Journal of Engineering Science and Technology
Vol. 20, No. 2 (2025) 427 - 441
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ENHANCING MANUFACTURING EFFICIENCY: A CASE STUDY ON AUTOMOTIVE ASSEMBLY LINE BALANCING TECHNIQUES FOR IMPROVING PRODUCTION CAPACITY

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Abstract

The automotive Assembly Line Balancing Problem (ALBP) is a classic NP-hard combinatorial optimization problem. The ALBP is the process of maximizing the distribution of jobs or workstations in an automotive Assembly Line (AL) in the automotive industry to reduce idle time for employees and equipment and guarantee that the output of production meets demand while keeping the required quality level. The objective of this study is to identify the cause of the unbalanced AL, apply the ALB technique to increase the capacity of the current AL, and eventually propose improvements that should be made to the current assembly by allocating the necessary number of workers in the AL and figuring out the appropriate processing time for the various processes. This study categorizes objectives into identification, data collection and analysis, and method of improvement. A literature review serves as a reference for the study, drawing on validated sources in the field. The collected data were then analysed to propose an improvement method by conducting a time study methodology in ALB and determining the optimum number of workstations in the AL. A significant finding from this research is the effect of implementing ALB in AL, such as standard time, process flow, and optimum number of workstations in the assembly process. The outcome of this study will be presented to automotive manufacturing companies. This study improves the productivity of AL and improves the working conditions by assigning optimal task distribution in the workstation. The outcomes provide practical insights for professionals to optimize production capacity, streamline operations, and gain a competitive edge.

Keywords: Operational efficiency, Production capacity, Productivity improvement.

1. Introduction

Assembly Lines (AL) for automotive are now driven to competitive and demanding markets, requiring efficient design of their configurations. In an automotive assembly line, the work components move down a succession of workstations, where distinct assembly activities are completed sequentially for the given operating period. The workstations in the automotive assembly line have the same cycle time and a fixed work pace. The productivity of the automotive assembly line is heavily influenced by the performance of the bottleneck workstation, which has the highest sum of processing time.

Therefore, it is important to balance the activity of every workstation to eliminate idle time and Work-In-Progress (WIP). Automotive assembly lines should be built in a way that organizes and assigns duties to workstations promptly, maximizing line efficiency. The automotive assembly line Balancing Problem (ALBP) is a classic NP-hard combinatorial optimization problem. The goal of ALBP is to assign jobs to workstations in the most efficient way possible while considering certain limits. Bryton was the first to suggest the ALBP, while Salveson was the first to conduct scientific research on it. Readers can refer to a comprehensive overview of ALBP.

ALBP can be classified into many types based on the number of product models, factor characteristics, automotive assembly line styles, automotive assembly line aims and restrictions, and so on. It is divided into two categories: simple ALBP (SALBP) and general ALBP (GALBP).

According to Becker and Scholl [1], Single-model automotive assembly lines are used in SALBP, where the operation time of tasks is known as fixed, and specific criteria must be met. It becomes GALBP when more constraints or elements are added to the problem, such as multi-models, stochastic task timings, and U-shaped automotive assembly lines.

All of the problems have the same purpose or aim which is to meet the demand to establish the appropriate workstation-task assignment for identical and repetitive operations or activities by considering the requirement and cycle time. Any mass production system is primarily used for product models. This approach necessitates uniformity and specialization for similar and repeatable operations. Therefore, establishing the best feasible workstation-task assignment by minimizing the number of workstations, improving the rate of production, and lowering the idle time between the workstations in the process is important for a mass-production system.

1.1. Problem statement

Work is produced in sequential order along the line and transferred from one station to another. Some of the processes are repeated at each station to minimize the cycle time. The reason that may lead to this problem is the automotive assembly line is unbalanced because it depends on the standard of the scheduling industry and documents that do not precisely follow the task time that has been given at each station.

Other than that, the problem that is happening in the automotive assembly line is a Work-in-Progress (WIP). This is because the inventory may begin the production process but not finish the product or unfinished process and cannot be included in raw material. It will lead to waste and produce a low-quality product.

Lastly, the problem that damages the manufacturing automotive assembly line is the lack of infrastructure and technologies to detect the problems at the workstation and assess the complete automotive assembly line process. This is because the weakness pointed out may be hard to identify as soon as possible.

1.2. Objective of study

The objectives of this study are to identify the cause of the unbalanced AL, apply the ALB technique to increase the capacity of the current AL, and eventually propose improvements that should be made to the current assembly by allocating the necessary number of workstations in the AL and figuring out the appropriate processing time for the various processes.

1.3. Understanding of assembly line

In Manufacturing Industries, there are a lot of mechanisms and components that need to be taken care of. One of the main aspects of manufacturing or production is production management. Production Management usually describes the organization's ability to maximize production by using the optimum resources to avoid loss and overspending. This method has been implemented in industries since the Second Industrial Revolution after the factories back in the day started to implement Automotive assembly lines in their production.

At that time, AL had brought much attention as the system had been proven to achieve higher production capacity and produce more quality products in a shorter time. AL is implemented for mass production capacity. After the introduction of the AL, there has been much improvement by the players in the industry. From 1900 until today, the development of manufacturing technology has been tremendous. As we can see now, the production line has been implementing the IR4.0 technology. This technology consists of an automated conveyor, a robotic arm, and the internet and Artificial Intelligence (AI).

Automotive assembly lines need to evolve. To evolve, continuous improvement needs to be applied. In this modern era, production achievement is improving towards method and analysis to reduce variance and waste, this method is driven by Lean Manufacturing and another method. Similarly, Berhe et al. [2] stated that as competitiveness in manufacturing industries is increasing, many tools have been adopted such as Lean Manufacturing (LM), Lean Six Sigma (LSS), Total Quality Management (TQM), and many more.

1.4. Automotive assembly line balancing (ALB)

Automotive assembly line balancing (ALB) is the process of maximizing the distribution of jobs or workstations in an Automotive assembly line (AL) to reduce idle time for employees and equipment and guarantee that the output of production meets demand while keeping the required quality level [3].

In AL, a product is moved from one workstation to the next until it is finished, with each workstation carrying out a distinct task [4]. ALB involves allocating tasks to each workstation to reduce idle time and guarantee that each workstation's output rate corresponds to the automotive assembly line's speed. It is claimed that ALB is a method to determine the number of workstations according to the cycle time without disrupting the process flow [5].

1.4.1. Component of ALB

The number of models present on the automotive assembly line can be divided into mixed-model, multi-model, and single-model systems [6]. Each of these systems will conduct a different result because the system used is also different. Furthermore, problems have also been classified according to the layout of the automotive assembly line. Examples are basic straight lines, straight lines with several workstations, circular transfer lines, U-shape lines, and asymmetric lines.

Automotive assembly line systems come in a wide variety. The traditional automated intermittent and lean manufacturing models are a couple of typical versions 9 [7].

1.4.2. Workstation

A workstation is a designated area where one or more employees perform a specific activity or group of duties during a production process. Workstations are usually set up in sequential order on an Automotive assembly line (AL), and each workstation carries out a particular task on the product as it moves down the line [8]. Depending on the nature of the production process and the jobs being performed, workstations can differ greatly in size, layout, and complexity. For instance, a workstation at a car manufacturing facility might have several employees as well as specialized tools, like assembly jigs or robots, to do a broad range of activities.

1.4.3. Process cycle time

Cycle Time (CT), which is calculated from the beginning of the first task to the conclusion of the last task, is the actual amount of time spent working on creating an item or rendering a service. Both value-added and non-value-added time are included in cycle time [9].

The essential term in the definition is "actual," as many businesses use "cycle time" to refer to the anticipated amount of time it will take to produce an item, even though these two timeframes are frequently not the same. An integrated decision approach for line balancing and AGV scheduling in smart assembly systems minimizes cycle time and total tardiness, making it an efficient managerial tool [10]. The formula to calculate Cycle Time (CT) is shown in Eq. (1).

$$\text{Cycle Time}=(\text{Net production time})/(\text{Number of units produced}) \tag{1}$$

1.4.4. Steps of improvement

Implementing ALB involves several steps, beginning with assessing whether the production line requires remodelling or layout improvement [11]. The initial step is establishing goals for the production line and aligning the entire organization toward productivity, process efficiency, and improved quality. Once the goals are set, the next step is calculating the Takt Time (TT), tracking available working time over customer demand [12, 13].

To ensure a steady production flow, each process cycle time must be less than the Takt Time and as consistent as possible. Following this, a time study is conducted to determine the time required for each task in the production line, using the gathered data for analysis [14]. Task time and cycle time determination, as outlined by Sivasankaran and Shahabudeen [14], are essential steps in balancing the automotive assembly line. The formula for calculating Takt Time is provided in Eq. (2).

Takt Time (TT)= (Production Time Available)/(Customer Demand) (2)

The next step is to identify the bottleneck points in our system. Identifying bottlenecks involves identifying the stage or process in a system where the maximum amount of time, effort, or resources are being consumed, resulting in a slowdown of the overall system's performance.

According to Chao et al. [12], eliminating bottlenecks can improve the productivity in production lines. When a bottleneck point has been identified, the situation needs to be analysed with different conditions. This is to test and make configurations to isolate the performance issues. After the bottleneck analysis has been identified, the next step is to optimize the point of the problem to improve the process flow.

2. Methods

The methodology section describes the approach and procedures used in conducting the study for the project. It includes details on the study’s design, the methods used to collect and analyse data, and any specific techniques or tools employed. The flow of conducting this study is interpreted using a flow chart, and the study method is explained in the study’s design.

After that, the data collection process is performed in the real manufacturing case that is conducted through site visits. Then, the data will be analysed to reach the result and conclusion of this study. The purpose of this section is to provide enough information for others to understand and replicate the study, as well as to demonstrate the rigor of the study.

2.1. Design of study

The design of a study is a structure, or the collection of methods and techniques used to gather and examine information on the factors listed in a specific study subject. This section is important to the validity of the method used during the study, and it shows the study variable and limitations that affect the study results. It can be used through two different types of methods Qualitative Study and Quantitative Study.

Qualitative study focuses on exploring and gathering data from a non-numerical study such as to understand claims supported by evidence such as journals, perspectives, theories, and personal experiences. This evidence can be collected through questionnaires, surveys, literature reviews, and interviews with people involved in the study field.

On the other hand, Quantitative study takes more on a statistical and numerical approach. The data is gathered, then measured and analysed using a variety of computation, formulas, and calculation techniques. It allows for identifying the connection between collected data and the results using statistical measurement and analysis. Some studies provide a more comprehensive understanding when conducting the study.

2.2. Study flow chart

The overall methodology is depicted in Fig. 1, which describes the actions taken to reach the study's goal. A Flow Chart will be inserted in the Methodology to create a guideline that indicates each stage or action that must be completed in a specific order to complete the study.

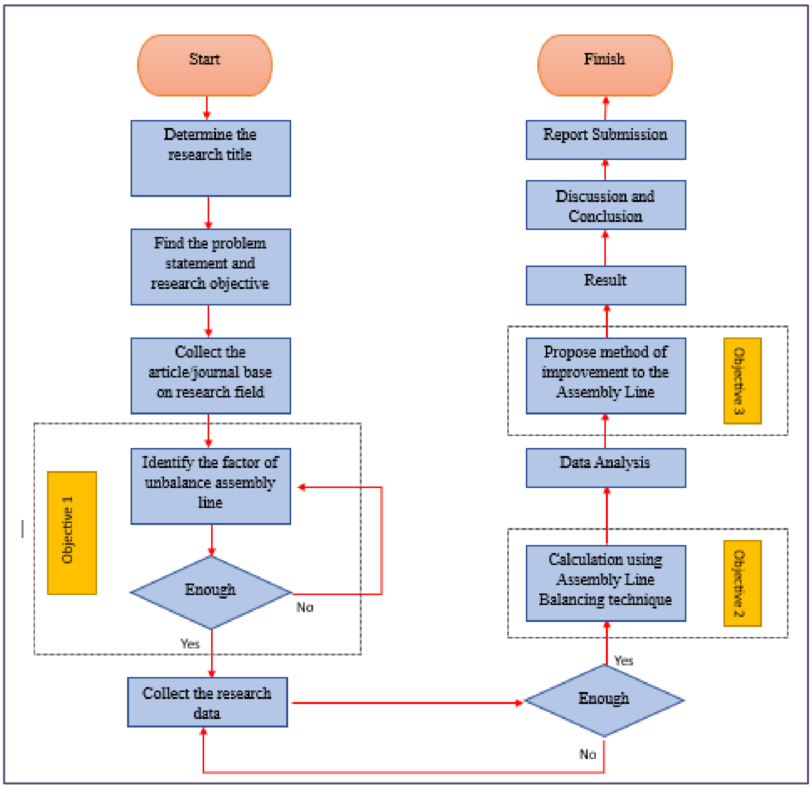

Fig. 1. Detailed process flow of study methodology.

2.2.1. Identify study problem and question

The first step in this study is to identify and define the problems and objectives. This involves pinpointing challenges in the manufacturing industries, particularly related to automotive assembly line issues such as worker allocation, skill levels, and processing time variability. Once the study problem is defined, a corresponding study question is formulated, guiding the systematic and thorough methodology to ensure reliable and relevant findings.

2.2.2. Establish study scope and objective

The subsequent step in defining the study involves specifying its scope and goals. The study scope outlines the study's parameters, focusing on manufacturing industries. Identifying study objectives creates specific goals tied to the study problem, guiding the study's trajectory. This study aims to review and enhance the automotive assembly line in a transformer manufacturing company, categorizing objectives into identification, data collection and analysis, and method of improvement. These objectives are set to be achievable, measurable, and relevant to the study problem.

2.2.3. Literature review

A literature review serves as a reference for the study, drawing on validated sources in the field. It aids data collection from books, journals, and relevant materials published within the last five years. The gathered information is thoroughly examined, filtered, and summarized to form a strong foundation of knowledge for the study. The literature review, focused on Automotive assembly line Balancing, addresses topics like efficiency, workstations, process flow, and process time in manufacturing. It helps identify formulas and methods for analysing data, determining the number of workstations, and standard time in the automotive assembly line. This approach allows for the identification of gaps and areas for high-quality study in the study.

2.3. Data collection

Effective data collection is crucial for thorough study, involving methods commonly used by past studies to maintain study integrity. For this study, data is gathered on process time, production capacity, and the number of labourers at each workstation in the current automotive assembly line. Data accuracy ensures study validity, with collection methods varying for numerical and descriptive data.

3. Result and Discussion

3.1. Definition of the production problems

This section discusses the issues identified in Company X’s automotive assembly line, focusing on the production of a Honda Civic body frame (Model T20). The data gathered using real-time tools like time studies, worker input, and observations, highlighted inefficiencies despite partial automation. The assembly process involved both spot welding and MIG welding, which, despite the automation, led to the highest cycle time in the line.

To address these issues, Automotive Line Balancing (ALB) techniques were applied. ALB is essential for improving the efficiency of production by minimizing idle time and ensuring an even distribution of work across workstations. The analysis revealed that optimizing the layout and process flow was crucial in reducing bottlenecks and increasing productivity.

After analysis, the study proposed improvements to Company X's automotive assembly line, aligning with its third objective. Cause-and-effect diagrams, why-why analysis, and the DMAIC problem-solving approach were used for efficient Lean Six Sigma solutions.

3.2. Data collection

3.2.1. Time study

The collected data represents the processing times in APL 6, specifically for the automotive assembly line dedicated to the Frame Rear Comp Right part of model

T20. This data was collected using a stopwatch at each workstation, capturing both the cycle times and the idle times as the part moved through various stages of assembly. This is crucial for understanding the efficiency and consistency of each workstation, as well as identifying potential bottlenecks and areas for improvement. Figures 2 and 3 further illustrate the cycle times and the standard times set by Company X for these processes.

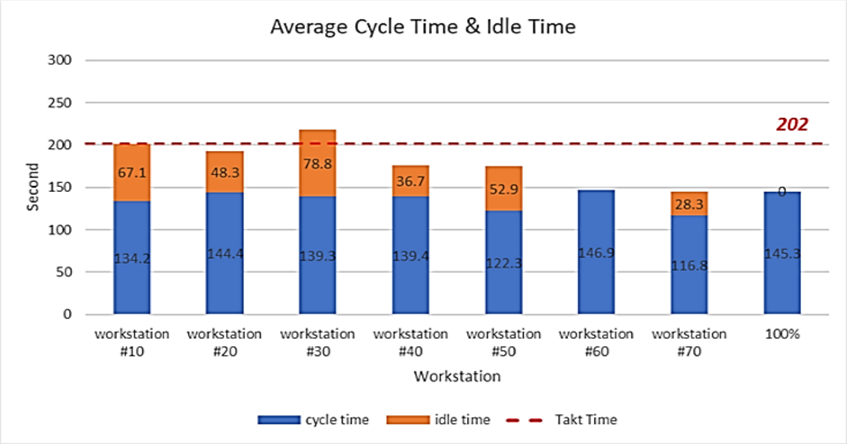

Fig. 2. Graph time taken for each workstation.

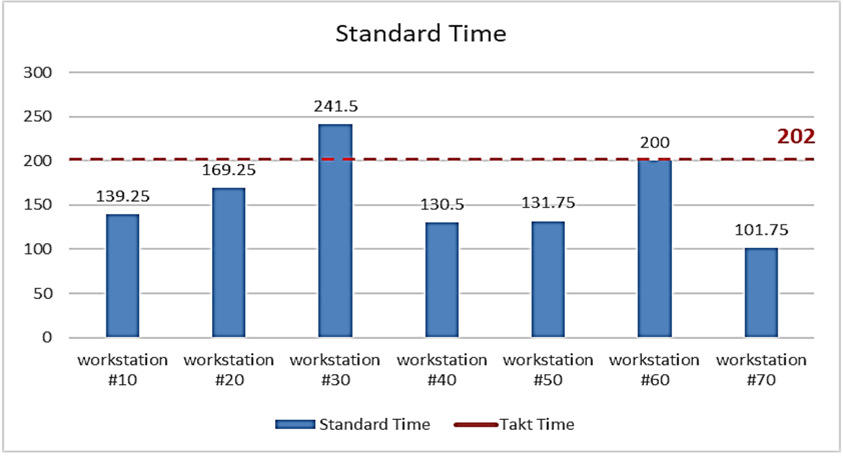

Fig. 3. Standard time taken by company X.

3.2.2. Calculation of takt time

Takt time is a critical measure in lean manufacturing as it ensures that production is aligned with customer demand. In Company X's case, the takt time was calculated based on a daily production goal of 150 units, which resulted in 202 seconds per unit.

When the study proposed reducing the number of workstations from 7 to 6, it redistributed the work across fewer stations. The average cycle time per station would be 181.43 seconds-still lower than the takt time of 202 seconds. This means that production could meet the demand without compromising efficiency, as long as each station remains balanced in terms of workload.

Given the customer demand of 1410 units for November and a daily production goal of 150 units, the takt time-defined as the available production divided by the required output-was calculated to be 202 seconds per unit. This measure is essential for aligning production rates with customer demand.

$$\text{Takt Time} = \frac{(8.25 \times 60 \times 60)}{150} = \frac{30300 \text{ seconds}}{150 \text{ unit}} = 202\ s\text{econds per unit}$$

There are several effects of reducing the number of workstations from 7 to 6 on manufacturing performance compared to the current situation:

By reducing the number of workstations to 6, the workload needs to be redistributed among fewer stations. Each-station will now take on more work. The average cycle time per station under 6 workstations would be Cycle Time per Station=1088.66=181.43 seconds. This is lower than the takt time of 202 seconds, meaning each station would still be able to meet the required production rate (as long as they can process one unit in under 202 seconds).

Waiting time in a manufacturing line is influenced by bottlenecks and idle times. If the total cycle time for each workstation is well balanced, there should be minimal waiting time because each workstation is processing a unit within the takt time. The goal of reducing from 7 to 6 workstations seems to be the elimination of excess capacity, which could reduce unnecessary waiting or idling between workstations. However, if the cycle times are not evenly distributed, there could be bottlenecks at certain workstations, which would increase waiting time.

Throughput will likely remain unchanged if the new configuration is optimized. Since the takt time (202 seconds) remains the same and the cycle times per workstation are within this limit, the production rate will not be affected negatively. If the cycle times are not balanced, throughput could be impacted if one station becomes a bottleneck, slowing the entire line.

Reducing the number of workstations eliminates waste (under-utilized capacity) and can reduce labour costs and operational expenses. Fewer workstations may also lead to more streamlined management and better utilization of space and resources.

Waiting time is minimized when the production line is balanced, i.e., when each workstation has approximately equal cycle times. If the new configuration with 6 workstations has an imbalance (some stations have significantly higher cycle times than others), the waiting time could increase for downstream stations. It is important to review the cycle times at each station after redistribution to ensure that they are close to the calculated cycle time per station (181.43 seconds).

However, care must be taken to balance the cycle times across the remaining 6 stations to avoid bottlenecks that could lead to increased waiting times or reduced throughput.

3.2.3. Calculation for number of workstations

The total cycle time of 1088.6 seconds across all workstations was divided by the takt time (202 seconds), resulting in an optimal number of six workstations. This adjustment is beneficial as it helps remove waste associated with under-utilized capacity, as well as reducing labour and operational costs.

The new setup proposed reducing the number of workstations without negatively impacting throughput, provided that cycle times remain balanced. This reduction also helps to improve line management and resource utilization.

Based on the total cycle time across all workstations and the calculated takt time, it was determined that the optimal number of workstations for the assembly process is six, instead of the current seven. This reduction would help eliminate waste and reduce costs.

Total Cycle Time = 134.2+144.4+139.3+139.4+122.3+146.9+116.8+145.3

= 1088.6 seconds

Number of Workstation = $\frac{1088.6}{202}$= 5.3 ≈ 6 workstations

3.2.4. Line efficiency

The line efficiency calculations showed a significant improvement when the new workstation configuration was applied. With 7 workstations, the efficiency was 63%, while with 6 workstations, the efficiency increased to 89%. This represents a major improvement in productivity by reducing excess capacity and balancing the workloads more effectively across the remaining workstations.

To enhance production capacity, the line efficiency was calculated using both the current cycle times and the newly determined cycle times from the time study. The results indicate that by optimizing the cycle times, the line efficiency can increase from 63% to 89%, thus meeting the production demands more effectively.

i. Calculation of line efficiency using current Cycle Time at Company X

$\text{Line Efficiency} = \frac{1088.6}{7\times 245} = 0.63 \times 100\% = 63\%$

ii. Calculation of line efficiency using New Cycle Time

$\text{Line Efficiency} = \frac{1088.6}{6\times 202} = 0.89 \times 100\% = 89\%$

3.3. Data analysis

In the data analysis process within the DMAIC framework (Define, Measure, Analyse, Improve, Control), understanding the underlying causes of inefficiencies in the assembly line is paramount. The collected data from Section 3.2 provides a foundation for this analysis, which is aimed at identifying the root causes of delays, defects, and other production issues.

A key tool in this analysis is the cause-and-effect diagram (also known as the Ishikawa or Fishbone diagram), which visually maps out the potential factors contributing to these problems. This diagram is especially useful in manufacturing environments, as it categorizes possible causes into groups such as Man, Machine, Method, and Material (the 4Ms), providing a structured approach to problem-solving.

Following the identification of potential causes, the Why-Why Analysis is employed to delve deeper into these issues. This iterative questioning technique helps to trace each problem back to its root cause, ensuring that solutions address the underlying issues rather than just the symptoms. By applying these tools, the study aims to propose effective strategies for improving the efficiency and balance of the automotive assembly line.

Cause and Effect Diagram is a problem-solving method used to find and examine potential reasons for a particular issue. It is sometimes referred to as Ishikawa or Fishbone analysis. The Fishbone analysis, Fig. 4.

Derives its name from the way it looks-it resembles a fish's skeleton. Man, Machine, Material, and Method, or the 4M factors, are relevant to production and manufacturing. It is taken into consideration when carrying out a Fishbone analysis**.**

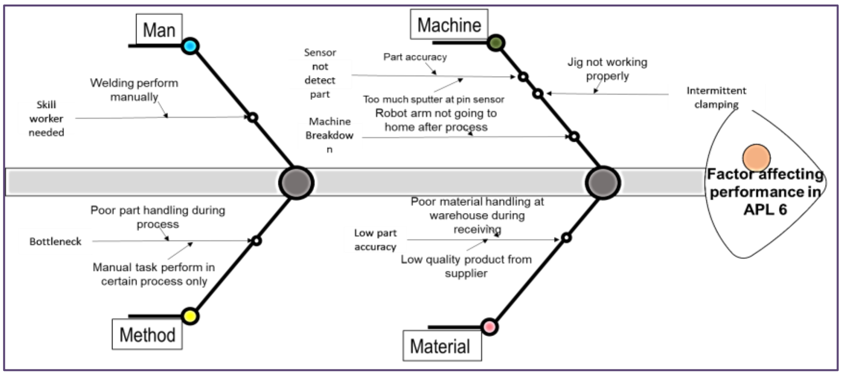

Fig. 4. Cause and effect diagram.

3.4. Process improvement

Process improvement in the Automotive assembly line (AL) as shown in Table 1 needs to be implemented to increase the capacity of the automotive assembly line.

Table 1. Propose improvement table.

Factor	Root Cause	Improvement
Machine	Improper steps of the process carried out at the workstation	- Provide clear and comprehensive training - Continually Examine and Strengthen SOPs
Method	Limited workspace to store child part that increases movement to worker	- Increase the ergonomics in the working space. - Review the current layout and working area in the workstation
	High cycle time at a workstation	- Reduce manual welding points to reduce cycle time - Transfer activities to the workstation in front to reduce process time and balance workload
Material	Inefficient material handling practices in the warehouse	- Apply proper machinery to improve the efficiency of material handling such as pallet jacks, trolleys, and ergonomic tools for material handling - Optimize workflow of material kitting upon receiving for better efficient material handling
	No proper system of quality assurance for incoming parts at the warehouse	- Create a proper system to make sure the quality of incoming parts is following the standard
Man	Lack of emphasis on employee training and development for workers' skill growth	- Provide training and skill development programs to the skilled worker - Provide monitoring and performance feedback - Improve the condition and ergonomics of the workstation

In the context of organizational efficiency, productivity, and quality management, providing clear and comprehensive training along with continually examining and strengthening Standard Operating Procedures (SOPs) represents a substantial theoretical contribution to several key areas of organizational and management theory. Human Capital Theory posits that investing in employees through training enhances their productivity and effectiveness.

Clear and comprehensive training ensures that employees understand their roles, responsibilities, and the processes they must follow. This increases their skill levels, reduces errors, and enhances overall productivity, leading to better organizational performance. Theoretical Contribution: By systematically developing human capital through clear training, organizations can achieve a higher return on investment in their workforce, leading to sustained competitive advantage. Theoretical models can further quantify the impact of training on productivity and innovation.

Increasing ergonomics in the workspace and reviewing the current layout of workstations are significant areas of focus within organizational management and occupational health, contributing substantially to both theory and practice. By applying ergonomic principles, organizations can create workspaces that reduce physical strain and mental fatigue, leading to improved productivity and efficiency. This ties into theories of flow and cognitive load, suggesting that a well-designed workspace enables employees to focus better, maintain higher engagement levels, and perform tasks more efficiently.

Reviewing workstation layouts contributes to a wide range of theoretical areas, from productivity and safety to employee well-being and organizational adaptability. These contributions highlight the interconnectedness of physical workspace design with broader organizational theories, emphasizing the importance of considering ergonomics and layout in strategic planning. The strategies of reducing manual welding points to decrease cycle time and transferring activities to the workstation in front to reduce process time and balance workload can both have substantial theoretical contributions to production efficiency, lean manufacturing, and operations management especially in Lean Manufacturing and Waste Reduction.

The application of proper machinery to improve the efficiency of material handling and optimizing the workflow of material kitting upon receiving are both vital concepts in operations and supply chain management. These practices not only streamline processes but also provide substantial theoretical contributions to the fields of industrial engineering, ergonomics, and operations management through enhanced productivity through mechanization, ergonomics and human factors engineering, and economies of scale and cost efficiency.

When discussing the substantial theoretical contribution of implementing initiatives like providing training and skill development programs, offering monitoring and performance feedback, and improving the condition and ergonomics of the workstation, it's important to consider several key theories from organizational behaviour, human resource management, and ergonomics.

These theories help explain why these initiatives can significantly impact both individual performance and overall organizational effectiveness. By providing training and skill development programs, an organization can increase its human capital, leading to higher efficiency, better problem-solving, and greater adaptability to changes. The theoretical contribution here lies in the understanding that continuous investment in human capital not only improves individual employee capabilities but also contributes to the long-term competitive advantage of the organization.

3.5. Control method on proposed improvement

The last phase of practicing DMAIC is Control. This control phase as shown in Table 2 is to sustain the improvement method that has been proposed during the improvement phase. Based on the suggestion; to maintain the workers to comply with the SOP is company can create a more detailed work process for every station stressing about maintaining the cleaning in the workspace as the sputter from the welding process can slow the process in the workstation. Another method to control the improvement method is to make constant monitoring and measurement.

Table 2. Control method for improvement method.

4M	Propose Improvement	Control Method
Machine	-Provide clear and comprehensive training -Continually Examine and Strengthen SOPs	-Provide a check sheet to monitor the downtime of the machine based on the problem that occurs. -Standardization of workflow in a workstation that is to understand to follow.
Method	- Increase the ergonomics in the working space. - Review the current layout and working area in the workstation	-Use a control chart to gain feedback on the changes that are implemented for future assessment. - Implement the 5S method to create standardization in the work environment.
	-Reduce manual welding points to reduce cycle time -Transfer activities to the workstation in front to reduce process time and balance workload	A process monitoring system is a method to ensure the improvement steps such as Statistical Process Control (SPC) -Process audit using a dashboard or software system.
Material	-Apply proper machinery to improve the efficiency of material handling such as pallet jacks, trolleys, and ergonomic tools for material handling -Optimize workflow of material kitting upon receiving for better efficient material handling	-Increase technology investments with technologies for higher process efficiency. -Foster a culture of continuous improvement by encouraging ongoing suggestions and experimentation with new techniques to further optimize the workflow
	- Create a proper system to make sure the quality of incoming parts is following the standard.	-Install software that monitors production data automatically, including output quantities, cycle times, and scrap rates. For precision, this can be integrated with RFID tags or barcode scanners.
Man	-Provide training and skill development programs to the skilled worker -Provide monitoring and performance feedback -Improve the condition and ergonomics of the workstation	- To see the key performance indicators (KPIs) associated with the improvement, use performance dashboards and reports. - Mapping the employer's skill program for better skill development progress -Use ergonomic effect analysis to monitor the working conditions in the workstation.

4. Conclusions

The research conducted at Company X identified key inefficiencies in the assembly of the Honda Civic body frame part (Model T20) and proposed targeted improvements. Through the use of time studies, Automotive Line Balancing (ALB), and Lean Six Sigma tools, the study revealed that reducing the number of workstations from 7 to 6 would improve production efficiency without negatively impacting throughput. The final result of this study is a proposed reduction of workstations from 7 to 6, which leads to several significant improvements:

The cycle time per station after redistribution was calculated at 181.43 seconds, which is below the takt time of 202 seconds. This ensures that the production line can meet the required production rate. The reduction to 6 workstations increases line efficiency from 63% to 89%, optimizing resource usage and eliminating waste. These adjustments would streamline the production process, minimizing waiting times and balancing workloads across stations.

In summary, the research successfully aligns production rates with customer demand while improving operational efficiency and reducing costs, fulfilling the study’s objectives of enhancing the automotive assembly line's performance. By employing the DMAIC method, Why-Why Analysis, and Fishbone Diagrams, the root causes of inefficiencies were accurately identified. These analytical tools provided structured methods to diagnose the specific issues hindering productivity, which laid the groundwork for the subsequent improvement phase.

Proposed Improvements and Long-Term Control: After identifying the root causes, the final objective of the study was achieved through the proposal of targeted improvement methods. Using the DMAIC framework, the improvement phase focused on addressing the identified issues by refining processes and implementing solutions to enhance efficiency. These improvements were aimed at reducing cycle time, balancing workloads, and streamlining operations. The study emphasizes the importance of the Control phase in DMAIC, which ensures that the improvements are sustained over time.

References

1. Becker, C.; and Scholl, A. (2006), A survey on problems and methods in generalized assembly line balancing. *European Journal of Operational Study*, 168(3), 694-715.
2. Berhe, H.H.; Gebremichael, H.S.; and Beyene, K.T. (2023). Development, validation and verification of innovative integrated kaizen philosophy (CI) framework and its implementation procedure for enhancing manufacturing industries sustainable competitiveness. *International Journal of Quality & Reliability Management*, 40(10), 2463-2518.
3. Trung, N.P.; and Tai, L.M. (2019). Researching and applying the line balancing methods in optimizing automobile assembly lines. *Applied Mechanics and Materials*, 889, 574-579.
4. Li, Y.; Kucukkoc, I.; and Tang, X. (2021). Two-sided assembly line balancing that considers uncertain task time attributes and incompatible task sets. *International Journal of Production Research*, 59(6), 1736-1756.
5. Sancı, E.; and Azizoğlu, M. (2017). Rebalancing the assembly lines: Exact solution approaches. *International Journal of Production Research*, 55(20), 5991-6010.

6. Lv, Y.; Zhang, J.; and Qin, W. (2019). Simulation-based production analysis of mixed-model assembly lines with uncertain processing times. *Journal of Simulation*, 13(1), 44-54.
7. Lazai, M.; Santos, L.C.D.P.; Grossi Chamie, N.R.; Pierezan, R.; Loures, E.R.; Santos, E.P.D.; Costa, S.E.G.D.; and Lima, E.P.D. (2020). Automated system gains in lean manufacturing improvement projects. *Procedia Manufacturing*, 51, 1340-1347.
8. Eghtesadifard, M.; Khalifeh, M.; and Khorram, M. (2020). A systematic review of research themes and hot topics in assembly line balancing through the web of science within 1990-2017. *Computers & Industrial Engineering*, 139, 106182.
9. Pogowonto, A.; and Amrina, U. (2020). Reduction of cycle time in vehicle engine assembly lineusing karakuri kaizen. *International Journal of Engineering Research and Advanced Technology*, 06(10), 49-57.
10. Rahman, H.F.; Janardhanan, M.N.; and Nielsen, P. (2020). An integrated approach for line balancing and AGV scheduling towards smart assembly systems. *Assembly Automation*, 40(2), 219-234.
11. Karatepe Mumcu, Y. (2022). Application of heuristic assembly line balancing methods to lighting automation industry. *European Journal of Technic*, 12(2), 204-208.
12. Chao, B.; Zhang, C.; Zhang, Y.; Guo, H.; Ren, Y.; and Zhang, H. (2022). Research on optimization and simulation of sand casting production line based on VSM. *International Journal of Lean Six Sigma*, 13(6), 1185-1199.
13. Sordan, J.E.; Oprime, P.C.; Pimenta, M.L.; Lombardi, F.; and Chiabert, P. (2021). Symbiotic relationship between robotics and lean manufacturing: A case study involving line balancing. *The TQM Journal*, 34(5), 1076-1095.
14. Sivasankaran, P.; and Shahabudeen, P. (2017). Comparison of single model and multi-model assembly line balancing solutions. *International Journal of Computational Intelligence Research*, 13(8), 1829-1850.