Improvement of an Assembly Line in the Automotive Industry: a Case Study in Wiring Harness Assembly Line

Ikhlef Jebbor, Zoubida Benmamoun, Hanaa Hachimi,
Youssef Raouf, Mehdi Haqqi and Mehdi Akikiz

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Ikhlef JEBBOR
GS Laboratory,
Sultan Moulay Slimane University
Morocco
ikhlef.jebbor@usms.ac.ma

Zoubida BENMAMOUN
Faculty of Engineering
Liwa College of Technology Abu
Dhabi, UAE
zoubida.benmamoun@ect.ac.ae

Hanaa HACHIMI
GS Laboratory,
Sultan Moulay Slimane University
Morocco
hanaa.hachimi@usms.ma

Youssef RAOUF
GS Laboratory,
Sultan Moulay Slimane University
Morocco
youssef.raouf@usms.ac.ma

Mehdi HAQQI
GS Laboratory,
Sultan Moulay Slimane University
Morocco
mehdihaqqi@gmail.com

Mehdi AKIKIZ
GS Laboratory,
Sultan Moulay Slimane University
Morocco
akikizmehdi123@gmail.com

Abstract—**Today industrial companies are subject to major and profound changes. It is constantly confronted with a world of ruthless competition that continually aims to improve quality, cost, and lead time. Each company works to satisfy the requirements of its customers and to do this, it continually improves its performance and controls its manufacturing processes from the reception of raw materials from the suppliers to the shipment of the final product to the customer. In this paper, the study focuses on the assembly area of an electrical wiring harness production line and adopts a Lean Manufacturing approach to reduce the time waste and improve the efficiency of this line of engine wiring harness using Line balancing and the work allowed an eliminate of Waiting Muda and increase the efficiency.**

Keywords—Lean manufacturing, Line balancing, Efficiency

I. INTRODUCTION

Serial production systems are becoming more and more flexible. Producing many products is typical in many manufacturing systems. Monitoring and planning play a key role in ensuring efficiency and productivity to satisfy customer requests for different products. [1]

An assembly line is a manufacturing process in which stations are added in sequence from workstation to workstation until the final assembly is produced [2], by some kind of transportation system for example a carrousel or a conveyor belt, and each product spends the same amount of time called the cycle time in every station.

There are many tools and strategies to improve line assembly as well as eliminate waste. Line balancing is a simple tool introduced in this project to improve the efficiency and productivity of line assembly [3].

This work was carried out in a company belonging to the automotive plant dedicated to the production of electrical harnesses for cars: there are many types of harnesses in the car: engine harness, engine room, body, main harness, and smalls for doors, shunt grounds, and other

The research is focused on an electrical harness for the engine "K9K Full Engine harness". And the goal of this work is to implement improvements for the production line to increase its productivity and efficiency.

II. LITERATURE REVIEW

In 1945 Kiichiro Toyoda, Taiichi Ohno, Shigeo Shingo, and others develop the Toyota Production System (TPS) and refine it throughout the subsequent decades, introducing concepts such as Just-in-time, Poka-yoke (error proofing) and zero-proofing. In 1980 Toyota becomes the world leader in car production. In 1990 lean was used for the first time in the book "The machine that changed the world" [3] by James P. Womack, to describe TPS. This gives good insight into the history of lean manufacturing [4] [5].

Lean Manufacturing is a management philosophy focusing to improve the work. This philosophy mainly aims to eliminate or reduce waste in the manufacturing system [6], using lean tools [4]. Basically, in the automotive industry, the lean objectives are obtaining the raw materials in less time since the order (Lead time) [7] [8]; receiving products with low cost and high quality [6] [9], and reducing wastes during the production chain using value stream mapping (VSM) [10], or waste identification diagrams (WID), line balancing, SMED, TPM, S, DMAIC, Six sigma, PDCA [11] [12]: all these tools are obtaining the good result and help the company to reduce wastes and improve the work with low cost [8] [13] [14] [15].

The waste in Japanese called "Muda" corresponds to any activity that consumes resources but adds no value as specified by the customer. All Mudas are defined by seven forms: Transport inventory, motion, waiting, over-processing, overproduction, and defects [12].

In this paper, lean line balancing would be used as a lean tool to eliminate the 'waiting muda' and improve the efficiency of line assembly of automotive wiring harness companies.

III. METHODOLOGY AND RESULTS

Line balance means a production strategy that involves balancing production. Line balancing aims to ensure that the time taken for each operation is in balance with those operations on either side at or below the Takt Time.

Before proceeding further, below are some important terms used in this paper:

- **Task:** A specific space or area where a task or group is performed in the assembly line;
- **Workstation:** A workstation is a specific physical area where a task or group is performed in the assembly line.
- **Output:** (OPt) Number of harnesses produced during work time;
- **Work time: (WT)** In this study, the operator work

8 hours – break time (40 min) = 7.33 min;

- **SMH:** Standard man Hour is the average time to produce one harness by a single operator [16]. This time assigned to the product by costing engineers
- **Cycle Time:** means the total amount of time it takes to complete one task from start to finish;
- **Takt time: (TT)** Takt-time is the time in which we must produce a harness to meet customer requirements during the working time [17] [18] [19]:

$$TT\ (min) = \frac{SWT(min)}{OPt} = \frac{440(min)}{OPt} \quad (1)$$

SWT: Shift work time

OPt: Output.

- **Efficiency:** Efficiency is calculated using the number of harnesses produced, the standard hour value, the number of operators, and the number of hours worked by each operator [20]:

$$Eff\ \% = \frac{OPt * SMH(h)}{NOp * WT(h)}$$
$$= \frac{OP * SMH(h)}{NOp * 7.33(h)} \quad (2)$$

NOp: Number of operators.

This paper aims to implement line balancing to improve the efficiency of the assembly production lines. The research is focused on an automotive production line for an electrical harness for engine vehicle "K9K Full Engine harness".

This line consists of a total of 32 workstations but focused only on the (Preblocking, lay-up, and Taping) because the stability and balance of other workstations are shown in the flow chart and line assembly in Figures 2 & 3.

So, this study focused only on the workstations below:
- Seven workstations for Pre-blocking where the operator inserts wires in connectors using the Pre-block diagrams;
- Three workstations for lay-up; make the sub-assembly in boards and finish the rest of the insertions;
- 12 workstations for tape: make the covering and tape the harness.

Fig. 1 below shows an example of an electrical engine harness.

Fig. 1: Example of Electrical Engine Harness

The average SMH for this engine harness is:

SMH= 2.16 hours;

and the customer demand in the maximum scenario is 1020 harnesses per week So the production output is :

Output = 85;

during 2 Shift (see tab. 1) :

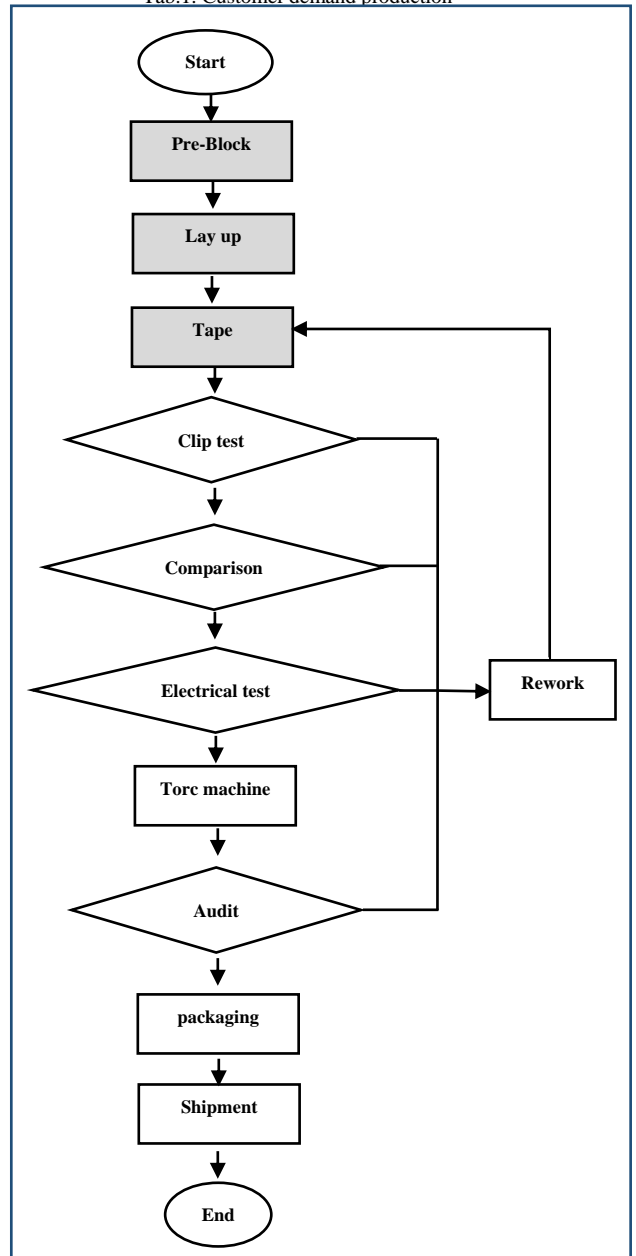| Output Production		
1020	170	85
Per Week	Per Day (6 days)	per Shift (2 shifts)

Tab.1: Customer demand production

Fig. 2 : Flow chart for studied assembly line

And below the description of workstations stadied :
- **Preblock:** This step consists of inserting the terminals of the circuits into the connectors that correspond to them manually, using diagrams called Preblock diagrams as in Fig. 4;
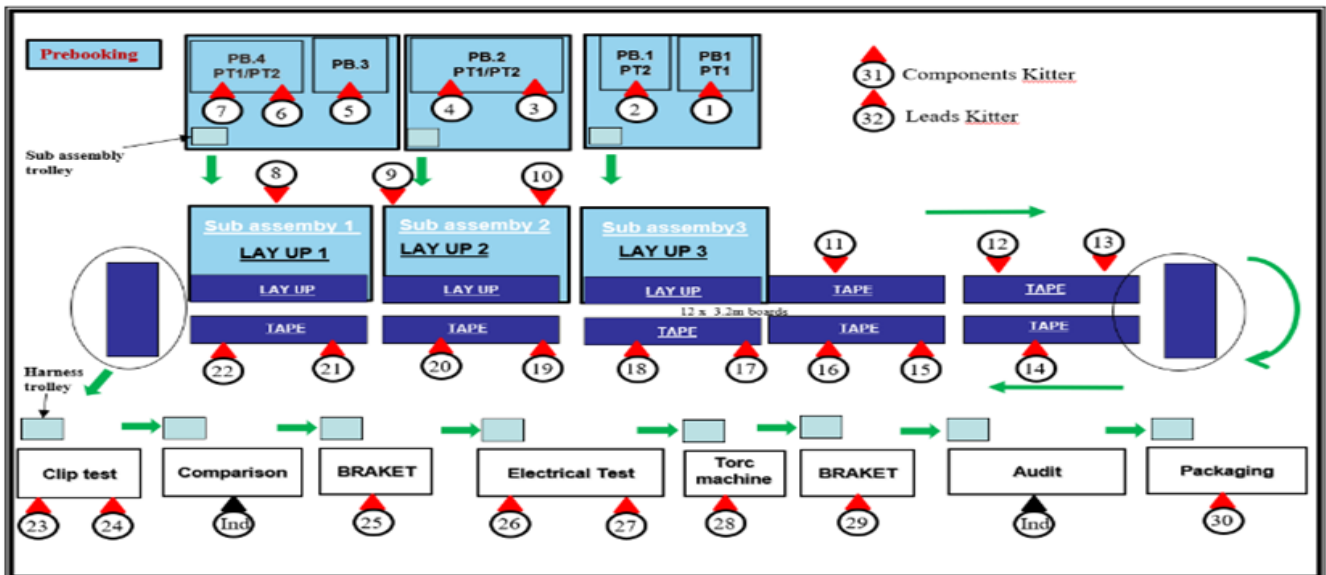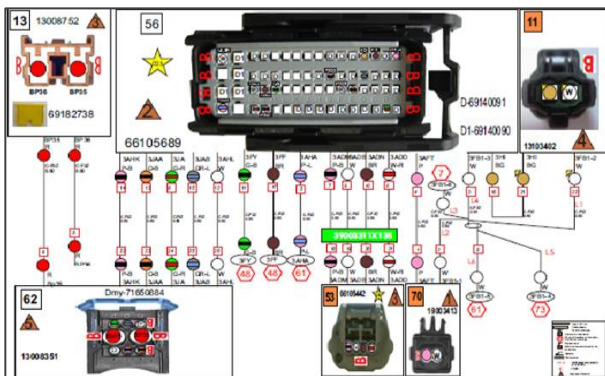
Fig. 3: Electrical harness Assembly
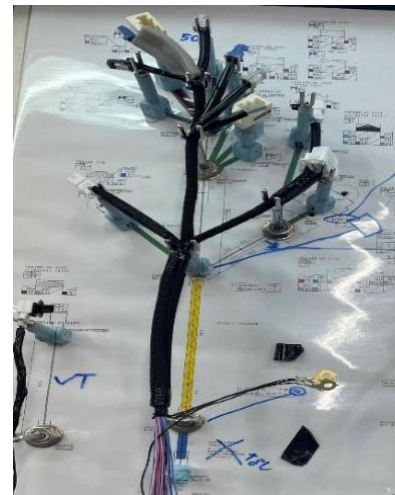

Fig. 4: Preblock diagram

- **Lay up**: is the operation that covers the wires once inserted by ribbons and protectors. the operation carried out on a linear or rotataion conveyor depending on the size and complexity of the cable. (fig. 5).
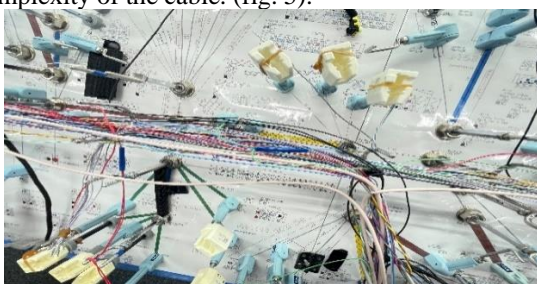

Fig. 5: Example of lay up operation

- **Tape:** after the lay up the tape is to cover the wires with ribbons; PVC; or others and protectors. (fig. 6).

Working by 32 direct Operators (2 indirect);

Based on (1) the Takt time is:

$$T(min) = \frac{440(min)}{OPt} = 5.18 \, min \, .$$

Using (2): the Efficiency planned:

$$\mathbf{Eff} \, (\%) = \frac{\mathbf{OPt} * \mathbf{SMH(h)}}{\mathbf{NOp} * \mathbf{WT(h)}} = \frac{85*2.16}{32*7.33} = 78\%;$$

Fig. 6: Example of taping

Initial Measurement :

The method used is time measurement [21]: The cycle time was measured for 10 observations by chronometer using the performance rating as in the formula below:

$$\boldsymbol{Tm}(min) = \frac{TO * PR(\%)}{100} \tag{3}$$

Tm : Time mesurment ;
TO : Time observed ;
PR: Performance raiting.

The performance rating is the factor with which the observer judges the work of the operator, it is expressed as a percentage (exemple 80% ,85%,...).

After the time study for the workstations measured for Preblocking, lay-up, and tape. The result is obtained in the fig. 7.

After this observation is carried out 10 measurements, following the result of the maximum cycle time the output produced and the reel efficiency:

- **NOp:** 32 operators;
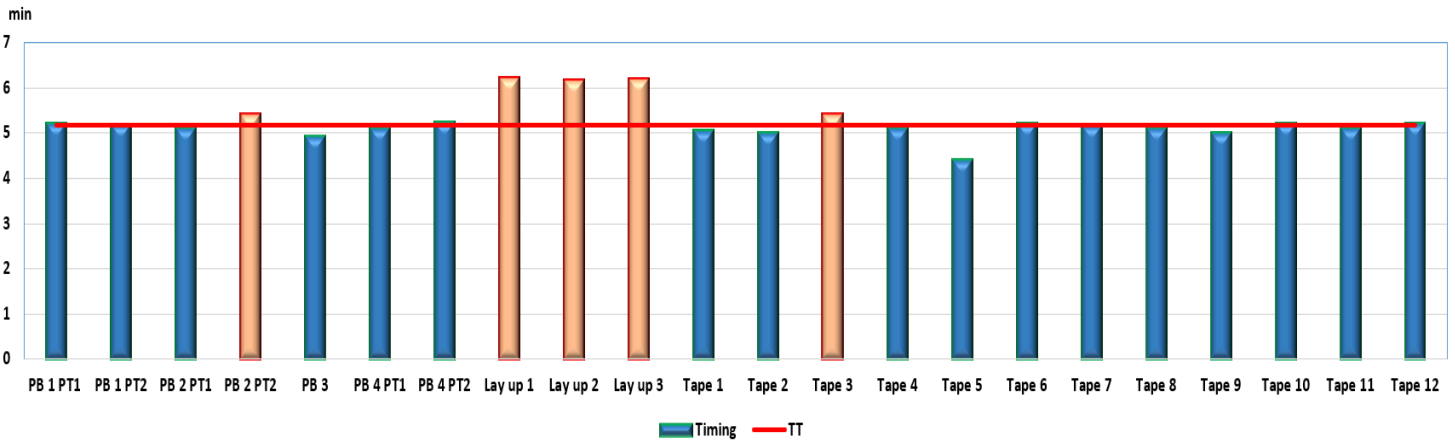- $\boldsymbol{Eff} \, (\%) = \frac{71*2.16}{32*7.33} = 65\%;$

Fig. 7: Initial time measurements for workstations studied in the assembly line

- Max Cycle Time : (CTmax) the high cycle time is remarked in lay-up workstations:
- **CTmax:** 6.22 min;
- **The output : OPt**=440/6.22= 71;

Analysis:

Figure 7 immediately shows a problem. Look at lay-up operators. We must produce a unit every 5.18 min but these operators are taking (6.22min, 6.18min, and 6.21min) to do the required work for those operations ; and the waste for lay-up workstations is 1.04 min for each product.We are not going to successfully produce the 85 units per shift that the customer requires. Meanwhile, the remaining operator Pre-block PB 3 and tape 5 have some extra time on their hands. Generally, they will overproduce, and note that they have the materials and equipment to do the job.

The more common "solution" to this problem is to have everyone produce in batches and have a buildup of material between one operation and the next, while everyone is doing their best to stay caught up.

Some of the work presently being done by operator PB2 PT2 can be given to operator PB 3, for example, and the same work being done by operator tape 3 can be given to operator tape 5.

Improvement:
- Balancing between the Pre-block PB2 PT2 and Pre-block PB3, eliminating the insertion of 6 leads in connector 6 and adding them to the operator Pre-block 3(see fig. 8).
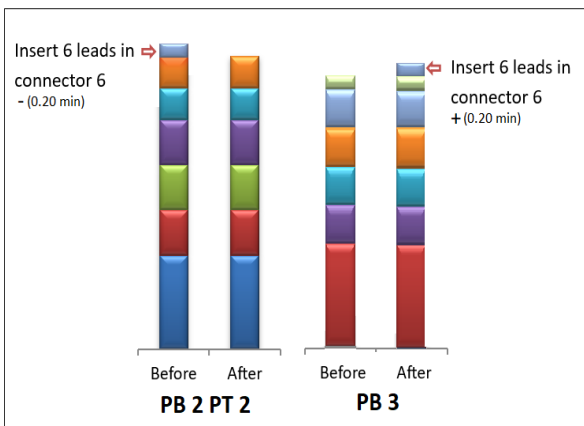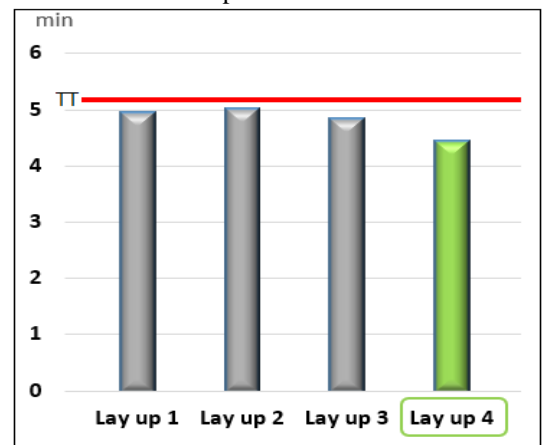

Fig 8: Balance the Preblock PB2 and Preblock 3

- And for the lay-up because of high difference, adding one other operator (lay-up 4) is the best way to solve this difference: for the three first operators put the sub-assembly of the wires in its place in the assembly board and the 4th operator finishes the rest of the

insertion of leads in connectors (see fig. 9);

Figure 9: Balance the lay-up workstations

- For tape 3 the improvement is eliminating the insertion of the convolute tube and PVC tape between 2 nodes and adding them to the operator Tape 5(see
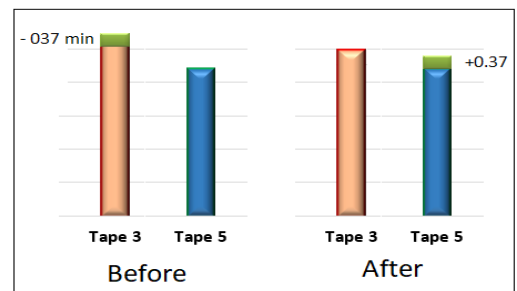

fig. 10);

Fig.10: Balance between tape 3 and tape 5

Measurement and result after implementation:

Two weeks after the implementation of this improvement; adding one operator in lay-up (showing in figure 11 the new location of the operator added).
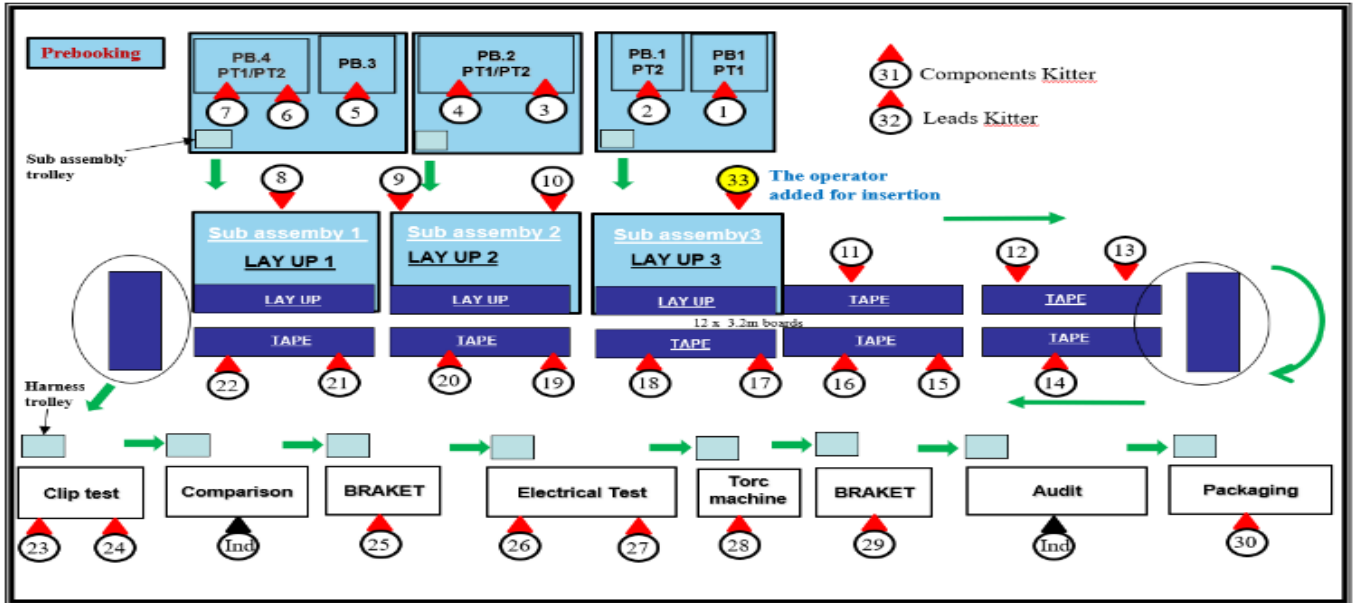
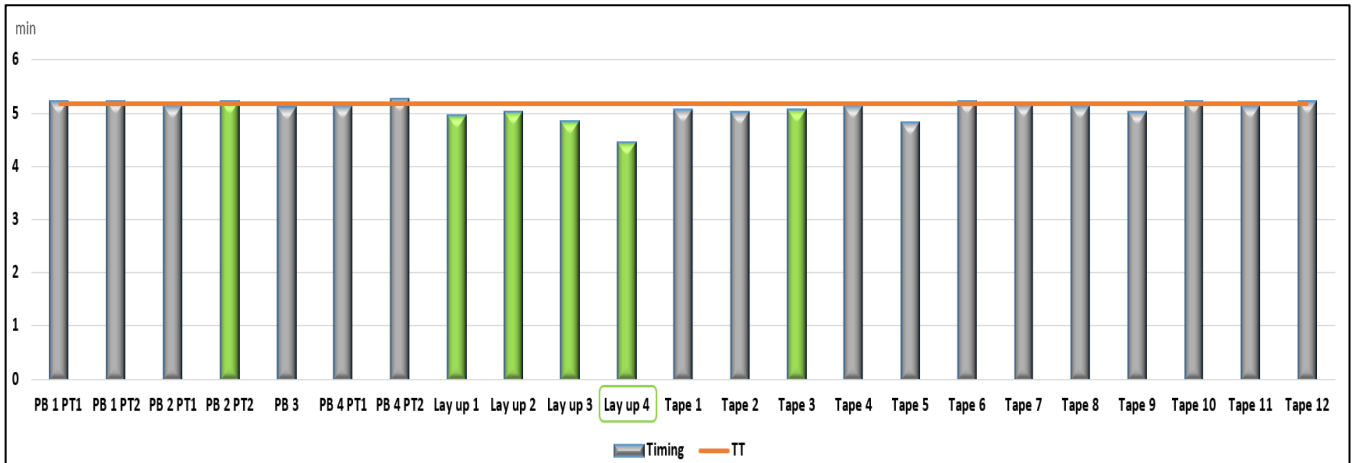Fig. 11: Electrical harness assembly line after line balance

Fig. 12: the final time measurements for workstations after implementing the line balancing for the assembly line

Measuring second time the stations that have wasted time and obtaining the result shown in Figure 12.

Below is the new calculation of maximum cycle time, output, and efficiency:

Max Cycle Time: the operator that has the maximal timing is the operator Pre-block PB4 PT:

- **CTmax:** 5.24 min;
- **OPt:** 440/5.24= 95;
- **N op:** 33 operators;
- $Eff \% = \dfrac{95*2.16}{33*7.33} = 85\%$;

IV. DISCUSSION

Figure 13 compares the first condition and after the implementation of improvement: the productivity is increased from 71 to 95 Harnesses per shift, and the efficiency increase from 65% to 85%.
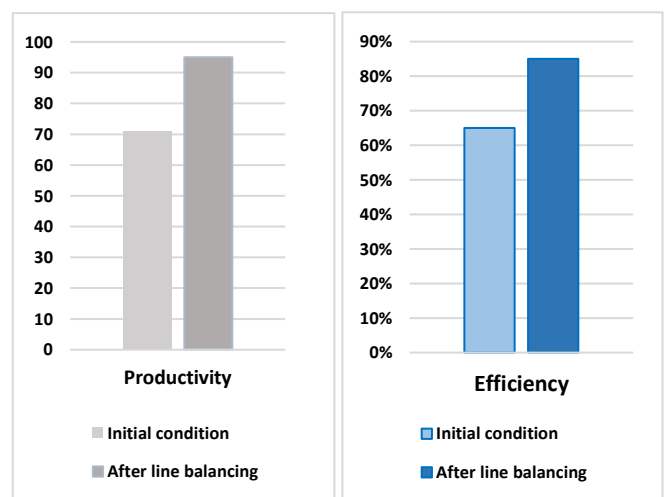

Fig.13: The comparison between the productivity and efficiency before and after the line balancing

Adding operators in line does not always decrease the efficiency, but adding operators with the balancing of tasks for some workstations can increase productivity and also efficiency.

V. Conclusion

Using the line balancing method as a lean manufacturing tool in this project has proven that greatly increase the efficiency from 65% to 85% and increase the production to 95 per shift so in total 1140 per week. And the company is recommended to implement the line balancing study improvement for the other production lines to achieve more efficiency and productivity.

Also, below are additional conclusions that can be pointed out:
- After every serial production in an assembly line, need to implement line balancing because the theoretical or estimation data can't give the exact and efficient workstations;
- 5S, Kaizen, and other lean tools should be used to eliminate more waste and improve the efficiency of assembly lines.

Lean wastes are the cause of increasing manufacturing costs and a quality management system is such a change management tool that companies should promote to ensure continuous improvement in their process.

Waiting is the primary waste of the company followed by defect-making and inventories. The loss of production time in waiting for the output from the former process is the parameter that makes waiting a major waste for the company.

Generally, the study supports the suggestion that lean tools in this day's most important production system that companies seeking to stay on top of the competition should implement it.

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