Industrial Engineering and Applications
L.-C. Tang (Ed.)

doi:10.3233/ATDE230031

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

Ikhlef JEBBOR [a], Zoubida BENMAMOUN [b,1], Hanaa HACHIMI [a],
Youssef RAOUF [a], Mehdi HAQQI [a], Mehdi AKIKIZ [a]
[a] *GS Laboratory, Sultan Moulay Slimane University, Morocco*
[b] *Faculty of Engineering, Liwa College of Technology Abu Dhabi, UAE*
ORCiD ID: Ikhlef JEBBOR: https://orcid.org/ I.JEBBOR (0000-0002-6480-4847)

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

1. 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 others.

[1] Corresponding Author: Zoubida BENMAMOUN, email: zoubida.benmamoun@ect.ac.ae.

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.

2. 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.

3. 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;
- **Tact 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]:

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

With: **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]:

$$Eff\ \% = \frac{\mathrm{OPt * SMH(h)}}{\mathrm{NOp * WT(h)}} \tag{2}$$

; **NOp:** Number of operators.

$$= \frac{\mathrm{OPt * SMH(h)}}{\mathrm{NOp * 7.33(h)}}$$

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 Preblock 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.

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

Figure 1. Example of Electrical Engine Harness

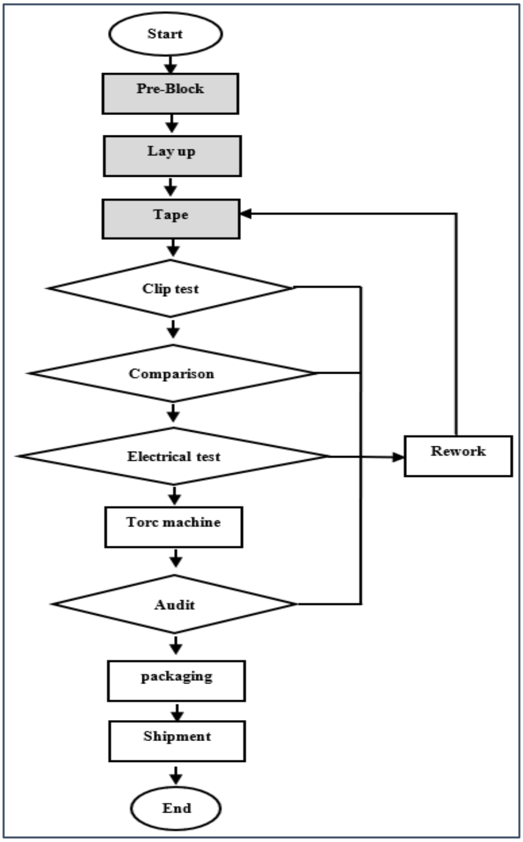

Figure 2. Flow chart for studied assembly line

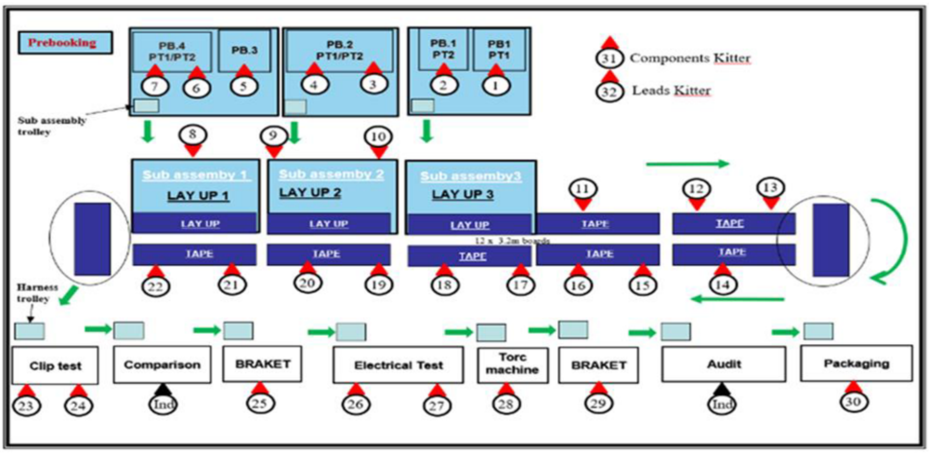

Figure 3. Electrical harness Assembly

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: Output = 85; during 2 Shift (see table 1):

Table 1. CCustomer demand production

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

And below the description of workstations studied:

- **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 figure 4;
- **Lay-up**: is the operation that covers the wires once inserted by ribbons and protectors. the operation carried out on a linear or rotation conveyor depending on the size and complexity of the cable. (Figure 5).
- **Tape:** after the lay up the tape is to cover the wires with ribbons; PVC; or others and protectors. (Figure 6).

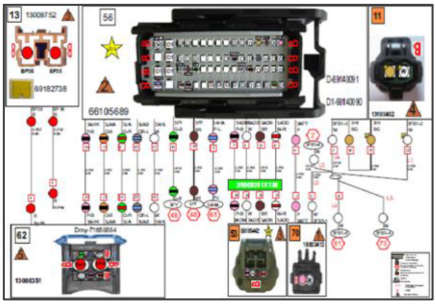

Figure 4. Example of lay-up operation

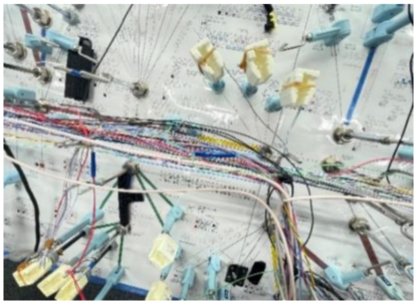

Figure 5. Preblock diagram

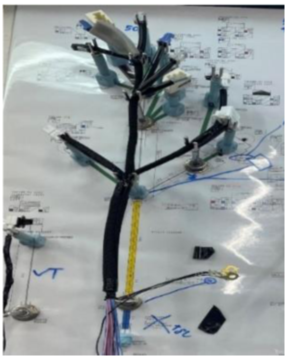

Figure 6. Example of taping

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:

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

With: Tm: Time measurement; TO: Time observed; and PR: Performance rating.

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

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

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

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

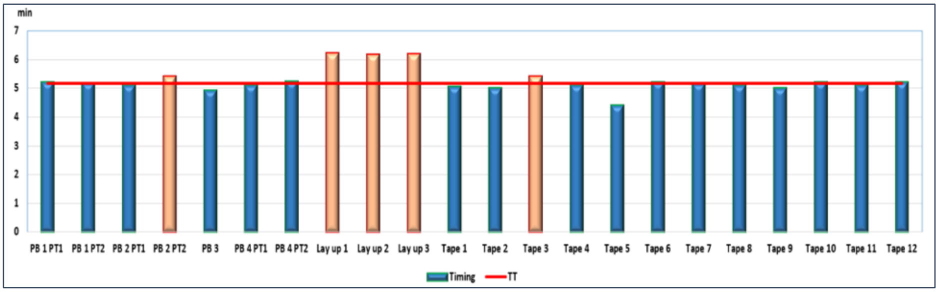

Figure 7. Initial time measurements for workstations studied in the assembly line

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 figure 8).

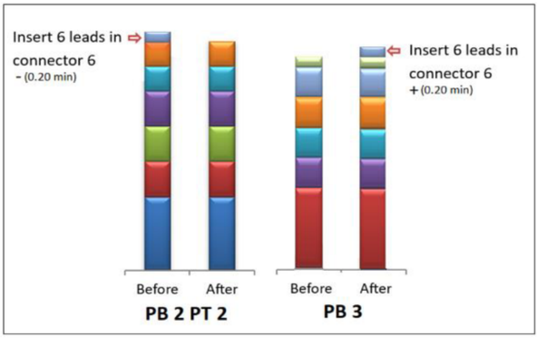

Figure 8. Balance the Preblock PB2 and Preblock 3

- 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 figure 9);
- 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 figure10).

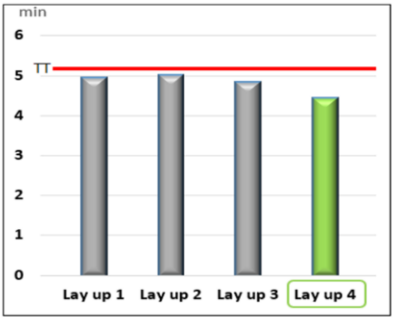

Figure 9. Balance the lay-up workstations

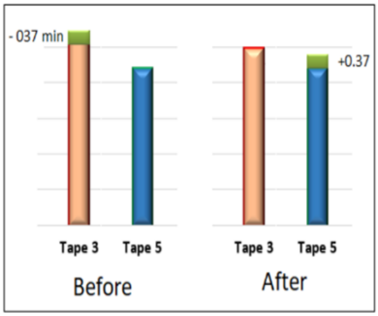

Figure 10. Balance between tape 3 and tape 5

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).

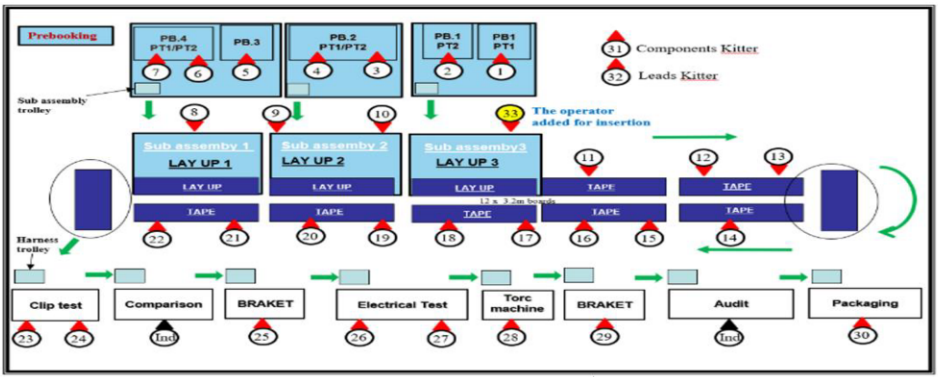

Figure 11. Electrical harness assembly line after line balance

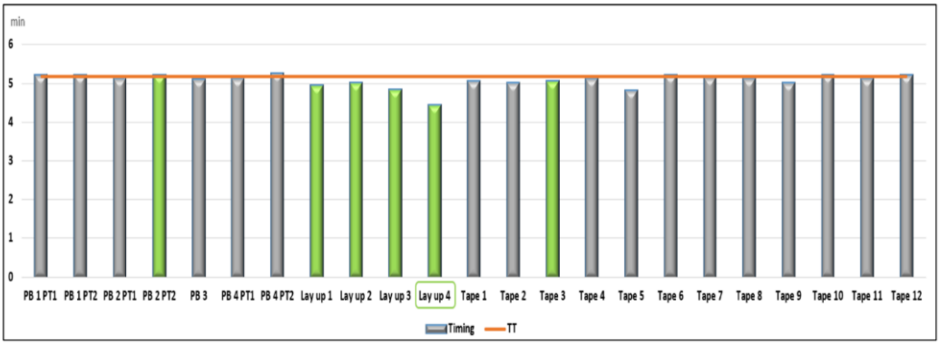

Figure 12. The final time measurements for workstations after implementing the line balancing for the assembly line

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;
- **NOp:** 33 operators;
- $\boldsymbol{Eff}\ \% = \frac{95*2.16}{33*7.33} = 85\%$;

4. 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%.

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.

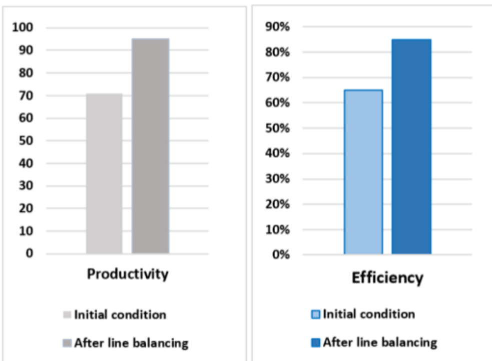

Figure 13. The comparison between the productivity and efficiency before and after the line balancing

5. 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.

References

[1] C. Zhao and J. Li, "Production Control of Door Manufacturing Line at an Automotive Assembly PlantÕ," IFAC-PapersOnLine, vol. 48, no. 3, pp. 1652–1657, Jan. 2015, doi: 10.1016/j.ifacol.2015.06.323.
[2] H. T. Benchekroun, Z. Benmamoun, and H. Hachimi, "Implementation and Sustainability Assessment of a Public Procurement Strategy,"Sustainability, vol. 14, no. 23, p. 15565, Nov. 2022, doi: 10.3390/su142315565.
[3] J. P. Womack, D. T. Jones, and D. Roos, "The Machine That Changed the World".
[4] M. Manzouri, M. Ab-Rahman, C. Zain, and E. Jamsari, "Increasing Production and Eliminating Waste through Lean Tools and Techniques for Halal Food Companies," Sustainability, vol. 6, no. 12, pp. 9179–9204, Dec. 2014, doi: 10.3390/su6129179.
[5] Z. Benmamoun, H. Hachimi, and A. Amine, "The lean applied to stock management to an optimum solution in a Moroccan company," May 2016.
[6] I. Antoniolli, P. Guariente, T. Pereira, L. P. Ferreira, and F. J. G. Silva, "Standardization and optimization of an automotive components production line," Procedia Manufacturing, vol. 13, pp. 1120–1127, Jan. 2017, doi: 10.1016/j.promfg.2017.09.173.
[7] H. T. Benchekroun, Z. Benmamoun, and H. Hachimi, "How to select suppliers when implementing a sustainable procurement strategy," in 2019 5th International Conference on Optimization and Applications (ICOA), Kenitra, Morocco, Apr. 2019, pp. 1–4. doi: 10.1109/ICOA.2019.8727666.
[8] D. Stadnicka and P. Litwin, "Value Stream and System Dynamics Analysis – An Automotive Case Study," Procedia CIRP, vol. 62, pp. 363–368, 2017, doi: 10.1016/j.procir.2016.06.038.
[9] M. Elkhechafi, Z. Benmamoun, H. Hachimi, A. Amine, and Y. Elkettani, "Firefly Algorithm for Supply Chain Optimization," Lobachevskii J Math, vol. 39, no. 3, pp. 355–367, Apr. 2018, doi: 10.1134/S1995080218030125.
[10] M. Rother and J. Shook, "Learning to see: Value stream mapping to create value and eliminate muda," Lean Enterprise Institute. 2003.
[11] K. Filali, Z. Benmamoun, and H. Hachimi, "Optimization of consumable consumption in hypermarkets during the Coronavirus pandemic period," 4th European International Conference on Industrial Engineering and Operations Management, IEOM 2021, pp. 1573–1579, 2021.
[12] Z. Benmamoun and H. Hachimi, "Inventory management optimization using lean six-sigma," 2017.

[13] J. Sternatz, “Enhanced multi-Hoffmann heuristic for efficiently solving real-world assembly line balancing problems in automotive industry,” European Journal of Operational Research, vol. 235, no. 3, pp. 740–754, Jun. 2014, doi: 10.1016/j.ejor.2013.11.005.management to an optimum solution in a Moroccan company,” May 2016.
[6] I. Antoniolli, P. Guariente, T. Pereira, L. P. Ferreira, and F. J. G. Silva, “Standardization and optimization of an automotive components production line,” Procedia Manufacturing, vol. 13, pp. 1120–1127, Jan. 2017, doi: 10.1016/j.promfg.2017.09.173.
[7] H. T. Benchekroun, Z. Benmamoun, and H. Hachimi, “How to select suppliers when implementing a sustainable procurement strategy,” in 2019 5th International Conference on Optimization and Applications (ICOA), Kenitra, Morocco, Apr. 2019, pp. 1–4. doi: 10.1109/ICOA.2019.8727666.
[8] D. Stadnicka and P. Litwin, “Value Stream and System Dynamics Analysis – An Automotive Case Study,” Procedia CIRP, vol. 62, pp. 363–368, 2017, doi: 10.1016/j.procir.2016.06.038.
[9] M. Elkhechafi, Z. Benmamoun, H. Hachimi, A. Amine, and Y. Elkettani, “Firefly Algorithm for Supply Chain Optimization,” Lobachevskii J Math, vol. 39, no. 3, pp. 355–367, Apr. 2018, doi: 10.1134/S1995080218030125.
[10] M. Rother and J. Shook, “Learning to see: Value stream mapping to create value and eliminate muda,” Lean Enterprise Institute. 2003.
[11] K. Filali, Z. Benmamoun, and H. Hachimi, “Optimization of consumable consumption in hypermarkets during the Coronavirus pandemic period,” 4th European International Conference on Industrial Engineering and Operations Management, IEOM 2021, pp. 1573–1579, 2021.
[12] Z. Benmamoun and H. Hachimi, “Inventory management optimization using lean six-sigma,” 2017.
[13] J. Sternatz, “Enhanced multi-Hoffmann heuristic for efficiently solving real-world assembly line balancing problems in automotive industry,” European Journal of Operational Research, vol. 235, no. 3, pp. 740–754, Jun. 2014, doi: 10.1016/j.ejor.2013.11.005.
[14] J. Azevedo et al., “Improvement of Production Line in the Automotive Industry Through Lean Philosophy,” Procedia Manufacturing, vol. 41, pp. 1023–1030, Jan. 2019, doi: 10.1016/j.promfg.2019.10.029.
[15] H. Hachimi and Z. Benmamoun, “Working Capital Maximization with the inventory management optimization Case of Spare parts Moroccan company,” Jan. 2017.
[16] Z. Ye, J. Cui, and F. Zhou, “Man-hour Estimation Model based on Standard Operation Unit for Flexible Manufacturing System,” presented at the MATEC Web of Conferences, Jan. 2017, vol. 100, p. 02017. doi: 10.1051/matecconf/201710002017.
[17] X. Brioso, D. Murguia, and A. Urbina, “Teaching Takt-Time, Flowline, and Point-to-point Precedence Relations: A Peruvian Case Study,” Procedia Engineering, vol. 196, pp. 666–673, Jan. 2017, doi: 10.1016/j.proeng.2017.08.056.
[18] R. M. Ali and A. M. Deif, “‘Dynamic Lean Assessment for Takt Time Implementation,’” Procedia CIRP, vol. 17, pp. 577–581, Jan. 2014, doi: 10.1016/j.procir.2014.01.128.
[19] Y. Zahir, N. Mahdou, and M. Moutui, “On S-weakly prime ideals of commutative rings,” Georgian Mathematical Journal, vol. 29, Aug. 2021, doi: 10.1515/gmj-2022-2141.
[20] P. Sivasankaran and P. Shahabudeen, “Literature review of assembly line balancing problems,” The International Journal of Advanced Manufacturing Technology, vol. 73, pp. 1665–1694, Aug. 2014, doi: 10.1007/s00170-014-5944-y.
[21] L. P. S. Hartanti, “WORK MEASUREMENT APPROACH TO DETERMINE STANDARD TIME IN ASSEMBLY LINE,” vol. 2, no. 10.