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JUDUL: ASSEMBLY LINE BALANCING IMPROVEMENT: A CASE STUDY IN AN ELECTRONIC INDUSTRY.

SESI PENGAJIAN: 2012/2013

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ASSEMBLY LINE BALANCING IMPROVEMENT: A CASE STUDY IN AN ELECTRONIC INDUSTRY

SITI FARAHIN BINTI BADRUL HISHAM

A thesis submitted in fulfilment of the requirements

for the award of the Degree of

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FACULTY OF MANUFACTURING ENGINEERING

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Dedicated to Mr.Badrul Hisham, Mrs. Fatimah, Siti Farizza and Siti Farhana

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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 electronic 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.

ABSTRAK

Penyeimbangan baris pengeluaran adalah tentang menyeimbangkan pengeluaran supaya terdapat aliran sekata dati satu stesen kerja kepada stesen kerja seterusnya. Penyeimbangan baris pengeluaran juga bertindak sebagai alat paling sukses bagi mengurangkan kesesakan di baris pengeluaran dengan menyeimbangkan jumlah masa tugas bagi mengelakkan kelambatan dan tiada orang terbeban dengan tugas mereka.Tesis ini membentangkan kajian kes masalah teknik penyeimbangan baris pengeluaran dalam sebuah syarikat elektronik dan kajian memberi tumpuan kepada *"Assembly line"* 11 dan 12 yang menghasilkan model peraruh HA00-08464 LFTR. Kajian ini bertujuan untuk meningkatkan produktiviti dan kecekapan baris pengeluaran juga untuk mencadangkan aktiviti penambahbaikan berdasarkan mengimbangi barisan pengeluaran dan analisis yang dilakukan dalam model simulasi. Simulasi ini dilakukan dengan menggunakan *"Tecnomatix Simulation Plant"*. Semua data yang diperlukan untuk analisis teknik penyeimbangan baris pengeluaran dikumpulkan dan model *"Assembly line"* dilengkapi dengan pengiraan secara manual dilakukan. Data ini kemudiannya disimulasi dalam *"Tecnomatix Simulation Plant"*. Antara aktiviti-aktiviti penambahbaikan dijalankan untuk mengimbangi barisan pengeluaran telah menggabungkan beberapa proses ke dalam satu proses, transformasi daripada proses manual kepada jentera dan mesin, dan mengurangkan pembaziran dari baris pengeluaran, sepanjang kajian tiga pelan kerja telah dicadangkan. Antara ketiga-tiga pelan kerja, hanya satu pelan kerja bakal diusulkan kepada syarikat. Pelan kerja terpilih adalah pelan kerja yang memiliki kadar kecekapan serta kadar produktiviti yang lebih baik.

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LIST OF ABBREVIATIONS

ALB	Assembly line balancing
ALBP	Assembly line balancing problem
ANOVA	One way analysis of variance
CNC	Computer Numerical Control
LB	Line balancing
MHU	Man Hour per Unit
SWCT	Standard work combination table
VMI	Visual Mechanical Inspection
WIP	Work in Progress
WS	Workstation
2D	Two dimension

CHAPTER 1

INTRODUCTION

1.1 Project Background

The project is about a case study at an electronic company. The case study is regarding improvement in assembly line balancing with the help of simulation model. The electronic company produces industrial electronic 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 electronic 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.

Aside 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 electronic 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.

1.2 Project Objective

a) To improve the productivity of the process.
b) To improve line efficiency.
c) To recommend improvement based on the line balancing and analysis done in the simulation model.

1.3 Project Scope

The study concentrates on the understanding of the theory and concept of assembly line balancing. The data collected from the industry will be simulated in a simulation by using Tecnomatix Plant Simulation software. In addition, continuous improvement activities will be conducted in order to improve the workstation layout. The case study is conducted at assembly line 11 and 12 which produces inductor model HA00-08464 LFTR. The research is done at BI Technologies Corporation Sdn.Bhd, located in Kuantan,Pahang.

1.4 Problem Statement

After visiting and researching at the company there are a few problems that are identified and can be improved. Firstly, is the poor work station layout. The work station layout is scattered and complicated. The winding section is quite far from the assembly line. However, the cycle time taken only starts at the stripping station so this does not affect the whole cycle time of the process. Secondly, some of the process in the assembly line has a cycle time much higher than the Takt time allocated by the marketing, when this occur it might be hard for the line to achieve the daily target. Next problem is regarding the number of non-value adding activities that have been found which bring unbalanced line. This non value adding activities need to be identified and improved in order to reduce the labor cost and to optimize the line. Finally, the process which takes the longest cycle time contributes to bottleneck problem. The clipping of E and I core is the bottleneck of the process as this process has the longest cycle time. Continuous improvement activities need to be done to reduce the bottleneck of the line.

1.5 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.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

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 is their strengths and weaknesses are. This chapter 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.

2.2 The concept of Assembly Line Balancing

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 (2000) 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 (2008) as the assembly line balancing problem.

2.2.1 Terminology used in assembly line balancing.

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. **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

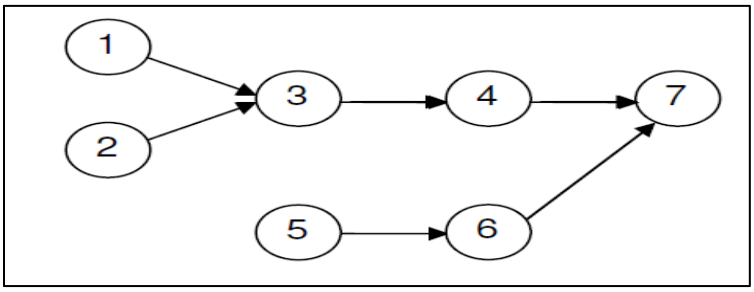


Figure 2.1: An example of precedence graph

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.

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,2006)

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 1998)

Figure 2.2 Single Model Assembly lines

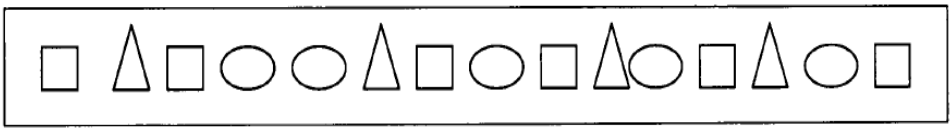


Figure 2.3 Mixed-Model Assembly lines

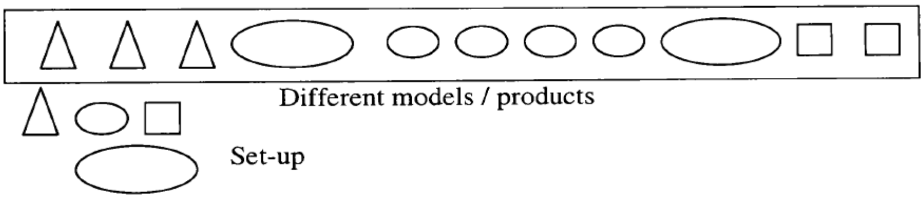


Figure 2.4 Multi-Model Assembly lines

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 (1996) 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,2006)

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, 2005).

This theory is supported by Barbars (1986), 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 (2002) 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 (2000) 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, 2005)

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(1955), 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 (2006)

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, C

Cycle time is longest time allowed at each station. This can be expressed by this formula:

$$Cycle\ time = \frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day} \quad (2.1)$$

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

$$Takt\ time = \frac{Total\ time\ available}{Total\ customer\ demand} \quad (2.2)$$

IV. To calculate the minimum number of workstation

$$Number\ of\ workstation = \frac{Total\ time\ for\ all\ task}{cycle\ time} \quad (2.3)$$

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

$$Number\ of\ workers = \frac{Total\ work\ content}{Takt\ time} \qquad (2.4)$$

VI. To compute the efficiency, the formula is

$$Efficiency = \frac{\sum Task\ time}{n.of\ workstationxlargest\ cycle\ time} \qquad (2.5)$$

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

$$Productivity = \frac{Output}{laborXproduction\ time\ per\ day(hour)} \qquad (2.6)$$

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, 2002)

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,2010)

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,2012)

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.

2.7.3 Productivity Improvement through line balancing (Hazmil, 2008)

The thesis determined that a poor layout design is a major problem contribution in small and medium industry. These particular problems thus affect the productivity and the line efficiency as well. After the related problems are identified, the current layout is redesign by computing the standard time and processing time in each workstation. In each workstation the processing time is different and the longest time consumption is workstation will be identified as a bottleneck workstation. This related line is studied by time study techniques. The time is taken by stopwatch. In this study, application of Computer Aided tools is introduced which in this study is WITNESS SOFTWARE. The related inputs are going to be simulated with this software. The manual calculation also included especially in line balancing algorithm. The goal of the thesis is to seek the best layout in terms of line efficiency and productivity rate hence proposed to the company. Throughout the study, three layouts have been achieved and only one is proposed to the company.

2.7.4 Productivity improvement through line balancing technique in a small medium enterprise (SME) manufacturing plant (Shahfiran, 2007)

This thesis discussed that the assembly lines has a great importance in the industrial production of high quantity standardized commodities and more recently even gained importance in low volume production of customized products. The study was done at a Small Medium Enterprise (SME) manufacturing plant. In this project, line balancing technique is used and WITNESS software act as a simulation tool to find the good solution for improving the productivity rate of the company. By defining the problem that occur in the exiting line and give some alternative for the new assembly line, the problem is solved.

2.7.5 Productivity improvement in industry by using WITNESS software (Wan Faizul, 2008)

This thesis study about how to improve productivity, reduce waiting time, how to increase the production rate and maximum space utilization of the production line. The study focused on the trim line production of Mercedes-Benz and the simulation is done by WITNESS software. Data collecting method is by direct observation, archival data and self-collecting data. Live experiments are conducted on production lines. Four problems are identified such as reworked, not enough manpower, delayed process, high waiting time, and low production which are not in the target for one day production. Interventions are made to rectify the problems such as to reduce waiting time in problem's section by adding buffer which for temporarily storage for finished part in order to minimize waiting time for finished section sent the finish part without have to wait. As a result, the production productivity for the trim line production is increased.

2.8 Conclusion

This literature review elaborates the idea and concept of Assembly line balancing (ALB) from various researches. The way the previous researcher explains the basic terms maybe different from one another but, the meaning of the term is still the same. The formula and calculations used by different researches are also studied in order to choose which equation suits the project.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, it will explain detail on the overall flow of the project from the procedures and data collection method. This methodology also acts as a guideline and direction to ensure a smooth flow of the project. In this project, many method will be used such as calculate the cycle time, takt time, number of workstation and number of workers. The cycle time, number of workers and line efficiency will be calculated manually at first in order to access the current performance of the line. Then, Tecnomatix software is used to simulate the line balancing and to further improve the layout of the process.

3.2 Project Flow Chart

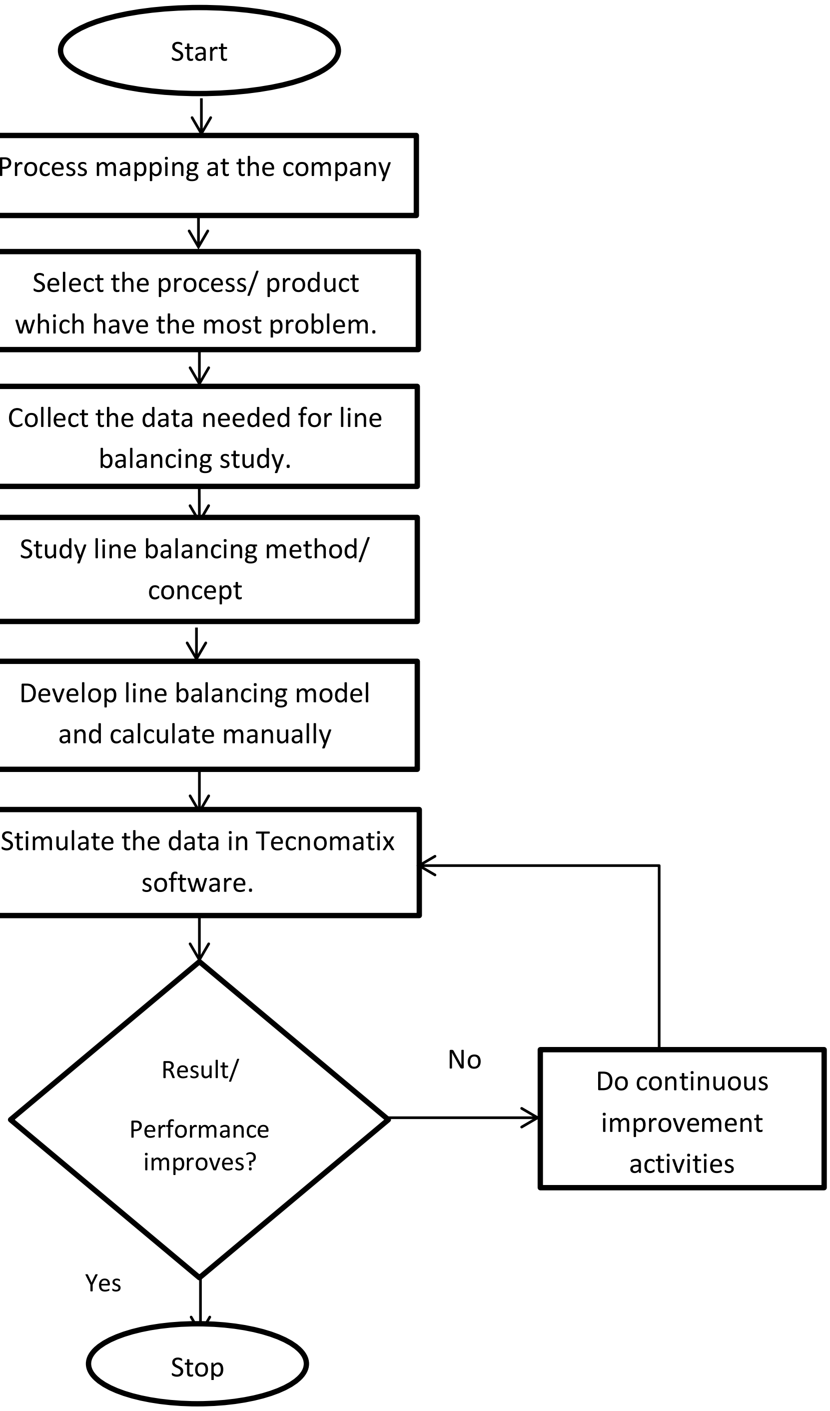


Figure 3.1: Project flow chart

3.2.1 Line balancing technique flow chart

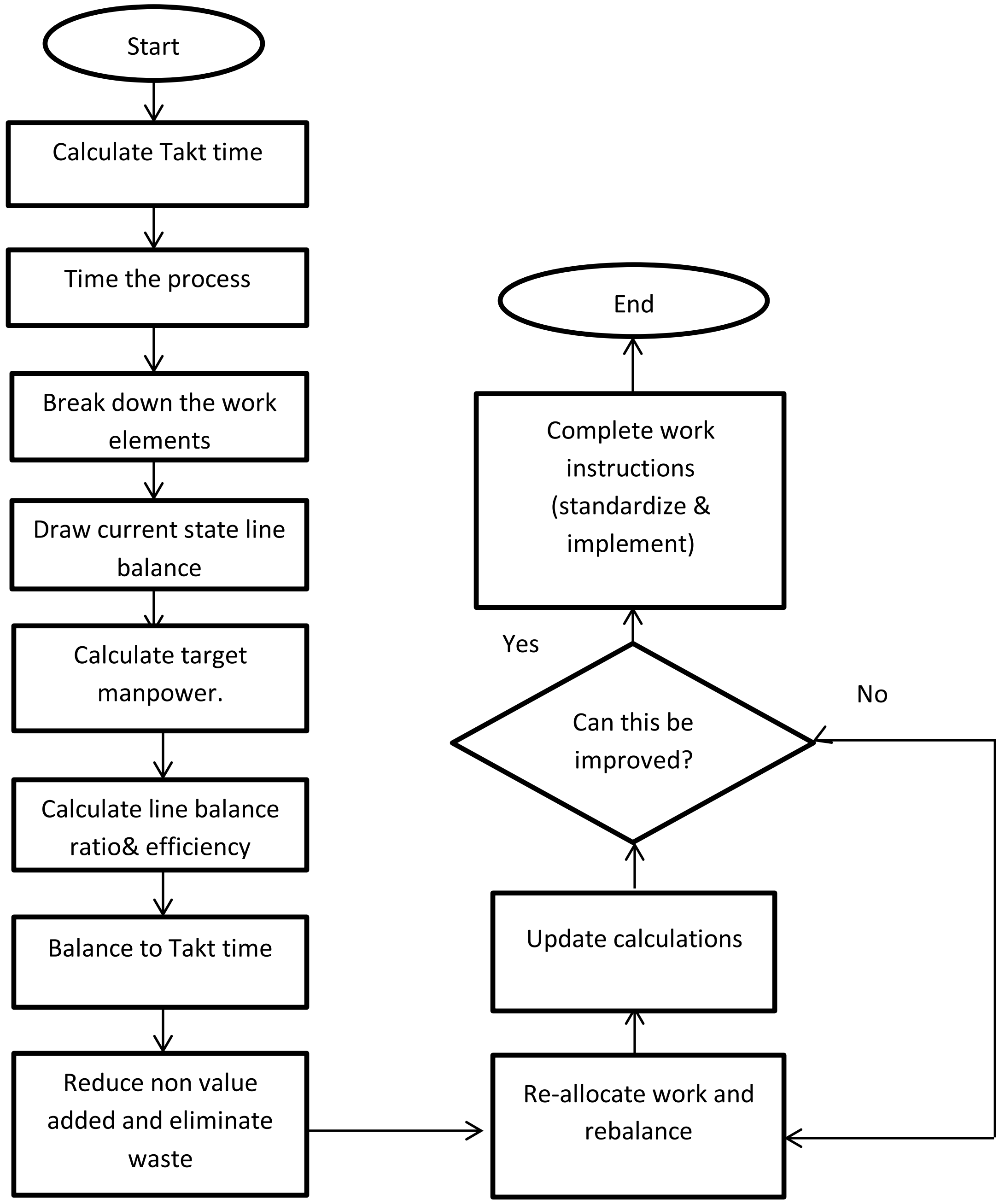


Figure 3.2: Line balancing technique flow chart

3.3 Process Mapping

Process mapping is a technique which visually represents the work process. Process mapping also provides a common understanding of the entire process and specific roles and contributions of each worker. Process mapping is very important, before improvement can be done in a process, it is crucial to understand the whole process first. Process mapping are good for streamline work activities and telling new people, as well as internal and external customers. Process maps also helped in the effort to reduce cycle time, avoiding rework, eliminating some inspections or to show quality control steps and also to prevent errors. Furthermore, process maps are a great problem solving tool in ways that it help us to determine what is the problem and what is not.

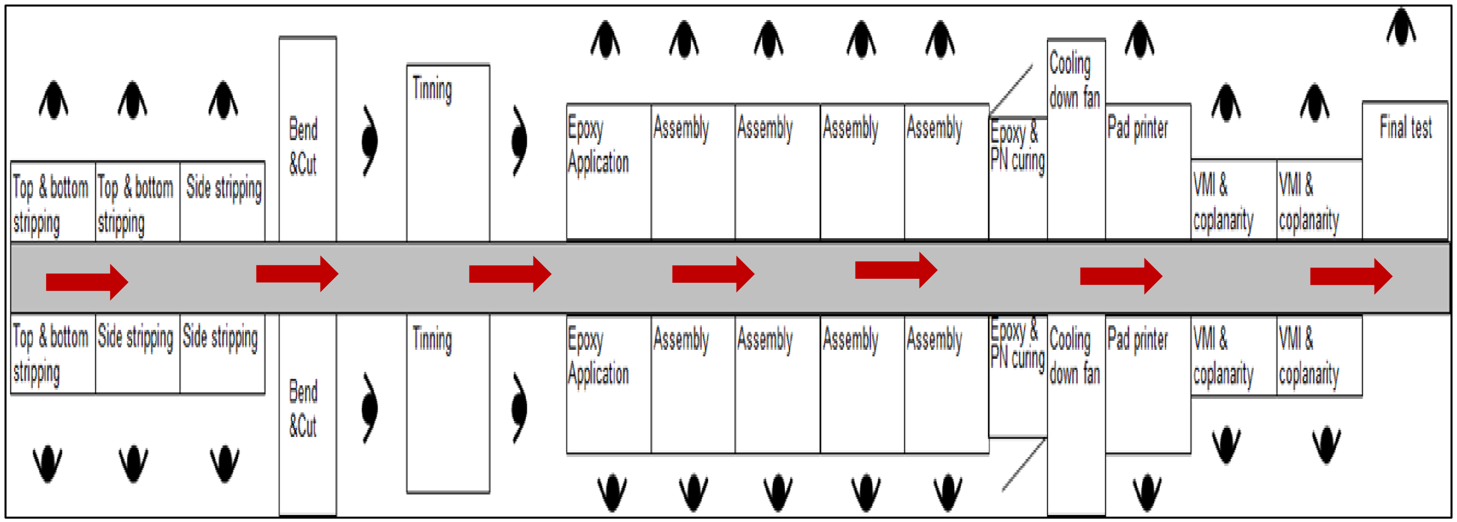


Figure 3.3: Process mapping for assembly line 11 and 12

The figure 3.3 shows the process map for the assembly line 11 and 12 which produces inductor HA00-08464LFTR. The assembly line starts with the bottom, top and side stripping using laser machine. This stripping process is to remove the insulation that exists at the air coil. The material handling for this process is plastic container, this container is passed through the operator by the conveyor. After stripping, bending and cutting process takes place. Bending and cutting process is done using bend and cut machine located at the line. Next is the soldering process, after the air coil undergoes tinning using existing solder pot. After soldering, operator 1 will bring the air coil for washing. The air coil washing uses existing ultra-sonic bath at the special washing room.

After air coil washing, applying epoxy three spots and also epoxy four spots takes place. This epoxy is a type of glue that is used to glue the air coil with I-core. Next, after the assembly of air coil and I-core, the E-core and I-core is clipped together. The clip functions to hold the three components together to prevent them from loose.

Next process is putting the E-core,I-core assembly into the oven curing. This oven curing process uses shelab oven which will ‘bake’ the E-core,I-core together with the epoxy glue to produce a tough inductor component. After the oven curing process, the inductor will undergo the printing part number process. The inductor is once again placed in the oven curing for another 30 minutes to dry the print number. Finally, the complete inductor undergoes boundary, visual mechanical inspection (VMI) and coplanarity inspection before final test and tubing.

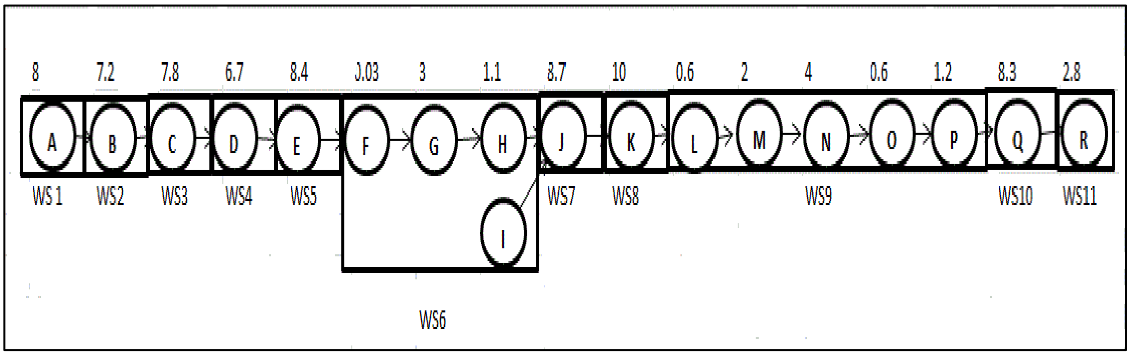


Figure 3.4: Precedence Diagram and workstation for line 11 and 12 before improvement

Table 3.1: Data set for assembly line 11 and 12(before improvement)

Task	Description	Time (seconds)	Predecessors
A	Bottom leadout stripping	8.0	None
B	Top leadout stripping	7.2	A
C	Side leadout stripping	7.8	B
D	Bend and cut	6.7	C
E	Soldering	8.4	D
F	Aircoil washing	0.03	E
G	Epoxy appX 3 spots	3.0	F
H	Epoxy appX 4 spots	1.1	G
I	E core		None(feeder line)
J	Aircoil-I core assembly	8.7	H,I
K	E core- I core clipping	10.0	J
L	Oven curing	0.6	K
M	Remove clip	2.0	L
N	Printing part number	4.0	M
O	Oven curing	0.6	N
P	Boundary inspection	1.2	O
Q	VMI & coplanarity inspection	8.3	P
R	Final test & tubing	2.8	Q
	Total time	80.3	

Figure 3.4 shows the precedence diagram for assembly line 11 and 12. There are 11 workstations available. These workstations are grouped according to the bottleneck of this assembly line. The bottleneck of this line is the E-core and I-core clipping process which has the longest cycle time of 10 seconds. Hence, the precedence diagram is grouped within 10 seconds for a workstation.

3.4 Product Selection

After the process mapping is done, brief discussion with the engineer at BI Technologies lead to two product option. The first option was the HA00-08464LFTR while the second option was Agilant Loveland transformer model. A few criteria was taken into account until the inductor model HA00-08464LFTR was chose rather than the transformer model. Firstly, the HA00-08464LFTR which runs at assembly line 11 and 12 is a straight line cell while the Agilant Loveland transformer runs at U-shaped line cell. Next, the cycle time of some of the process in this assembly line is higher than the Takt time allocated by the marketing. If the cycle time of a process is higher than the Takt time, the line will not able to produce the product according to the daily target. Many continuous improvement activities that can be done at this line such as their material handling system and rebalancing workload among operators in order to balance the line. The figure 3.5 shows the process cycle time of the assembly line 11 and 12 which shows a few processes which have cycle time higher than Takt time. The figure of inductor HA00-08464LFTR is attached on the appendix.

Figure 3.5: Inductor HA00-08464 LFTR

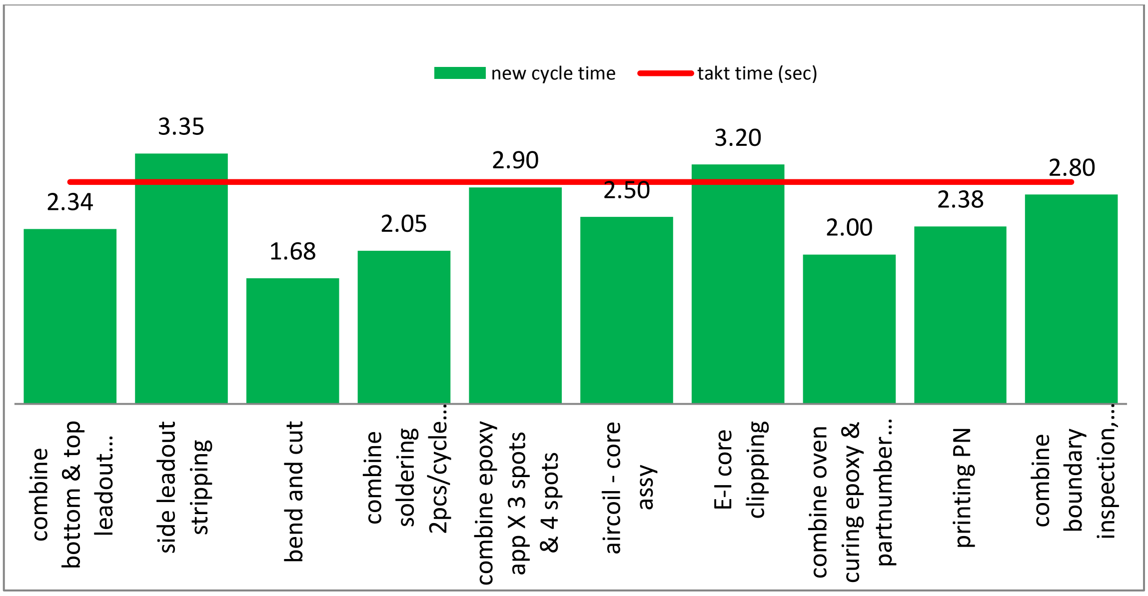


Figure 3.6: Process cycle time model HA00-08464LFTR (Before improvement)

3.5 Data collection

There are a few data that need to be collected in this case study. After understanding the flow of the process involved in assembly line 11 and 12, the precedence relations between assembly tasks is identified. The precedence relation is when one task must be completed before another task can be started. The first task is said to have precedence over the other. The cycle time for each process are also observed and recorded by using stopwatch. Cycle time is the time between the completions of two consecutive units. Next, after the cycle time of each process is recorded, the Takt time of the assembly line is calculated by using formula. The number of workers is also identified for each workstation. This is to know how many workers needed for each workstation and the total head count for the whole assembly line. The material handling system of this assembly line is also identified to know the movement of the process in the assembly line.

Table 3.2: Table for cycle time and head count for model HA00-08464LFTR (Before improvement)

Process	Cycle time (seconds)	Headcount
Bottom leadout stripping	8.0	3
Top leadout stripping	7.2	3
Side leadout stripping	7.8	5
Bend and cut	6.7	3
Soldering	8.4	3
Aircoil washing	0.03	Share
Epoxy appX 3 spots	3.0	1
Epoxy appX 4 spots	1.1	1
Aircoil-I core assembly	8.7	3
E core- I core clipping	10.0	4
Oven curing	0.6	Share
Process	Cycle time(seconds)	Headcount
Remove clip	2.0	Share
Printing part number	4.0	2
Oven curing	0.6	Share
Process	Cycle time (s)	Headcount
Boundary inspection	1.2	1
VMI & coplanarity inspection	8.3	2
Final test & tubing	2.8	1
Total	80.3	32

3.6 Calculation involves in line balancing

To calculate cycle time,

$$= \frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day} \quad (3.1)$$

$$= \frac{7.92x60x60}{12000}$$

= 2.38 seconds.

The current cycle time of the process is 2.38 s, while the process lead time (total task time) is 80.3s. In each 2.38s one inductor is produced.

To calculate maximum production per hour,

$$= \frac{60\, minutes}{Botteneck\ (minutes)} \tag{3.2}$$

$$= \frac{60}{0.17}$$

= 353 inductors per hour

The maximum production per hour is 353 inductors for every hour.

To calculate the line efficiency,

$$= \frac{Total\ task\ time}{BottleneckX\ Number\ of\ node} \tag{3.3}$$

$$= \frac{80.3}{10.0x11} \text{x}100\%$$

= 73.12 %

The current line efficiency is 73.12%. This efficiency can be improved by minimizing balance delay.

3.7 Simulation using Tecnomatix Plant Simulation

Simulation is the imitation of the dynamic process within a model to arrive at results that may be transferred to real systems. Simulation can reduce the cost as the factory can do ‘try and error’ method if they want to do changes or improvements at their factory layout or systems.

UGS Tecnomatix by Siemens consists of four main components. The components are the Tecnomatix factory cad, Tecnomatix factory flow, EmPlant(Plant simulation) and Jack. The component which will be used in this project is the EmPlant(Plant simulation)

Tecnomatix Plant Simulation is a discrete event simulation tool for statistical modeling of facilities where troughput, machine capacity constraints, queuing constraints are important. Tecnomatix Plant simulation allows for creating a dynamic computer model of a complex system to explore its characteristics and optimize the performance of the system. The computer model enables the user to run experiments and what if’s scenarios without disturbing an existing production, also can be used in the planning process long before the real system is installed.

Plant simulation can increase the throughput, resource utilization, utilization of the facilities and also decrease the throughput times. In addition Plant Simulation can identify bottleneck, reduce WIP and evaluate the effect of capital investments or changes in processes.

3.7.1 Steps involve in modeling a layout using Tecnomatix Plant Simulation

After collecting all the data needed the modeling phase can be proceed. The modeling phase includes building and testing the simulation model. These are the steps to build a plant in Plant Simulation:

i. Firstly, open Plant Simulation education on the Start menu. Click New and click OK on the manage class library tab.
ii. The plant will contain this following object: A source, SingleProc, A drain and an event controller.
iii. After a new model is created click Frame in the class library tab and right click to rename the new frame to Layout1.
iv. Now, insert source, Singleproc attach with line from the material flow section. Control C and Control V to make many copies of Singleproc+Line.
v. Rename each Singleproc. In order to rename, double click at the Singleproc icon and at the name section insert WS1.
vi. After renaming each SingleProc, add the lead time of each workstation in the time section.
vii. In order to complete the layout, insert Drain from the material flow section at the end of the line. Again add connector from Source to WS1.
viii. To run the simulation, double click the Event Controller icon on the frame. After the Event Controller window opens, change the date and time. Click Start on the Event Controller window, when finished click Stop and Reset.
ix. Now the layout1 is complete, save model and create another two layouts with different scenarios.

3.8 Conclusion

As a conclusion, this chapter describes the steps to conduct the whole project. Each step is described with appropriate figures and tables. The data collected from the company is used as a benchmark to predict the performance and outcome of the project. The simulation is used to create a virtual layout of the assembly line and how to do continuous improvement activities in the simulation without applying to the real assembly line.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Introduction

This chapter will provide the result and discussion of the study and the simulation runs of the models developed. Three layout proposal will be produce with different parameters as variables, this three layout will be simulated using Tecnomatix Plant Simulation and the results from the simulation is transferred into figures and graphs for analysis purpose. The result of the layout which is most productive and efficient will be proposed to the company.

4.2 Model conceptual

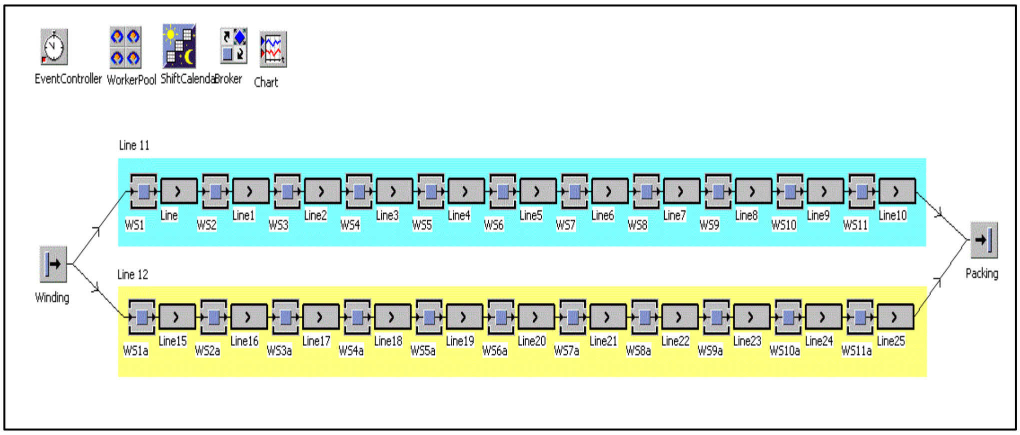


Figure 4.1: Layout for assembly line 11 and 12 before improvement in Tecnomatix Plant Simulation

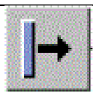
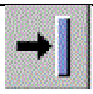
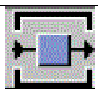
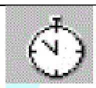
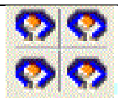
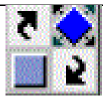
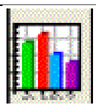
Figure 4.1 shows the modeling of assembly line 11 and 12 before the implementation of line balancing by using Tecnomatix Plant Simulation. The layout started from the winding process and end at the packing process. The demand for the inductor previously is 12000 before the improvement with the lead time is 80.3 seconds and the number of operators is 32 people. The line efficiency is 73.12%, the productivity is 47.35% and the MHU rate is 0.02112.The bottleneck of the line is identified in the aircoil and core assembly process because the total time needed is the longest which is 10.0 seconds compared to others. All the process was group in work stations according to the bottleneck. The calculation for assembly line 11 and 12 before improvement is shown in appendix A.

Table 4.1: Data set for line 11 and 12 also legend for figure 4.1

Symbol	Process	Cycle time (s)	Number of operators
WS1	Bottom leadout stripping	8.0	3
WS2	Top leadout stripping	7.2	3
WS3	Side leadout stripping	7.8	5
WS4	Bend and cut	6.7	3
WS5	Soldering	8.4	3
WS6	Aircoil washing Epoxy app X 3 spots Epoxy app X 4 spots	0.03 3.0 1.1	2
WS7	Aircoil-core assembly	8.7	3
WS8	E-I core clipping	10.0	4
WS9	Oven curing Remove clip Printing PN Oven curing Boundary inspection	0.6 2.0 4.0 0.6 1.2	3
WS10	VMI&coplanarity inspection	8.3	2
WS11	Final test & tubing	2.8	1
	Total	80.3	32

Tecnomatix Plant Simulation is a discrete event simulation tool used for statistical modeling of facilities where throughput, machine capacity constraints, queuing constraint (buffer and bottlenecks) are important. Tecnomatix Plant Simulation allows for creating a dynamic computer model of a complex system such as production to explore its characteristics and optimize the performance of the system. Model conceptual of the before improvement based on the process mapping done earlier is converted into a 2D layout. This 2D layout also called as Plant will contain the following objects: a source, entities, nine single process, drain, an event controller, workerpool, shift calendar, broker and chart. Single process represents each process occurred in the line and entities represents the part incoming and outgoing.

Table 4.2: The objects used in basic Plant Simulation model

Entity		A single part whose process is being tracked in this model.
Source		An entry point for an entity into the model.
Drain		An exit point for an entity from the model.
SingleProc		A single operation performed on the entity that takes up time.
Event Controller		The controlling object for starting, stopping, and initializing a simulation.
Worker pool		Defines the workers availability, amount, skill level, walking speed, efficiency and shift model.
Broker		Act as resource manager, receives operator requests and assigns operators to stations.
Chart		It displays statistic data and allows you to quickly evaluate and present the results of our simulations runs

4.3 Establish Takt time.

Takt time is the pace at which the customer is demanding a particular amount of product. It is the rate (time) at which a person/item/action needs to be served or completed at each step in a process in order to meet customer demand, in order for work to pile up. Takt time establishment is one of the most important step in implementing line balancing at line 11 and 12. New Takt time need to be compute after the demand decreased from 12000 to 9600 inductor.

Ouput per day = 9600

Total available time per day = 7.92 hours

$$\text{Takt time} = \frac{Available\ time\ per\ day}{customer\ demand\ per\ day}$$

$$= \frac{7.92 \times 3600}{9600}$$

= 2.97 second.

The new Takt time of the line is 2.97 second while the cycle time is 2.4 second. The cycle time of the assembly line cannot exceed Takt time in order to achieve target. Takt time can be used to balance the workload within the process itself. in order to prevent bottlenecks each process must have cycle time below 2.97 second.

4.4 Balancing the line.

Balancing the line can be done by breaking down work elements. Breaking down work elements is done by using Standard Work Combination Table (SWCT). This document is used for detailing each of the process elements that can be seen from the observation done. It is then used to highlight value added/non-value added, and waste with detail time. The Takt can then be seen clearly and the operations can be sketched out along the time frame. This document is the record of how the job is actually carried out and can be used at a later stage for balancing the work out between operators. The SWCT of this assembly line is attached at appendix A3.

4.5 Layout Modeling

After analyzing all the data related to the current layout, three layouts is proposed for improvement purpose. This three layout is simulated in Tecnomatix Plant Simulation and the data analysis is generated by the simulation itself.

4.5.1 Layout 1

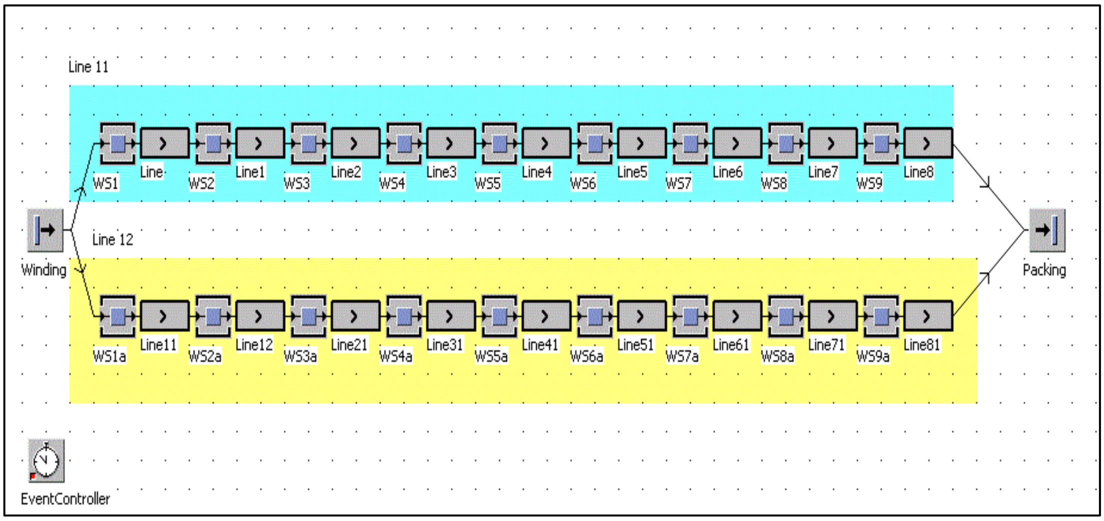


Figure 4.2: Layout 1 in Tecnomatix Plant Simulation

This layout combines a few processes into one in order to balance to Takt time. The process which is combined is the bottom lead out and top lead out stripping. The combination of this two process reduced the cycle time to 9.3 seconds. Next, the soldering process (2 pieces per cycle) is also combined with the air coil washing process which reduced the cycle time to 3.4 seconds. Furthermore, the epoxy application of three and four spots was also combined reducing the cycle time to 4.1 seconds. The oven curing epoxy is also combined with the part number printing decreasing the cycle time to 3.2 seconds. Lastly, the boundary inspection process is combined with the VMI and coplanarity inspection process reduced the cycle time into 9.5 seconds. The advantages of this layout is that it reduces the number of operators from 32 people to only 27 people, increases line efficiency from 73.12% to 99.29% and increases the productivity rate from 44.89% to 47.35%

Table 4.3: Data set for layout 1

	Before improvement	After improvement
Total task time(s)	80.3	69.5
Cycle time(s)	2.4	2.4
Takt time(s)	2.38	2.97
Number of operators	32	27
Line efficiency	73.12%	99.29%
Productivity	44.89%	47.35%

4.5.2 Layout 2

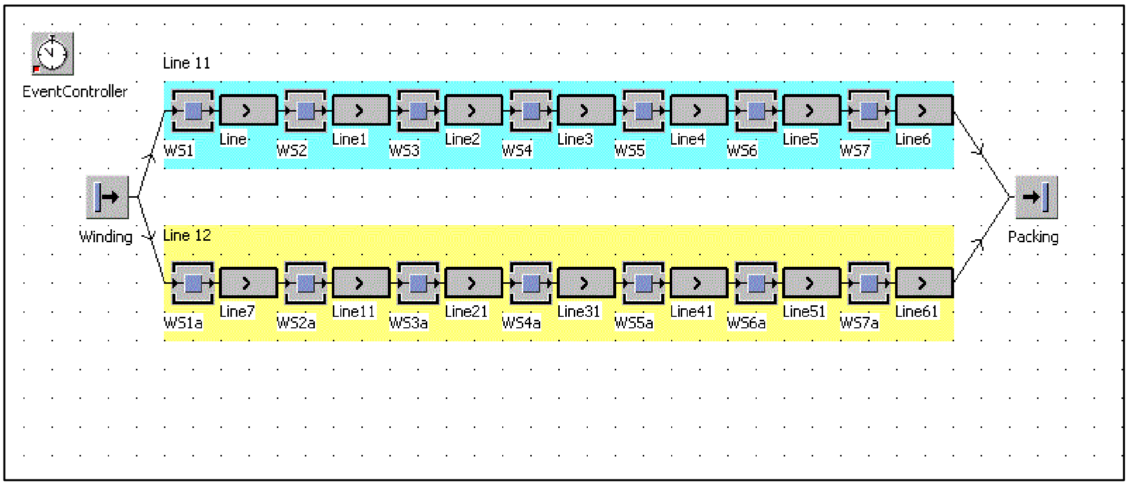


Figure 4.3: Layout 2 in Tecnomatix Plant Simulation

This layout introduces CNC stripping machine replacing the manual process of combining bottom and top lead out stripping. Hence reducing 9.3 seconds from the lead time. Other processes remain the same. The advantage of this layout is that it reduces the lead time from 80.3 seconds to 64 seconds only. This layout also reduces the man power from 32 operators to 22 operators only. The other advantages of this layout is it increases the line efficiency from 73.12% to 106.67% and productivity from 47.35% to 55.1%.

Table 4.4: Table data for layout 2

	Before improvement	After improvement
Total task time(s)	80.3	64.0
Cycle time(s)	2.4	2.4
Takt time(s)	2.38	2.97
Number of operators	32	22
Line efficiency	73.12%	106.67%
Productivity	44.89%	55.1%

4.5.3 Layout 3

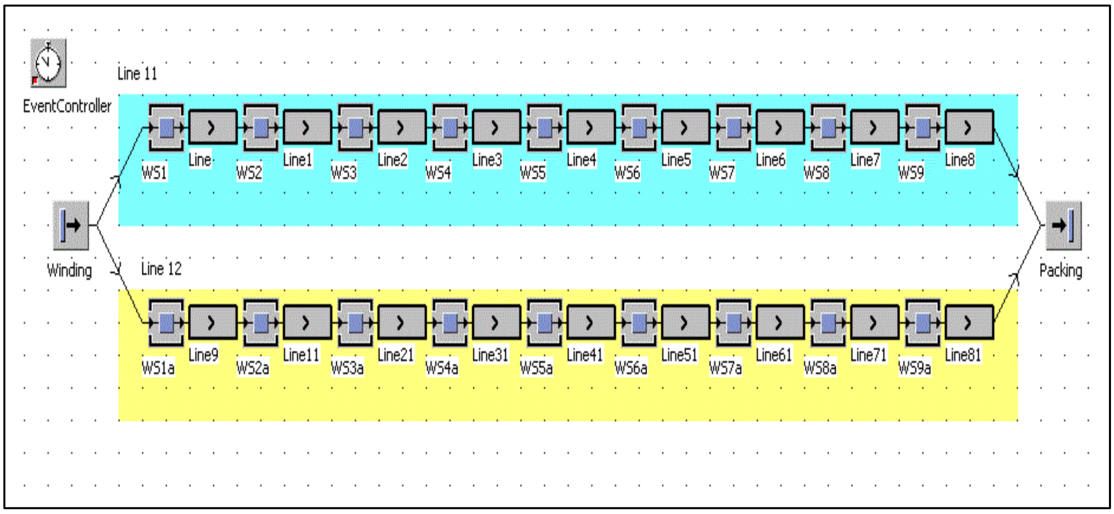


Figure 4.4: Layout 3 in Tecnomatix simulation

This layout introduced more machines compared to proposed layout 1 and layout 2. Firstly, the advantage of this layout is on the epoxy application, the previous layout uses only manual epoxy application while this layout converts it to X-Y table and reduces process time from 4.1 second to 2.8 second. Secondly, the advantage of this layout is that the assembly of the core-coil which is done manually is now done by mechanization core-core assembly. By using this machine, the coil core assembly which takes 8.7 second is reduced to 4.7 seconds only. Next, printing the part number which is done manually before this is also improved to laser marker machine, this machine improves the process time for printing part number from 6.6 seconds to 3.0 second. Furthermore, the final test and tubing process, which is done manually before this is also replaced to automatic test tape and reel machine, this machine reduce the process time from 2.8 second to 2.1 seconds only.

Table 4.5: Table data for layout 3

	Before improvement	After improvement
Total task time(s)	80.3	37.4
Cycle time(s)	2.4	2.4
Takt time(s)	2.38	3.3
Number of operators(s)	32	11
Line efficiency	73.12%	100.54%
Productivity	44.89%	98.84%

4.6 Discussion

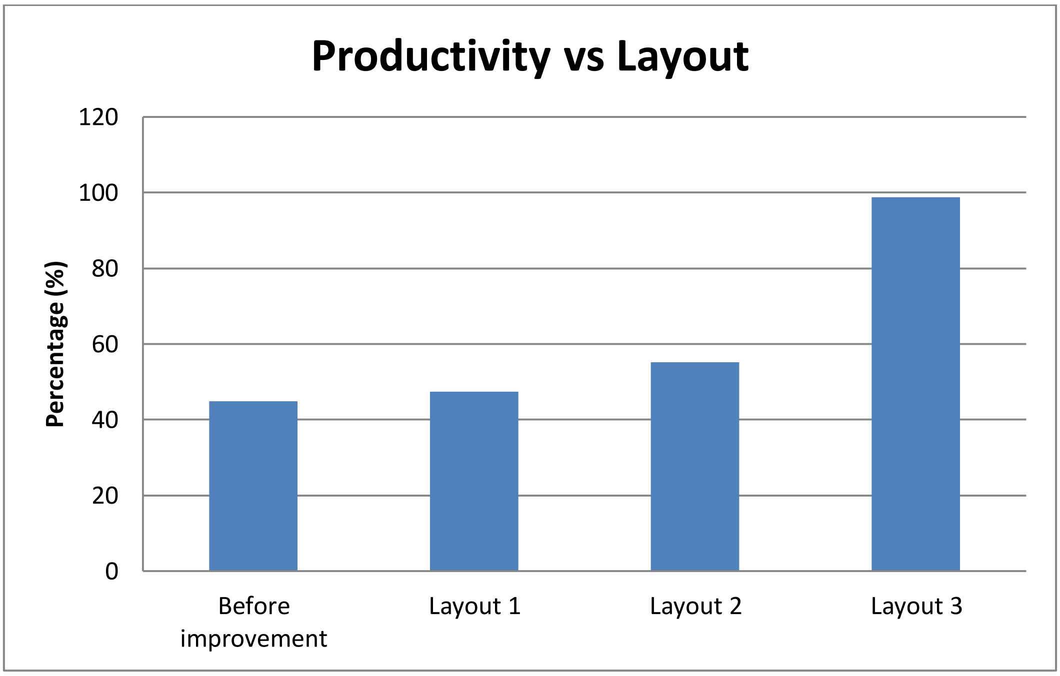


Figure 4.5: Histogram for Productivity versus Layout

Figure 4.5 shows the productivity level before the improvement and all the other layouts. Layout 3 shows the highest percentage of productivity with 98.89% compared to layout 2, 55.1%, layout 1, 47.35% and the lowest is before improvement layout with 44.89%.Productivity of layout 3 is the highest due to the reduce in total task time from 80.3 seconds to 37.4 seconds and also by reducing the number of operators from 32 operator to only 11 operator. The lesser the time needed to produce one inductor, the more productive the assembly line.

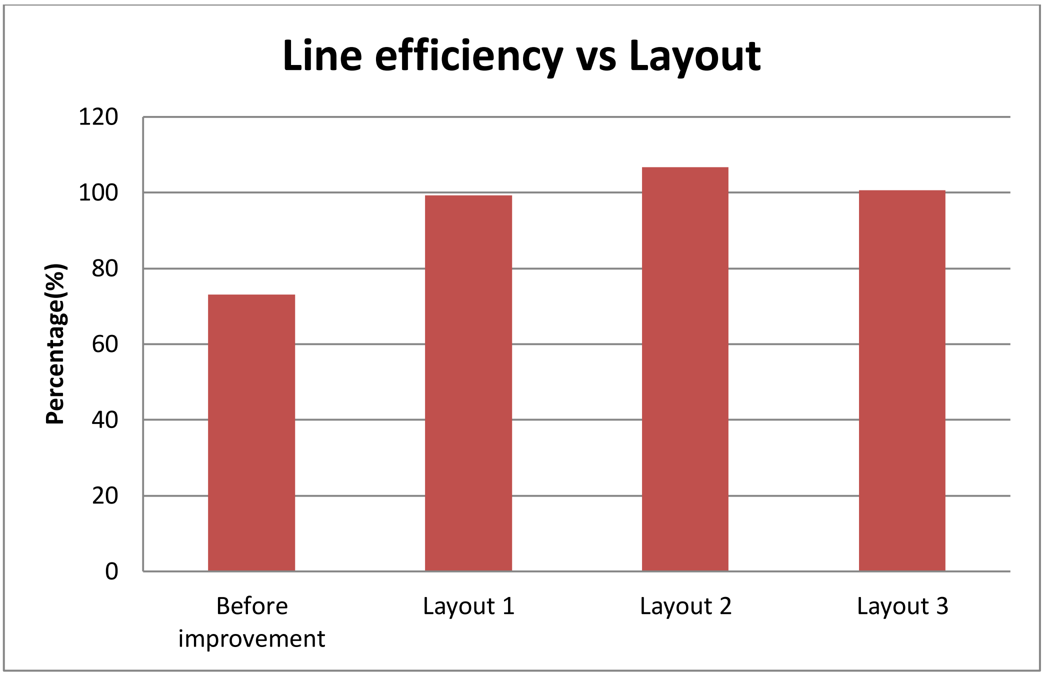


Figure 4.6: Histogram for line efficiency versus layout

Figure 4.6 shows the graph of line efficiency versus layout for all the layout produced. Layout 2 shows the highest percentage of efficiency with 106.67% followed by layout 3,100.54%, layout 1 with 99.29% and the lowest efficiency recorded by before improvement layout with 73.12%. The efficiency of layout 2 is higher compared to layout 3 which has the highest productivity is because the increase in total available working hours from 7.92 hours to 8.83 hours. Longer working hours may cause fatigue to operators hence reducing the efficiency of the line.

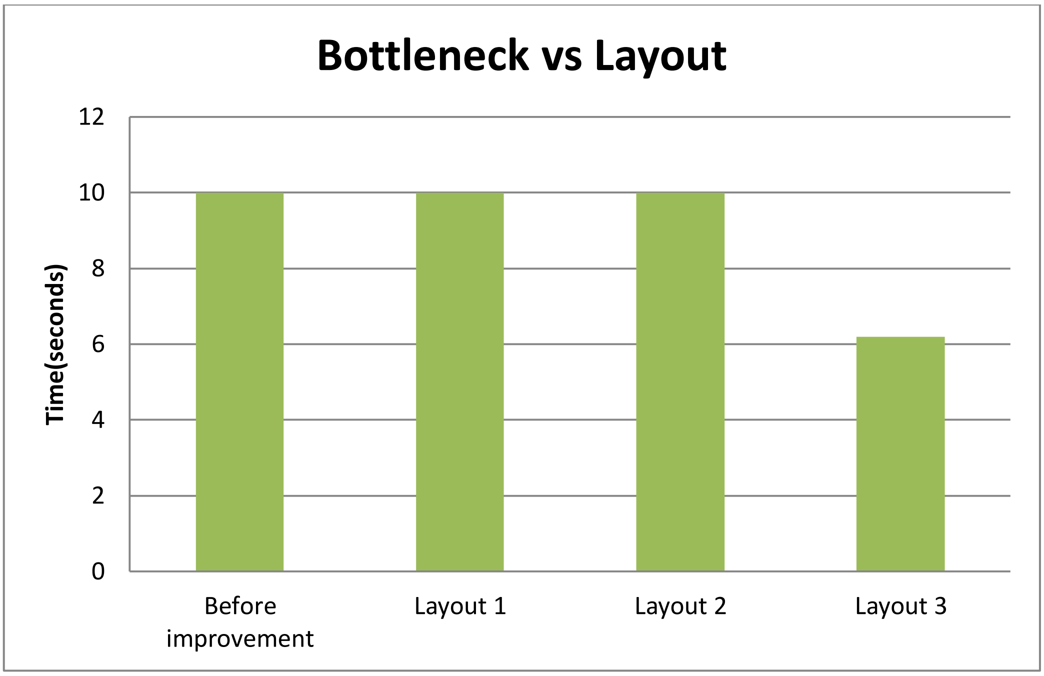


Figure 4.7: Histogram for bottleneck versus layout

Figure 4.7 shows the graph of bottleneck versus layout. Layout 3 shows the lowest bottleneck time compared to others with only 6.2 seconds compared to all other layout proposed which their bottleneck maintains at 10.0 seconds. Layout 3 successfully reduced the bottleneck after the core-coil assembly successfully transformed into mechanization.

4.7 Improvements done

Many improvements have been done in the past one year of the line balancing of line 11 and 12. Among the improvement done is combining a few processes into one after reviewing the work sequence. The bottom and top stripping is combined to become one single process. After the combination of this process, a CNC stripping machine was installed and successfully removing three operators (1 epoxy, 1 clipping, and 1 VMI). Next improvement is from manual four spots epoxy application to X-Y table machine and combined it with existing one spot epoxy application X-Y table into one station. This X-Y table successfully eliminated one headcount from total 2 operators doing the processes before. The bottleneck of the process, the E-I core clipping which take 10.0 seconds before improvement is successfully reduced to a shorter time of 6.2 second by using core-core machine. The photos and figures of improvement done is attached on appendix F.

4.8 Conclusion

Three proposed layout is able to generate with the use of Tecnomatix Plant Simulation. Plant simulation enables the study to run the experiment and what-if scenarios at line 11 and 12 without disturbing the existing production layout. Adding more mechanization to layout 3 really improved the productivity of the line when simulated in Plant Simulation model.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The project presented the findings of a simulation study on line balancing improvement using Tecnomatix Plant Simulation for assembly line 11 and 12 for inductor model HA00-08464 LFTR. The study has identified a few problems that affecting the productivity of line 11 and 12. The bottleneck problem and the long lead time problem is dealt with using line balancing technique aided with a few improvements. Three layouts with different improvement approach were modeled in Tecnomatix Plant Simulation and the graph of each layout was generated together with the workstation which has the most bottleneck problem. The results shows that the line can be balance by combining process and mechanization and lesser number of operators to improve productivity. The study also shows that by removing non value added activity can reduce the bottleneck of a process. The objective of the study was achieved.

5.2 Recommendation

There are a few recommendations that can be done for future research in improvement of line balancing using simulation. This recommendation is divided to two categories, the production and the simulation.

Productivity in assembly line 11 and 12 can be further improved by adding buffer to the assembly line. Buffer is the parts that is ready to use as back up if any incoming part from preceding work station arrived late than the cycle time. Buffer is also efficient in reducing bottlenecks. Ergonomics of the operator movement also need to be taken into account. Longer working hours has causes fatigue to the operator's thus decreasing line efficiency. Position restriction at the end of the line makes it hard to connect the new auto tape and reel machine. If a flexible conveyor line can be used this problem can be overcome.

For simulation wise, adding Experiment Manager to evaluate the influence of the number of carrier and the transportation speed to the throughput. This experiment manager can analyze more on material handling of the line.

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APPENDICES

APPENDIX A1GANTT CHART/PROJECT SCHEDULE FOR FYP1

No	Items		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Received the PSM title & collect FYP	P															
	handbook	A															
2	Discuss the project title,Objectives &	P															
	Scopes with SV	A															
3	Literature review study	P															
		A															
4	Finish writing chapter 1	P															
		A															
5	First visit to BI Technologies	P															
		A															
6	Do process mapping	P															
		A															
7	Second visit to BI Technologies	P															
		A															
8	Manual calculation for the line balancing	P															
	and construct precedence diagram.	A															
9	Third visit to BI Technologies	P															
		A															
10	Exploring Tecnomatix software	P															
		A															
11	Finish writing Methodology	P															
		A															
12	Mock presentation FYP with SV	P															
		A															
13	Final FYP 1 Presentation	P															
		A															
		P															
		A															

Plan to be done on
Action done
Action delayed

APPENDIX A2: GANTT CHART/PROJECT SCHEDULE FOR FYP 2

No	Items		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17
1	Collect FYP 2 logbook	P																	
		A																	
2	Collect report & discuss with sv	P																	
	further improvement	A																	
3	Do correction for chapter 1-3	P																	
		A																	
4	Do proposal on layout improvement	P																	
		A																	
5	Visit to BI Tech	P																	
		A																	
7	Tecnomatix software training	P																	
		A																	
8	Data analysis& discussion	P																	
		A																	
9	Layout Modelling	P																	
		A																	
10	Conclusion & Recommendations	P																	
		A																	
11	PSM Fair	P																	
		A																	
12	Thesis &CD Submission	P																	
		A																	

Plan to be done on
Action done
Action delayed

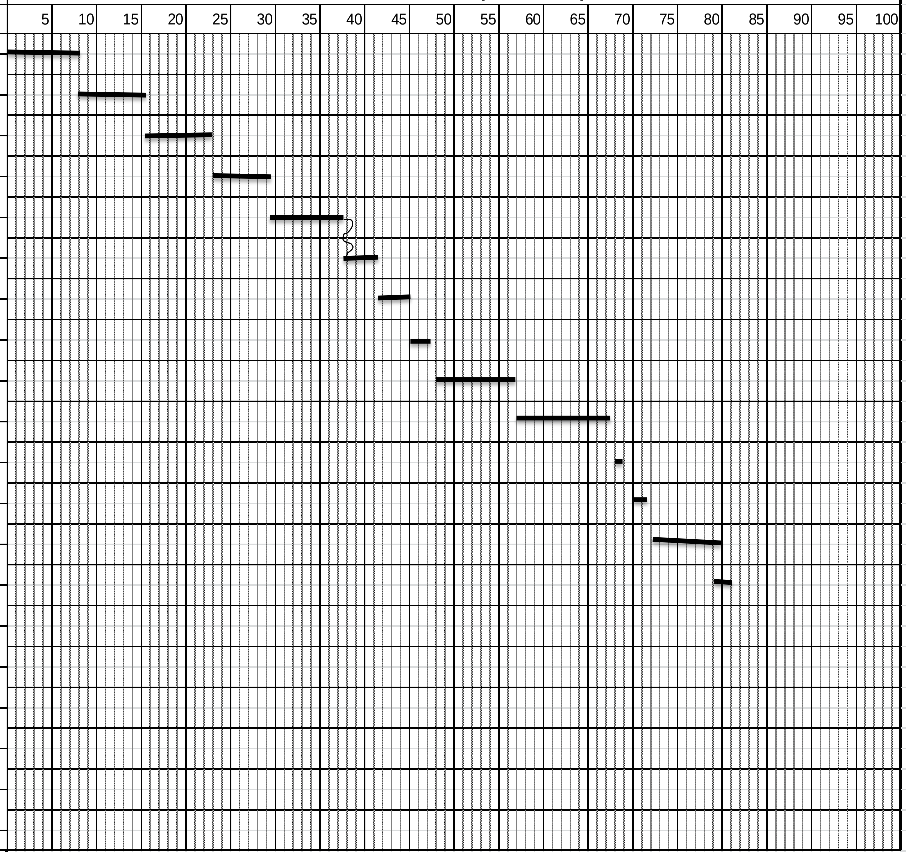
APPENDIX A3

STANDARDIZED WORK COMBINATION TABLE

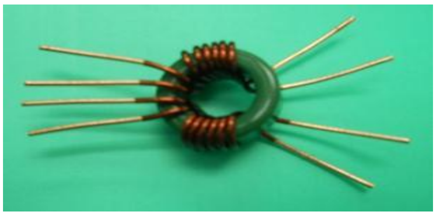
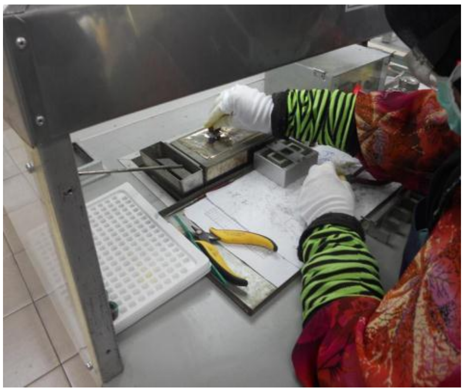
PART NO & NAME	HA00-08464LFTR	STANDARD WORK COMBINATION TABLE	DATE	30/04/2013	REQUEST SHIFT		MANUAL
PROCESS			SECTION		TAKT-TIME	2.97s	AUTO / WALK

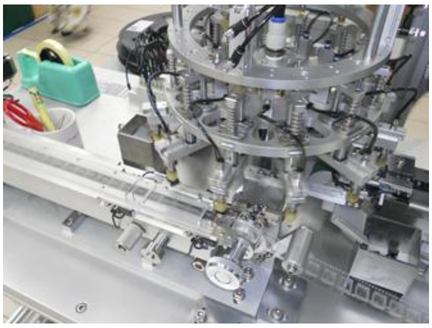
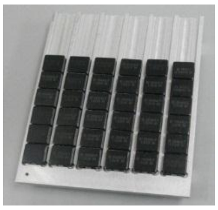
NO	OPERATION	TIME MANUAL	TIME AUTO	TIME WALK
1	Bottom leadout stripping	8.0		
2	Top leadout stripping	7.2		
3	Side leadout stripping	7.8		
4	Bend and cut	6.7		
5	Soldering	8.4		2.4
6	Aircoil washing	3.0		
7	Eppoxy app X 3spots	3.0		
8	Eppoxy app X 4spots	1.1		
9	Aircoil-core assy	8.7		
10	E-I core clipping	10.0		
11	Oven curing	0.6		
12	Boundary inspection	1.2		
13	VMI& coplanarity inspection	8.3		
14	Final test & tubing	2.8		
15				
16				
17				
18				
19				
20				
	TOTAL	80.3	Wait	2.4

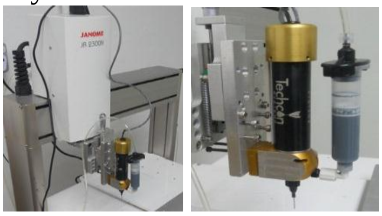
OPERATION TIME (UNIT : SEC)



Appendix A4: Improvement done in assembly line 11 and 12

Improvement	Before	After
Stripping process- Manual stripping is changed into CNC stripping	 	 
Tinning- manual to auto rotary solder pot.	 	

Final test-manual tape & reel changed to auto tape & reel	 Electrical testing  Tape & reel packaging	 
Printing part Number-manual part printing to laser marker.	   Pad printing marking the oven curing	   Laser marker-no need oven curing

Epoxy application- Manual epoxy application to X-Y table	 	 x-y table  Precision rotary valve epoxy application system

Appendix A5

Calculation before improvement.

Output per day = 12000

Total working time = 7.92 hours

Number of operator = 32 people

Cycle time = $\frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day}$

$= \frac{7.92 \times 60}{12000}$

= 2.38 second

Number of operators = $\frac{Total\ work\ content}{Takt\ time}$

$= \frac{80.43}{2.38}$

= 32 operators

Number of workstation = $\frac{Total\ time\ for\ all\ task}{Bottleneck}$

$= \frac{80.43}{10.0}$

= 8 workstation @ 11 in real situation

Line efficiency = $\frac{Total\ task\ time}{Bottleneck \times number\ of\ nodes}$

$= \frac{80.43}{10.0 \times 11}$

= 73.12%

Productivity = $\frac{Output}{labor \times production\ time\ per\ day(hour)}$

$= \frac{12000}{32 \times 7.92}$

$= 44.89\%$

MHU rate $= \frac{Number\ of\ operator \times available\ working\ time}{Output}$

$= \frac{32 \times 7.92}{12000}$

$= 0.02112$

Appendix A6

<u>Calculation for Layout 1.</u>

Output per day = 9600

Takt time = 2.97 s

Total working time = 7.92 hours

Number of operators = 27 people

Cycle time = $\frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day}$

$= \frac{7.92 \times 60}{9600}$

= 2.4 second

Number of operators = $\frac{Total\ work\ content}{Takt\ time}$

$= \frac{69.5}{2.97}$

= 23 however in real situation 27 operators is used.

Number of workstation = $\frac{Total\ time\ for\ all\ task}{bottleneck}$

$= \frac{69.5}{10.0}$

= 6.95 @ 7 workstation

Line efficiency = $\frac{Total\ task\ time}{Bottleneck \times number\ of\ nodes}$

$= \frac{69.5}{10.0\ x\ 7}$

= 99.29%

Productivity $= \frac{Output}{labor \times production\ time\ per\ day (hour)}$

$= \frac{9600}{27 \times 7.92}$

= 47.35%

MHU rate $= \frac{Number\ of\ operator \times available\ working\ time}{Output}$

$= \frac{27 \times 7.92}{9600}$

= 0.0223

Appendix A7

Calculation for Layout 2.

Output per day = 9600

Takt time = 2.97 s

Total working time = 7.92 hours

Number of operators = 27 people

Cycle time = $\frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day}$

$= \frac{7.92 \times 60}{9600}$

= 2.4 second

Number of operators = $\frac{Total\ work\ content}{Takt\ time}$

$= \frac{64}{2.97}$

= 22 operators

Number of workstation = $\frac{Total\ time\ for\ all\ task}{bottleneck}$

$= \frac{64}{10.0}$

= 6.4 @ 6 workstation

Line efficiency = $\frac{Total\ task\ time}{Bottleneck \times number\ of\ nodes}$

$= \frac{64}{10.0\ x\ 6}$

= 106.67%

Productivity $= \frac{Output}{labor \times production\ time\ per\ day(hour)}$

$= \frac{9600}{22 \times 7.92}$

= 55.1%

MHU rate $= \frac{Number\ of\ operator \times available\ working\ time}{Output}$

$= \frac{22 \times 7.92}{9600}$

= 0.0182

Appendix A8

Calculation for Layout 3.

Output per day = 9600

Takt time = 3.3 s

Total working time = 8.83 hours

Number of operators = 11 people

Cycle time = $\frac{Production\ time\ available\ per\ day}{Units\ required\ per\ day}$

$= \frac{8.83 \times 60}{9600}$

= 0.06 second

Number of operators = $\frac{Total\ work\ content}{Takt\ time}$

$= \frac{37.4}{3.3}$

= 11 operators

Number of workstation = $\frac{Total\ time\ for\ all\ task}{bottleneck}$

$= \frac{37.4}{6,2}$

= 6.03 @ 6 workstation

Line efficiency = $\frac{Total\ task\ time}{Bottleneck \times number\ of\ nodes}$

$= \frac{37.4}{6.2x6}$

= 100.54%

Productivity = $\frac{Output}{labor \times production\ time\ per\ day (hour)}$

$$= \frac{9600}{11x8.83}$$

= 98.84%

MHU rate $= \frac{Number\ of\ operator \times available\ working\ time}{Output}$

$$= \frac{11x8.83}{9600}$$

= 0.0101

Appendix A9: 3D visualization of before improvement layout.