Assembly Line Balancing Improvement: A Case Study in a Production Industry

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Abstract-Line balancing is about arranging a production line so that there is an even flow of production from one work station to the next. Line balancing also a successful tool to reduce bottleneck by balancing the task time of each work station so that there is no delays and nobody is overburden with their task. This thesis presents a case study on a line balancing problem in an Production company and the study focused on assembly line 11 and 12 which produced inductor model HA00-08464 LFTR. This study aims to improve the productivity and line efficiency also to recommend improvement activities based on the line balancing and analysis done in the simulation model. The simulation was done by using Tecnomatix Plant Simulation. All the data needed for the line balancing analysis was collected and a line balancing model equipped with manual calculation was done. This data gathered is then simulated in Tecnomatix Plant Simulation. Among the improvement activities conducted in order to balance the line was combining a few process into one, transformation from manual process to mechanization, and removing waste from the line. Throughout the study, three layouts were proposed. Among these three layouts only one will be proposed to the company. The layout proposed has a better line efficiency and rate of productivity.

Keywords: *Line Balancing Simulation Software, Production Line, Precedence Diagram, line efficiency, rate of productivity.*

1. Introduction

The project is about a case study at an Production company. The case study is regarding improvement in assembly line balancing with the help of simulation model. The Production company reduces industrial Production components by implementing lean manufacturing system in their plant. Line balancing for instance has proved that it is an effective tool in reducing the amount of workers even without decreasing the productivity in this Production company.

Technically, line balancing is one of the components of cellular Manufacturing which consist of major tenants in lean manufacturing. The concept of line balancing itself is everyone is working together in a balance fashioned where everyone doing the same amount of work, the variation is smoothed, no one is overburden, no one is waiting and the work is done in a well single piece flow. Line balancing is also can be defined as the allocation of sequential work activities into a line called work stations in order to achieve best utilization of labor and equipment thus minimizing idle time. In addition, balancing may be achieved by rearrangement of the work stations and by equalizing the workload among assemblers so that, all operations take about the same amount of time. Furthermore, line balancing benefits an assembly area in many ways, as it minimizes the amount of workers and work station which can reduce cost and space for the assembly area. Line balancing also benefits in a way that it can identify the process which causes bottleneck and standardization of work between the operators can ease the bottleneck problem.

A side from identification of bottleneck, line balancing equalized the workload among the workers so that there's no worker which is overburden. Finally, line balancing helps to assist the plant layout which will lead to the reduction of production cost by the reduction of worker and the reduction of idle time. Assembly line grouped in their respective workstations is represented manually in the form of a precedence diagram. Commonly, a traditional way of doing assembly line balancing is by using precedence diagram. A precedence diagram specifies the order or sequence in which the activities must be performed. Each circle is a node, and the number inside each circle identifies particular operation. The number outside circle represents duration of operation or the cycle time. Arrow represents directions of flow of operation.

Simulation models of line balancing are still not widely used in the assembly section of the Production industry as many still using precedence diagram and standard work combination sheet. In contrary, simulation model is a new and effective way to build the real life situation of the assembly process. There are many types of simulation model that can help not only to identify and reduce bottleneck but also can build the exact plant layout virtually. The more realistic the simulation model the more accurate and effective the design for implementation on the assembly area. Simulation technology is an important tool for planning, implementation, and operating complex technical system. There are many simulation software created just to build the virtual layout of the assembly area such as WITNESS and ARENA software. However, the simulation used in this project is the Tecnomatix Plant Simulation software created by SIEMENS. Tecnomatix Plant Simulation can increase profitability of a facility by increasing throughput, resource utilization and utilization of the facility. Plant Simulation also able to decrease throughput times, required resources and storage requirement provided that all accurate data inserted in the analysis. Furthermore, Plant Simulation able to identify the bottlenecks, reduce WIP, evaluate the effects of capital investments or changes in processes and avoid planning errors as the simulation was done virtually without applying to the facilities first.

2. LITERATURE REVIEW

The literature review is an account of what has been published on a topic by accredited scholars and researchers. The purpose of this chapter is to convey what knowledge and ideas that have been established on a topic and what are their strengths and weaknesses are. This also identifies the gaps in the previous research and what that needs to be further investigated. Furthermore, this chapter also defines all the terminology, definitions, concept and equation relating to line balancing. Lastly, this chapter also introduced the simulation topic and sub-topic related to it. The concept of Assembly Line Balancing is about arranging a production line so that there is an even flow of production from one work station to the next. Line balancing also a successful tool to reduce bottleneck by balancing the task time of each work station so that there is no delays and nobody is overburden with their task.

According to Falkenauer (2015) Assembly Line Balancing, or simply Line Balancing (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. At these workstations, work pieces can be transferred by using labor force as well as equipment, and tasks are assembled taking into consideration precedence constraints and cycle time. The decision problem of optimally balancing the assembly work among the workstations is pointed out by **M.Baskak (2015)** as the assembly line balancing problem.

2.2.1 Terminology used in assembly line balancing.

According to Pekin (2016), 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. **Task time** or processing time is the necessary time to perform a task by any specific equipment. The same or different equipment might be required to produce the tasks. The area within a workplace equipped with special operators and/or machines for accomplishing tasks is called **workstation. Cycle time** is the time between the completion times of two consecutive units. Since the tasks are the smallest work elements, in a simple assembly line balancing problem the cycle time cannot be smaller than the largest time of a task. The work content of a station is the sum of the processing times of the tasks assigned to a **workstation**. The tasks are produced in an order due to the technological restrictions that are called the precedence relations or precedence constraints. Processing of a task cannot start before certain tasks are produced. These tasks are known as the predecessors of that task. The successors of a task are the tasks that cannot be performed before the completion of this task. The precedence relations can be represented graphically as illustrated in Figure 2.

In the figure, the nodes represent the tasks and an arc between the nodes i and j exists if task i is an immediate predecessor of task j. accordingly, tasks 1, 2 and 3 are predecessors of task 4 and task 3 is its immediate predecessor. Task 7 is successor of all tasks and an immediate successor of tasks 4 and 6.

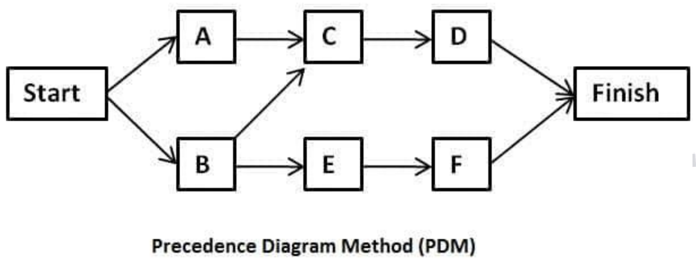

Figure 2.1: An example of precedence graph

2.3 The Assembly Line Balancing.

The classical assembly line balancing problem (ALBP) considers the assignment of tasks to the workstations. Main concern of the assignment is the minimization of the total assembly cost while satisfying the demands and some restrictions like precedence relations among tasks and some system specific constraints (Pekin,2016)

2.3.1 Classifications of assembly line systems.

Assembly lines can be classified as single-model, mixed-model, and multi model systems according to the number of models that are present on the line.

Single-Model Assembly lines have been used in single type or model production only. There are large quantities of the products, which have the same physical design on the line. Here, operators who work at a workstation execute the same amount of work when a sequence of products goes past them at a constant speed.

Mixed-Model Assembly lines are usually used to assemble two or more different models of the same product simultaneously. On the line, the produced items keep changing from model to model continuously.

Multi-Model Assembly lines. Several (similar) products are manufactured on one or several assembly lines. Because of significant differences in the production processes, rearrangements of the line equipment are required when product changes occur. Consequently, the products are assembled in separate batches in order to minimize set-up inefficiencies. While enlarging batch sizes reduces set-up costs, inventory costs are increased. (Scholl 2017)

Figure 2.2 Single Model Assembly lines

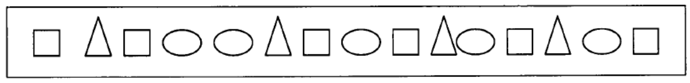

Figure 2.3 Mixed-Model Assembly lines

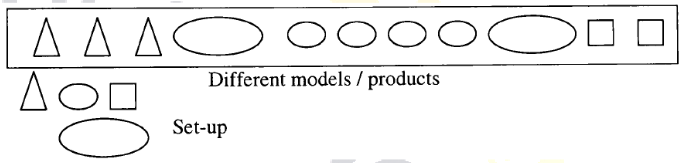

Figure 2.4 Multi-Model Assembly lines

2.3.2 Variation of task time

Another important classification of the lines is the variation of the task times. The task times are classified as deterministic and stochastic. The automated manufacturing systems or assembly lines which are equipped by flexible machines or robots are assumed to work at a constant speed hence the **deterministic** task times are well fit. Sometimes the variations of the task times may be significant in affecting the performance of the system; hence the task times are **stochastic**.

When the lines are operated manually, the variations of the task times are expected due to the skills and motivations of the employees. Moreover, due to the learning effects or successive improvements of the production process variations between the task times may occur .This is supported by Suresh et al (2017) that assembly line balancing problems can be classified into two groups: stochastic and deterministic assembly lines. When an assembly line is fully automated, all the tasks will have a fixed operation time. Variability (or stochasticity) comes into the picture when tasks are performed manually at the workstations. (Pekin,2016)

2.4 Problems in Line Balancing

Nowadays assembly lines move towards cellular manufacturing in terms of variety of production. As a result of this, usage of special equipment and/or professional workers, which are able to perform more than one process, is increasing. In order to benefit from continuous productions advantages, these equipment and workers must be added to the line in a way by which high efficiency measures (maximum usage, minimum number of stations) can be achieved (Agpak and Gokcen, 2018). This theory is supported by Barbars (2018), he stated that while designing the line, the list of task to be done, task times required to perform each task and the precedence relations between them are analyzed. While tasks are being grouped into Stations based on this analysis, the following goals are regarded:

1. Minimization of the number of workstations for a given cycle time.

2. Minimization of cycle time for a given number of work stations. Nicosia et.al (2019) studied the problem of assigning operations to an ordered sequence of non-identical workstations, which also took precedence relationships and cycle time restrictions into consideration. The aim of the study was to minimize the cost of workstations. They used a dynamic programming algorithm, and introduced several fathoming rules to reduce the number of states in the dynamic program.

Falkenauer (2015) listed a few of the difficulties that must be tackled in a line balancing tool in order to be applicable in the industry. Those difficulties are:

I. Workstation cannot be eliminated. Since each workstations has their own identities, it is obvious that the workstations cannot be eliminated unless the workstations were in front or at the end of the line. The elimination of any workstation at the middle will create a gap or holes in the assembly line.

II. The load needs to be equalized. A small increase in the maximum lead time may yield a substantial reduction in load misbalanced. Takt time is normally set by the company"s marketing that sets production target. The cycle time must not exceed the given Takt time. But, it is normally useless to reduce the line"s cycle time below that value. Minimizing the cycle time is only required as long as it exceeds the Takt Time. Once, the objective is met, equalization of workload should be pursued instead.

III. Multiple operators. Once a workstation features more than one operator, the workstation"s lead time ceases to be a simple sum of durations of all operations assigned to it. Firstly, the whole workstation need to have time equal to the "slowest" operator to complete all operations assigned to the workstation. Since different workstation has different workload, hence it is surely not equal to the sum of durations divided by the number of operator. The precedence constraint that nearly exists among the workstations may introduce idle (waiting) time between operations. This idle time reduces efficiency of the workstation and must be reduced as much as possible.

Next problem in line balancing is related with machinery. This problem was normally met in factory where some machinery is manufactured and assembled. In this factory, there are limited number of specific machines and limited number of workers that can use these machines. For example, there is a special cutting tool that can cut metals in a specific width and shape. In this situation, the problem is assigning these tools/machines and workers to the stations. In assembly lines, where specific operation robots are used, the importance of simultaneously balancing of the resources and the assembly line can be understood better (Agpak and Gokcen, 2018)

2.4.1 Bottleneck

Line balancing problem is the bottleneck of flow production. According to theory of constraints (TOC) by (Goldratt and Cox, 1986) the throughput of manufacturing systems is constrained by the capacity of bottleneck machines. In most situations, the final throughput of manufacturing systems could be notably improved if the bottleneck machines are well scheduled and controlled. However, how to define the bottleneck and how to design an easily-implemented bottleneck detection method are still problematic at present. In intermittent manufacturing, it is almost impossible to balance the available capacity of the various workstations with the demand for their capacity. As a result, some workstations are overloaded and others are under-loaded. The overloaded workstations are called bottlenecks. Throughput is the total volume of production passing through a facility. Bottlenecks control the throughput of all products processed by them. If work centers feeding bottlenecks produce more than the bottleneck can process, excess work-in process inventory is built up. Work centers fed by bottlenecks have their throughput controlled by bottleneck and their schedules should be determined by that of the bottleneck.

2.5 Line Balancing Analysis.

After the mathematical formulation of the assembly line balancing problem (ALBP) for single-model assembly lines was first stated by Salveson(2019), many extensive research has been done in the area. In order to solve a line balancing procedure, many researches has come up with similar procedures. This is the procedures listed by G.Andrew (2020)

I. Draw a precedence diagram Precedence diagram need to be drawn to show a connection between a workstation. Processing of a task cannot start before certain tasks are produced.

II. Determine the Cycle Time, Cycle time is longest time allowed at each station. This can be expressed by this formula:

$$Cycle\ Time = \frac{Production\ time\ available\ per\ day}{Units\ Requires\ per\ day} \quad (1)$$

III. To compute the Takt time of the line, the formula below were applied:

$$\text{Takt Time} = \frac{Total\ Time\ available}{Total\ Constomer\ demand} \quad (2)$$

IV. To calculate the minimum number of workstation

$$\text{Number of Workstation} = \frac{Total\ Time\ for\ all\ task}{Cycle\ Time} \quad (3)$$

V. To calculate the number of workers, the formula is

$$\text{Number of Worker's} = \frac{Total\ Work\ Content}{takt\ Time} \quad (4)$$

VI. To compute the efficiency, the formula is

$$\text{Efficiency} = \frac{€\ Tast\ time}{No.of\ Work\ Stationxlar\ gest\ cycle\ timer} \quad (5)$$

VII. The productivity of the assembly line also can be calculated by using this formula

$$\text{Productivity} = \frac{Output}{Labor \times Production\ time\ Per\ day\ (Hour)} \quad (6)$$

2.6 Simulation.

There are many simulations available in order to solve line balancing problem. Simulation imitates the real things or process. There are many advantages by using the simulation such as to analyze the utilization or fixed resource and variable resources, we can test the model without damaging or disturbing the original model, to estimate the operating characteristic or objective function value and analyze the problem. A lot of software development companies try to offer the best optimization solution for the assembly systems design. They are confronted with a very sharp concurrency fight, giving a high dynamics to the concerned market. Starting from some basic design conception such as three dimension product modeling, multiple users, web accessible data bases, friendly graphical interfaces and, not at least, powerful interactive simulation tools and being fully object oriented. (Rekiek et.all, 2020) Many simulations have been used by the previous researches to solve the line balancing problem such as WITNESS, ARENA and Tecnomatix software.

However, in this project Tecnomatix software will be used as our simulation tool. Tecnomatix digital manufacturing solutions from Siemens PLM Software are to increase productivity performance by analyzing the bottleneck process and reducing it. The reduction of bottleneck hence can increase the efficiency and optimize production resources.

2.7 Previous research

2.7.1 Productivity improvement via simulation method (manufacturing industry) (Hasbullah, 2019)

This thesis presents a simulation of the current performance of outputs and profits using WITNESS simulation software. An electric connector, manufacturing company is chosen for this study. The data collected was the cycle time, standard of procedure (SOP), work in progress (WIP), downtime, standard time and production layout. A total of three alternative layouts were proposed and simulated to determine their effect on the production performance. One way analysis of variance (ANOVA) test with multiple comparisons was conducted to select the best.

2.7.2 Line balancing technique implementation in a small and medium industry (Koh, 2020)

The thesis discussed about the implementation of line balancing technique in a Small and Medium Industry. The simulation was done using software called Arena where it gave an overall picture of the future condition and analyze the result of production after improvement using line balancing technique. This project described how to use line balance to save production time. Takt time and cycle time were computed with formula. The times were recorded and shorten by reducing downtime and wastes.

III Conclusion

As a conclusion, this chapter elaborates on the overall of the study involving the line balancing as well as the simulation techniques used in manufacturing systems. The problem statement describe about the problem that occurs and leading to this study. While the project objectives, set the purpose of this study and why this project is done. Finally, the project scope involves the scope of the study, the boundaries and the assumption made.

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