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Improving Productivity of an Assembly Line Using Lean Manufacturing Line Balancing – A Case Study

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ABSTRACT:In today's fast-moving market, businesses compete to survive and sustain. One of the driving forces behind this competitive market place is customer demand. To meet this fast-paced customer demand manufacturing industries work round the clock striving to achieve maximum production. But still, some industries are unable to fulfill or keep-up with the growing demand. In this scenario, industrial engineering techniques and tools can help these industries to achieve this demand. With Line balancing and Lean manufacturing techniques productivity and efficiency are improved. These techniques are used to analyze and increase the efficiency and productivity of a production system by reducing waste, optimizing the material flow, and soaring the production rate. In this paper, real-time data was used to analyze and improve the production line of a company by creating robust manufacturing and workplace design that is capable to increase the production rate.

KEYWORDS:Line balancing, Lean manufacturing, Balance delay, Work-in-progress (WIP) inventory

I. INTRODUCTION

Productivity is the ratio of the output produced to the input needed to produce that output. Output is any item that is ready to be sold to customers. Input can be a combination of elements, including time, energy, equipment and raw materials. Productivity is a measure of efficiency. In order to be efficient, processes must be streamlined to ensure maximum performance. Efficiency is the ability to do something or produce something without wasting materials, time or energy. Thus, efficiency is sometimes represented as a percentage, with 100 percent being the ideal aim for maximum efficiency, resulting in the production of goods at the lowest average total cost, with all else being constant. However, many manufacturing companies may only be running at 60-80% efficiency. The complexity of assembly processes today makes it impossible for businesses to maintain a work-life balance, which has an impact on how much time is spent at each workstation and leads to non-value-added activities that increase cycle times overall. There are various ways to boost efficiency that also boost productivity: investing in improvements in the manufacturing line and those responsible for it. Line balancing and lean manufacturing are some of the techniques used to improve productivity and efficiency.

1.1 Line Balancing

Line balancing is the process of setting up a production line such that production moves evenly from one work station to the next. Line balancing is an effective method for reducing bottlenecks since it evenly distributes the task time around each workstation, preventing delays and overburdening anyone with work. Assembly lines are the most important components of mass production systems. The unequal workload among workstations of assembly line increases work in progress (WIP) inventory and waiting time of manpower and machines. A variety of issues on how to allocate operations to meet takt times must be addressed in order to balance an assembly line.

Assembly line balancing is the process of distributing work load in an assembly line across successive workstations so that no resource and time are wasted is studied by Meby Mathew, D. Samuelraj (2013) [1]. According to Falkenauer (2000) Assembly Line Balancing, or simply LineBalancing (LB), is the problem of assigning operations to



workstations along an assembly line, in such a way that the assignment be optimal in some sense. Furthermore, an assembly line can also be defined as a system which is formed by arranging workstations along a line.

According to Pekin (2006), manufacturing a product on **assembly lines** requires dividing the total work into a set of elementary operations. A **task** is the smallest, indivisible work element of the total work content. The time required for a task to be completed by a piece of equipment is known as the processing time or **task time**. The tasks could be accomplished with the same equipment or with different equipment. **Workstations** are areas within an office that are furnished with unique devices and/or operators for carrying out tasks. Cycle time is the interval between the intervals at which two related units complete their respective tasks. In a straightforward assembly line balance problem, the cycle time cannot be less than the longest time of a task because tasks are the smallest labour units.

Assembly line has been categorized based on workload, shape of line and product etc. The Simple Assembly line balancing problems (SALBP) have been classified into five categories based on its attributes. Each category of the problems related to the design of assembly line have a set of unique objectives [2]. In type I problem (SALBP- I), the cycle time is fixed and objective of the assembly line is to minimize the number of workstations. In type II problem (SALBP- II), the number of workstations is fixed and the objective is to minimize the cycle time or takt time. Similarly, type III, IV and V problems have focus on the smoothness and relatedness of workload on each station along the assembly line [3].

Assembly lines have been categorized based on the variety and number of products get assembled. Three main types of assembly line are:

1. Single model assembly line
2. Mixed model assembly line
3. Multi model assembly line

II. METHODOLOGY

All the processes in assemblies and subassemblies were observed thoroughly and then the mentioned industrial engineering tools were shortlisted after a detailed study. We have applied these tools to enhance the productivity of the company. But, to maintain this secrecy, we will not disclose the name of the company, product, parts, and processes. Rather, they are given alternative names (numerically & alphabetically) to make the readers understand our project with ease. However, we have presented the real data of cycle time, wastes observed, and layout plan of every workstation and processes that are required to understand the implementation of industrial engineering tools in this paper.

Most of the research in assembly line balancing has been devoted to modelling and solving the simple assembly line balancing problem (SALBP). This classical single-model problem contains the following main characteristics:

- Mass-production of one homogeneous product; given production process
- Paced line with fixed cycle time 'c'
- Deterministic (and integral) operation times 't_j'
- No assignment restrictions besides the precedence constraints
- Serial line layout with 'm' stations
- All stations are equally equipped with respect to machines and workers
- Maximize the line efficiency, $E = \frac{\sum t_{ij}}{m * C}$ with total task time

Table 2.1: Classification of SALBP

No of workstation m	Cycle Time C	
↓	Given	Minimize
Given	SALBP-F	SALBP-2
Minimize	SALBP-1	SALBP-E

Table 2.1 Shows classification of SALBP

- Type 1 (SALBP-1) of this problem consists of assigning tasks to work stations such that the number of stations (m) is minimized for a given production rate (fixed cycle time, C).
- Type 2 (SALBP-2) is to minimize cycle time (maximize the production rate) for a given number of stations (m).
- Type E (SALBP-E) is the most general problem version maximizing the line efficiency (E) thereby simultaneously minimizing C and m considering their interrelationship.
- Type F (SALBP-F) is a feasibility problem which is to establish whether or not a feasible line balance exists for a given combination of m and C [4].



2.1 Existing Assembly Line

The assembly section has four workstations. Three of these workstations produce required sub-assemblies for final assembly while one workstation performs testing operation of the sub-assembly before the final assembly. The final assembly is performed at the last workstation. Current workforce of this assembly line consists of 3 workers per shift (1 for sub-assemblies, 1 for testing of sub-assembly, and 1 for sub-assembly and final assembly). The assembly line operates in 2 shifts of 8 hours each. The worker at each workstation has an additional job of maintaining and replenishing the inventory required for the sub-assemblies at his workstation. Once the inventory level required for sub-assemblies is full the worker initiates his task. This replenishment of inventory and sub-assemblies is done in batches at regular intervals throughout the shift. The size of the batch is generally not fixed. The sub-assemblies move from one workstation to another in a linear path throughout the assembly line. Thus, the line follows a fixed, standard path which results in less material movement for the sub-assemblies. The current throughput of this assembly line is 30 units per shift. However, the method of the work performed by the worker is not standardized.

The following table shows the activities and the worker allocated to each of the activity, also the table shows the precedence of the activities:

Table 2.2: Activities & Worker Allocation

Sr. No.	Sub-Assemblies	Precedence	Worker Allotted
1	Sub-Assembly 1		A
2	Sub-Assembly 2	1	
3	Sub-Assembly 3		
4	Sub-Assembly 4	2,3	
5	Testing	4	B
6	Sub-Assembly 5		C
7	Sub-Assembly 6		
8	Sub-Assembly 7	6,7	
9	Sub-Assembly 8		
10	Final Assembly	8,9	

2.2 Initial Layout of the Assembly Line

The movement of materials and across the four workstations and the position of workers viz. A,B, and C at their respective workstations is shown in Fig. 2.2 (a). The workers bring the required materials from the Bill of Materials (BOM) room to the inventory at their workstation and start assembling the sub-assemblies in batches. The movement of the workers is shown in the Fig. 2.2 (b)

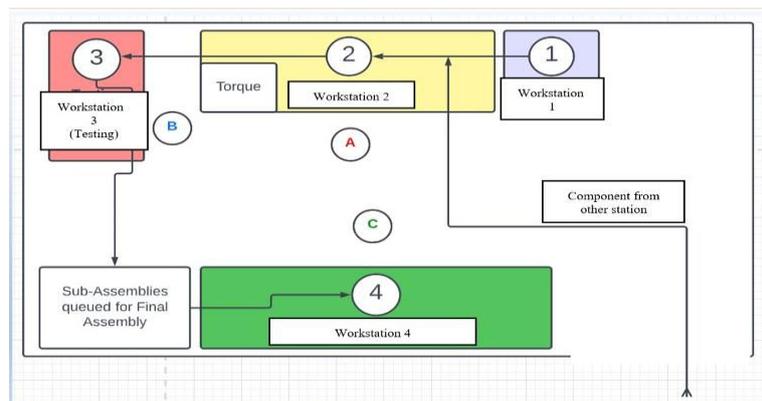


Fig. 2.2(a): Movement of Materials

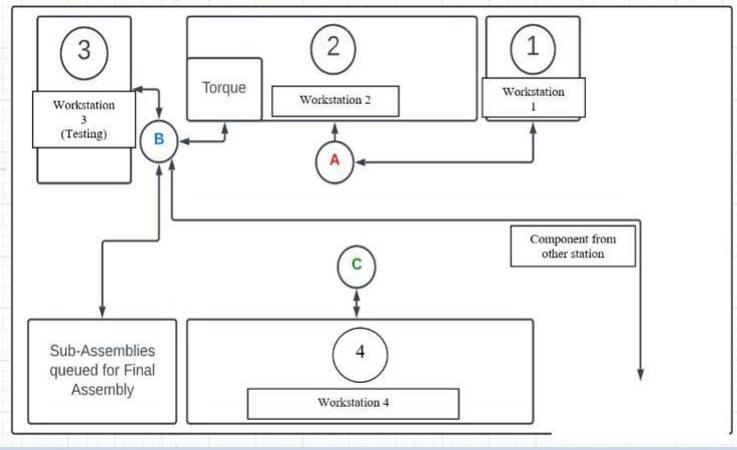


Fig. 2.2 (b): Movement of Workers

2.3 Types of Lean Wastes Observed

All the processes of every workstation were carefully observed and thoroughly studied. The following are the various types of wastes:

- Non-value adding works like performing marking and reaming operation on required parts which can be classified as waste of talent, leaving his own workstation to guide or help another worker.
- Delays like taking longer time than required to complete a sub-assembly, long and frequent breaks and batch production of the sub-assemblies.
- Unavoidable delays like downtime caused by long assembly time of station number 2 and the absurdly long cycle time of testing station.
- Unnecessary movement of workers like the movement of the worker to bring the required materials to his workstation from the store.
- Defects like leakage due to loose fitting in the sub-assembly.

The impacts associated to these wastes are shown in the following table:

Table 2.3: Associated Impacts

Non-Value adding work & Bottlenecks	Impacts
Marking operation on materials is done by one of the assembly workers	One worker remains unavailable at main station, which results in increased downtime
The worker at workstation 1 performs rimming operation	This is an unnecessary operation that becomes a bottleneck in sub-assembly 1
Excess movement of workers to get required materials	A huge amount of time is wasted in material replenishment
Batch production of all the sub-assemblies	Restricts the production rate from increasing
High cycle time of testing station	Becomes the single biggest bottleneck in the entire process



2.4 Tools & Techniques

In this case study, mainly the following categories of tools and techniques have been used for line balancing.

- Time Study
- Largest Candidate Rule (LCR)

2.4.1 Time Study

Time study is used to determine standard time for each task. In this case study, we recorded the activities of complete process for five times using video camera. The video has been then carefully watched and analysed to calculate the observed or normal time of each task. Furthermore, the order of activities, and workers required for performing job on each work station and their ratings was also noted.

The standard time of each activity is calculated as:

$$\text{Standard Time} = \text{Normal Time} \times (1 + \text{allowances})$$

Standard time is the period in which worker is trained to performed the activity by using specific methods according to his job or activity [5].

2.4.2. Largest Candidate Rule (LCR)

Largest Candidate Rule is commonly used method for line balancing to evenly distribute workload amongst workstations. It ensures smooth flow of work in progress (WIP) through the line with minimal or no buffer among the workstations. However, bottlenecks are often occurred because the assembly are difficult to balanced perfectly [6]. LCR considers the cycle time and precedence relationship in line designing. In this method, the work elements are assigned to workstations based on size of elements time, T_e (work elements time) values.

The cycle time, minimum no of workstations, balance delays, line efficiency, and line smoothness index of assembly line are calculated using given formulas [7].

$$\text{Cycle Time} = (\text{Total available production time}) / \text{Total No. of Units to be produced}$$

$$\text{Min no. of workstations required (theoretical)} = \text{Total Work Content} / \text{Cycle time}$$

$$\text{Balance delays} = [(\text{No of workstations} \times \text{Cycle Time} - \text{Total Work Content}) / (\text{No of workstations} \times \text{Cycle Time})] \times 100$$

$$\text{Line Efficiency} = (100 - \text{Balance Delay}) \%$$

$$\text{Line Smoothness Index SI} = \sqrt{\sum_{j=1}^g (S_{\max} + S_j)^2}$$

2.5 Calculations

$$\begin{aligned} \text{Cycle Time} &= (\text{Total available production time}) / \text{Total No. of Units produced} \\ &= 420 / 75 \\ &= 5.6 \end{aligned}$$

$$\begin{aligned} \text{Min no. of workstations required (theoretical)} &= \text{Total Work Content} / \text{Cycle time} \\ &= 26.65 / 5.6 \\ &= 4.75 \\ &\approx 5 \text{ (Rounding up to next higher integer)} \end{aligned}$$

$$\begin{aligned} \text{Balance delays} &= [(\text{No of workstations} \times \text{Cycle Time} - \text{Total Work Content}) / (\text{No of workstations} \times \text{Cycle Time})] \times 100 \\ &= [(5 \times 5.6 - 26.65) / (5 \times 5.6) \times 100] \\ &= 4.82 \% \end{aligned}$$

$$\begin{aligned} \text{Line Efficiency} &= (100 - \text{Balance Delay}) \% \\ &= (100 - 4.82) \% \\ &= 95.18 \% \end{aligned}$$

$$\begin{aligned} \text{Line Smoothness Index SI} &= \sqrt{\sum_{j=1}^g (S_{\max} + S_j)^2} \\ &= \sqrt{(7 - 2.84)^2 + (7 - 3.25)^2 + (7 - 5.4)^2 + (7 - 5.9)^2 + (7 - 5.8)^2 + (7 - 7)^2 + (7 - 7)^2} \\ &= 6.04 \text{ minutes} \end{aligned}$$



The above calculations show that the assembly line runs with percent of efficiency with balance delay of 4.82 percent. Line Smoothness Index (SI) is 6.04 minutes.

2.6 Proposed Assembly Line

The proposed assembly section would have five workstations. Three of these workstations produce required sub-assemblies for final assembly while two workstations perform testing operation of the sub-assemblies before the final assembly. The final assembly is performed at the last workstation. Now the workforce of this new assembly line would consist of 5 workers per shift. 2 workers for sub-assemblies and 2 for testing as well as sub-assembly, and 1 for sub-assembly and final assembly. The assembly line would still operate in 2 shifts of 8 hours each.

The worker at workstation 1, regarded as ‘helper’ or ‘H’, would perform sub-assemblies 1 & 2 and would have a certain stipulated target of number of sub-assemblies per shift. Worker A at workstation 2 would, initially, perform only sub-assembly 3 and meet the stipulated target of number of sub-assemblies per shift. Worker B would perform sub-assembly 4, as soon as worker A completes first sub-assembly 3, at workstation 2 (beside worker A) and then take it to workstation 3 (Testing station 1) for testing. He would repeat this after completing testing of each sub-assembly. Worker C would do exactly same as worker B as soon as the next sub-assembly is queued at workstation 2. Both of them would continue to do this till worker A has completed the target for sub-assembly 3 for the shift. After completing the target, worker A would perform sub-assembly 4 with all the queued sub-assembly 3. With this, workers B and C will now only perform testing of the sub-assemblies at their respective workstations. There is no change in worker C’s routine. The job of maintaining and replenishing the inventory required for the sub-assemblies at all workstation along with the job of marking on sub-assemblies would now be done by the ‘helper’ allowing other workers to focus on the task at hand and not leave their workstations.

The standard time required for each task was calculated by observing the complete sub-assembly and the noting the time required to complete the sub-assembly. This activity was carried out for each individual sub-assembly till the final assembly. All the cycle times were then carefully studied to figure out which tasks would be done simultaneously. This simultaneous sub-assemblies would be done by the workers B and C. This would reduce their idle time which otherwise would have been spent waiting for the next sub-assembly to arrive at their workstation.

The following table shows the activities and the worker and time allocated to each of the activity, also the table shows the precedence of the activities:

Table 2.4: Precedence of Activities

Process	Sub-Assemblies	Workstation Number	Workers/Helper Allocated	Cycle Time/unit (Sec)	Total Time (hrs)	Can Produce in Total Time (Target)
a	Sub-Assembly 1	1	H	35	2.84	144
b	Sub-Assembly 2			36		
c	Sub-Assembly 3	2	A	165	3.25	71
d	Sub-Assembly 4		A	277	3.4	44
			B		1	14
			C		1	13
e	Testing 1	3	B	590	5.9	36
f	Testing 2	4	C	590	5.8	35
g	Sub-Assembly 5	5	D	43	7	74
h	Sub-Assembly 6			30		148
i	Sub-Assembly 7			146		71
j	Sub-Assembly 8			76		71
k	Final Assembly			201		71

2.7 Proposed layout of the assembly line

After calculations and consideration of all constraints we developed a new and improved layout for the assembly unit. This layout was designed such that maximum space available is utilized and the flow of man and materials would not be disturbed in any way despite the addition of an extra workstation. The movement of materials and across the five workstations and the position of helper and workers viz. A, B, C and D at their respective workstations is shown in Fig. 2.5 (a) and the movement of the workers is shown in the Fig. 2.5 (b)

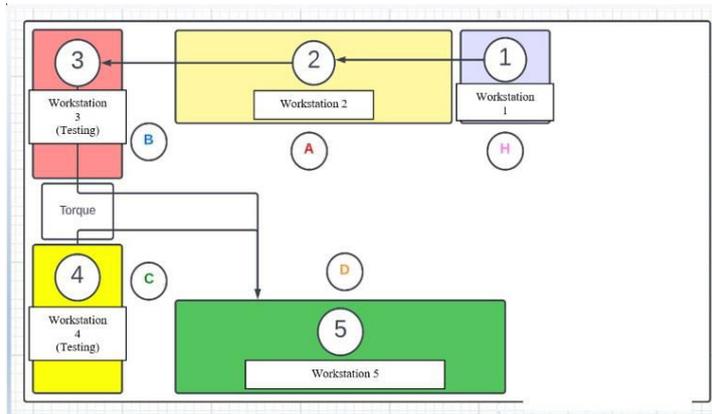


Fig. 2.5 (a): Positions of Workers

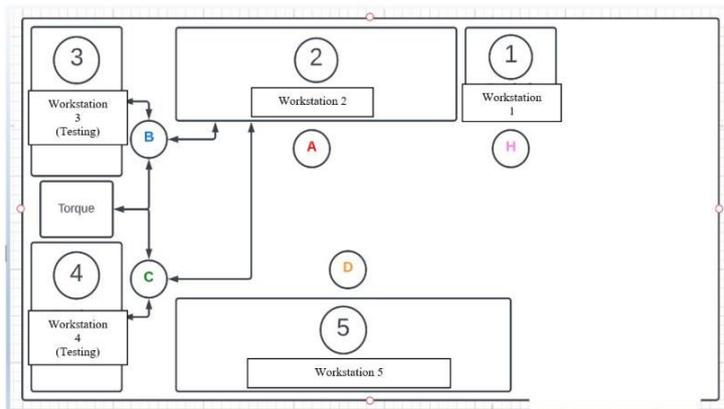


Fig. 2.5(b): Movement of Workers

III. RESULTS

3.1 Implementations & Benefits

After the successful implementation of the proposed method the productivity would increase significantly. With the standardization of the work procedures the wastes and delays will be removed. The suggested implementations and their associated benefits are summarized in the following table:

Table 3.1: Associated Benefits

Implementations	Improvements/Benefits
Marking will be done by the helper so that marked parts are ready for the next shift	Parts will be readily available for assembly & time spent by Assembly worker on this activity will be saved
Rimming operation will be eliminated completely	It will save time
Required materials will be replenished by helper at all workstations	Worker movements will be reduced and worker will be focused on his main job



Every worker will perform the assigned task ONLY	There will be aContinuous flow of Sub-assemblies in the process
An additional Testing stations is required	Downtime caused by one machine will be drastically reduced

3.2 Improvement in productivity

Due to unstandardized working methods the existing assembly line produces close to 30 units per shift. After balancing the entire assembly line, the new, improved layout and process designed is more efficient than the existing assembly line. With reduced cycle times, wait times, possible downtimes, excessive movements and delays the proposed method is capable of producing close to 71 units per shift. This is almost 133% increase in productivity as illustrated in Fig 3.2.

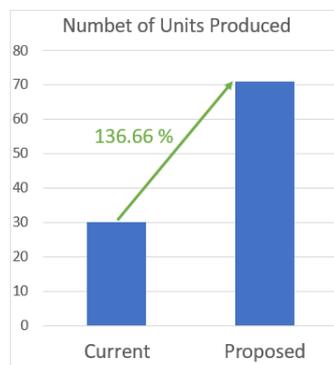


Fig 3.2: Percentage increase in productivity

IV. CONCLUSION

We implemented line balancing technique, an industrial engineering tool, and proposed improvements and alterations to the existing assembly line. We identified 4-5 types of lean wastes and ourlean management processesseeksto eliminate any form of waste in reference to time, effort or money by identifying each step inthe business process and revising steps that does not create value. Our proposed layout and operation sequence is more efficient than the current ones. The results obtained through calculations shows tremendous increase in productivity. Since, productivity and profitability are directly related to each other, the increase in productivity increases the profitability. A high rate of productivity in a company ensures that the company is profitable. Thus, reduction in the time taken by workers to assemble a single unit will result into greater number of outputs which in turn increases company’s capacity to produce and generate profit from increased number of sales without affecting the level of customization and variety offered to the customer.

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