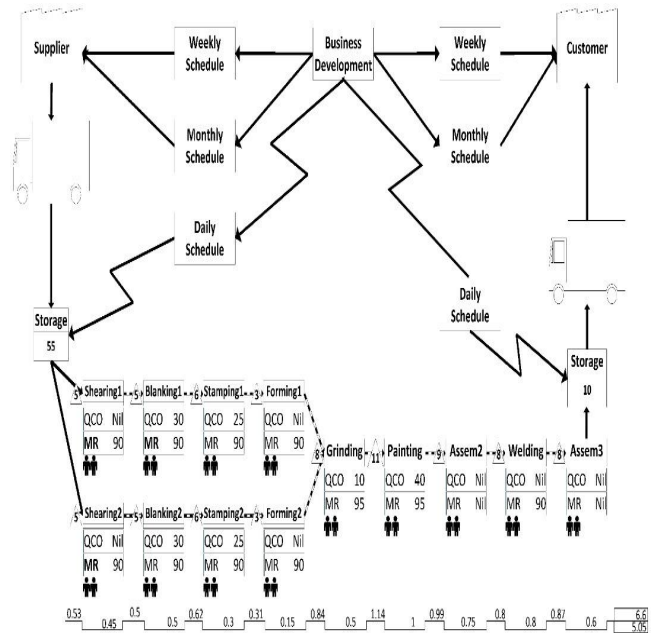

Fig 6 Proposed Process Value Stream Map
Source: value stream map designed for the proposed process.

4. CONCLUSION

The aim of the research which is to improve productivity on the production line of a manufacturing company with the use of Lean was achieved. Production model and maintenance practice from extensive analysis were found to have affected productivity including the presence of assembly 1 process which increased the overall Lead time. Lead time was used as measure for improvement in productivity. In view of this a new sub process line was proposed with removal of Assembly 1 station which brought the lead time and cycle time from 11.3 hours to 6.6 hours and 8.45 hours to 5.05 hours respectively. Production workers previously attached to assembly 1 station were moved to the new sub process line including 2 from painting, 1 from welding and 1 from assembly 3 respectively to the new sub process line as seen in Figure 6 (which is the proposed material and information value stream map). With the new lead time and cycle time, daily average production of 10 cabinets can be increased to further produce

more than 10 cabinets per day. The findings of research if implemented would enable the company to afford producing more than the monthly average of 240 cabinets, and could be used as a template for other local manufacturing companies that desire to go Lean.

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