

Analysis of Production Line Balance in the Final Assembly Area Using Line Balancing and Promodel Simulation in an Automotive Company

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ABSTRACT

An imbalanced workload on the production line is one of the main causes of low efficiency in the manufacturing industry. This study was conducted in the final assembly area of an automotive company producing premium brand four-wheeled vehicles, where a significant imbalance in working time was found between two operators. The objective of this study was to balance the division of tasks between operators on the production line. The methods used were line balancing and ProModel simulation. Through precedence diagram analysis and regrouping of workstations, the stamp inspection task was shifted from the first operator to the second operator, resulting in a more even work time of 18 minutes for the first operator and 21 minutes for the second operator. The workflow simplification also succeeded in reducing the number of processes from 8 to 5 workstations, with an increase in line efficiency from 39.06% to 55.55%. The results of the ProModel simulation confirmed this workload balance without any layout changes or additional workers. The ProModel simulation results, which showed an average system time of 17.50 minutes for the first operator and 20.50 minutes for the second operator, further confirmed the feasibility of the designed solution for direct implementation in the field. The time difference between Operator 1 and Operator 2 is utilized to inspect all components, ensuring their completeness and conformity to established standards.

1. Introduction

Competition in the automotive industry is getting fiercer every year, pushing every company to continuously improve its production process to remain efficient and competitive [1], [2]. One of the aspects measured is productivity, which serves as a key indicator of a company's ability to manufacture products efficiently. However, automotive companies often struggle to achieve high levels of productivity. A common consequence is delayed product delivery. Based on initial observations, there were 509 late deliveries out of 2,805 shipments during the fiscal year, or approximately 18.1%. Furthermore, the percentage of late deliveries showed an increasing trend, from 13.1% in the last month to 22.0%. These delays are indirectly caused by bottlenecks, where the production line fails to operate smoothly, often due to workload imbalances between workstations. Such conditions arise when processing times at certain workstations exceed those at others, resulting in waiting times, idle time, material accumulation, and low production capacity utilization.

One aspect that often becomes a concern is the balance of workload on the assembly line, especially in the final assembly area, which is the final stage before the product is ready for distribution [3]. When the workload between operators is not distributed evenly, the impact is not only felt in the increased process time but also on overall productivity, which also decreases [4]. This condition is known in the manufacturing world as the line balancing problem, namely how to distribute work elements proportionally to each work station so that no one station is overburdened while others are idle [5]. In practice, there is often an imbalance in work time between stations, where some operators experience excessive workloads while others have high idle time. This condition causes bottlenecks, accumulation of semi-finished goods, production delays, and low resource utilization. In addition to impacting productivity, line imbalance can also increase operational costs and reduce the company's ability to meet production targets. Therefore, analyzing and improving line balancing is important to improve the efficiency of the overall production system. To address this issue, various methods have been developed, one of which is Ranked Positional Weighting (RPW), which prioritizes work elements based on their positional weight within the process flow [6], [7]. Furthermore, the use of simulation tools such as ProModel is increasingly common because it allows researchers to virtually test various repair scenarios before they are actually implemented, thus minimizing the risk of errors in the field [8], [9].

This research stems from a real-world problem encountered in the final assembly area of an automotive company, where two operators working on the same line had significantly different processing times. This discrepancy indicates that the existing task allocation is not working as intended and, if left unchecked, will continue to hinder the achievement of optimal production capacity. Previous research has shown that implementing line balancing methods can improve production line efficiency [10], [11]. The Ranked Positional Weighting (RPW) method has been used to reduce idle time and improve workload balance between stations. The results of study previous showed increased line efficiency, decreased balance delay, and reduced bottlenecks, resulting in more optimal production capacity and easier production targets [12], [13].

Based on these problems, this study aims to rebalance the division of labor between operators using the RPW method combined with ProModel simulation, so that it is expected that both operators can work with a more equal load and the overall line efficiency can be increased [14]. More broadly, the results of this study are expected to be not only useful for the company as material for evaluation and operational improvement, but also can be a reference for further research that examines the application of line balancing and simulation in the context of the assembly industry.

2. Methods

This study employs a line balancing approach integrated with simulation, focusing on the analysis and improvement of production line balance in the final assembly area of an automotive company that produces vehicles using Line Balancing and ProModel methods [9], [15]. Data collection was conducted over a six-month period, from January to June 2025, with the research subjects being the work processes of two operators working in that area. This area was selected based on the significant disparity in working hours between operators, thus deeming it necessary to implement systematic improvements.

Data collection was conducted through four methods. First, direct field observation to record the actual time of each work process. Second, interviews with operators to understand the actual conditions during the process. Third, a literature review of relevant journals and literature was conducted. Fourth, documentation in the form of video recordings of the work process served as analysis material. The collected data covered seven work elements and their respective durations.

After data collection, analysis was conducted in two main stages. The first stage was the application of a line balancing method using the Ranked Positional Weight (RPW) approach [16], [17]. This method works by calculating the positional weight of each work element based on the processing time of that element plus the total time of all subsequent elements, then sorting them from highest to lowest weight as the basis for grouping them into work stations.[5] This process was assisted by the preparation of a precedence diagram to map the dependencies between work elements, and the calculation of path efficiency using the following formula:

$$\text{Path Efficiency} = \frac{(\text{Processing Time})}{(\text{Number of Stations} \times \text{Cycle Time})} \times 100\% \quad (1)$$

The second stage is a simulation using ProModel software. The line balancing data is input into four main ProModel elements: Locations to define each process point, Entities to represent the operators involved, Processing to determine the sequence and duration of each process, and Arrivals to regulate the arrival times of entities into the system [18], [19]. This simulation was run to verify whether the division of tasks resulting from line balancing actually resulted in a better workload balance between the two operators, while also providing a visual representation of the system's condition before the changes were implemented directly in the field.

Overall, the research flow can be described as follows: starting with field observations, literature review, problem formulation, data collection, processing and analysis using line balancing and ProModel simulations, and finally drawing conclusions. This stage can be seen in Figure 1.

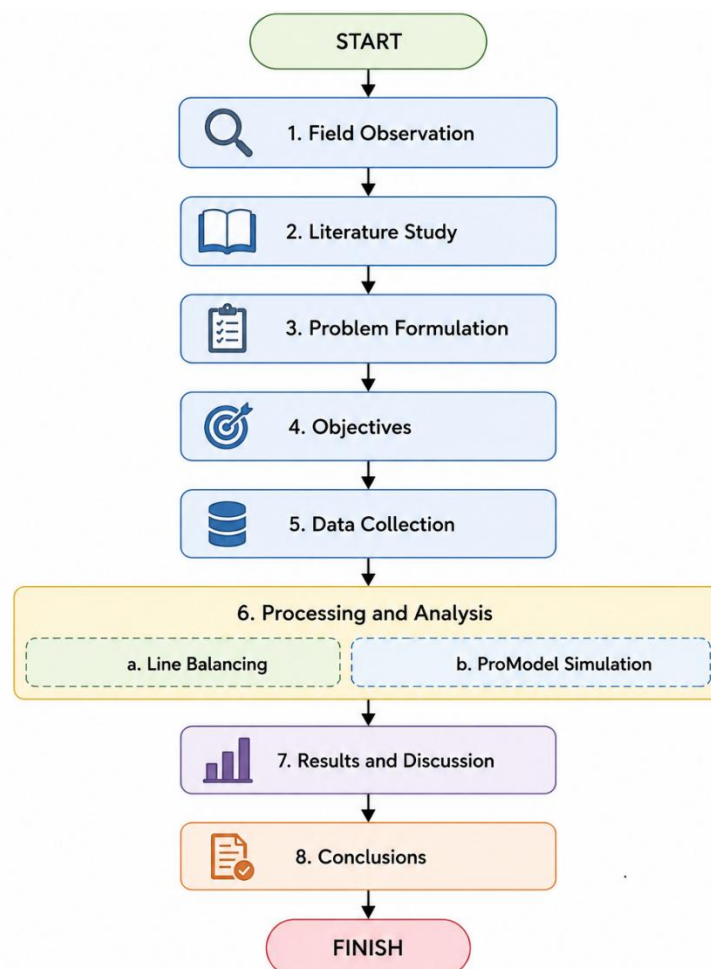


Fig. 1. Research Framework

The research began with field observations to identify the actual conditions of the production process, workflow, processing times, workloads, and issues on the production line. Subsequently, a literature review was conducted to establish a theoretical foundation regarding line balancing and ProModel simulation. Based on the observations and literature review, the research problem was formulated, and objectives were established to guide the study. The next stage involved data collection, gathering primary and secondary data such as processing times, capacities, targets, and production output. The collected data underwent processing and analysis using line balancing techniques to evaluate workload distribution and ProModel simulation to model system conditions and test improvement alternatives. The analysis results are presented in the "Results and Discussion" section, comparing actual conditions with improvement alternatives based on production

performance indicators. The final stage consists of drawing conclusions based on the research findings and providing recommendations for improvements to enhance line balance and production productivity.

3. Results and Discussion

3.1 Identify Production Line Conditions: Un-balance

The first step in this research was to map the actual conditions in the final assembly area. Based on direct observation, it was found that the work process in this area was divided into seven work elements with a total time of 35 minutes, but the distribution was very uneven. The first operator carried out the workload for 25 minutes, while the second operator only worked for 12 minutes. The details of this initial task distribution can be seen in the following Table 1.

Table 1. Production Process

No	Process	Operator 1 (min)	Operator 2 (min)	Process
1	Two man rule	2	2	Two man rule
2	Operator measures wiper	7	7	The operator performs the socket installation
3	The operator scans the barcode on the unit	3	3	The operator scans the barcode on the unit
4	The operator tightens the bolts	5	0	-
5	Operator performs stamp inspection	8	0	-

This imbalance is not simply a technical issue, but rather reflects systematic waste in the production process. The first operator worked far beyond their ideal capacity, while the second operator had a significant amount of unproductive downtime. The imbalance in the production line directly led to inefficiencies in the form of idle time and uneven workloads, which ultimately hampered the achievement of overall production targets. The layout of the final assembly area before the improvements can be seen in the following figure, where the lines of the first and second operators appear to be unequally distributed.

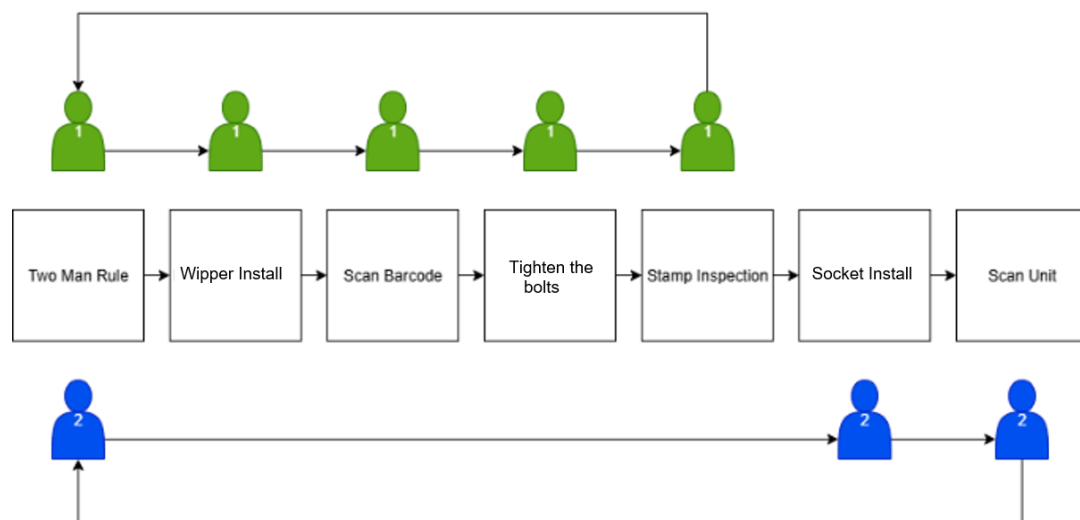


Fig. 2. Production System

Based on Figure 2, the production process comprises seven activities. The process flow indicates a division of tasks among several operators, marked by green and blue operator positions. The green operator handles the sequence of activities from the initial stage through to inspection, while the blue operator manages

the subsequent activities. This flow pattern reflects a distribution of workload and operator movement to meet production requirements. However, the grouping of activities requires evaluation based on the cycle time of each task, as disparities in processing times can lead to high workloads for some operators while others experience idle time. Furthermore, movement paths forming a loop pattern have the potential to generate motion waste and transportation time if the distances between activities are significant. Therefore, a line balancing analysis is necessary to determine a more balanced distribution of activities, identify bottlenecks, calculate line efficiency and balance delay, and subsequently validate improvement alternatives using ProModel simulation.

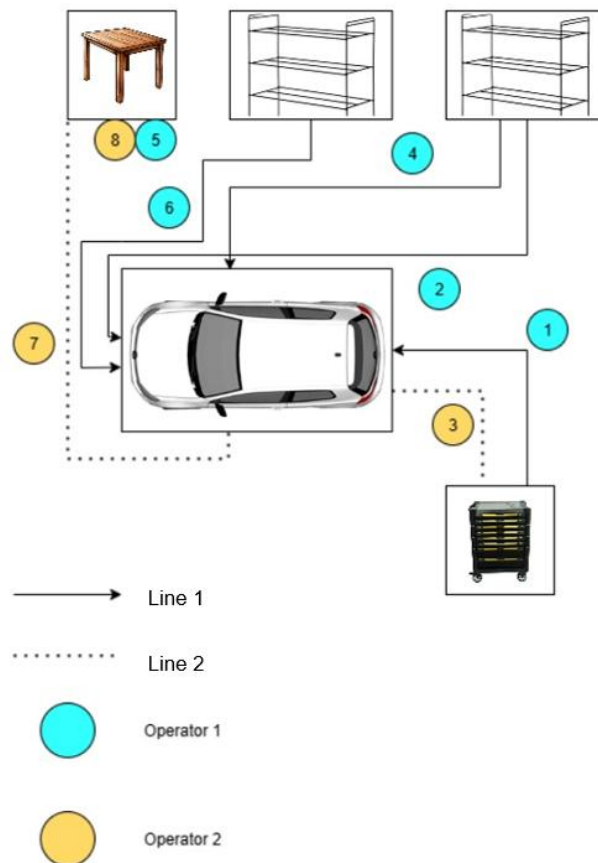


Fig. 3. Final Assembly Layout

Based on Figure 3, the company employs a fixed-position layout. This is a production facility arrangement method in which the main product remains in a single location, while manpower, tools, and raw materials move to the product.

3.2. Workflow Mapping Using Precedence Diagram

Before the improvement, all work elements were mapped onto a precedence diagram to understand the dependencies between processes. This diagram shows that the Two-Man Rule process is the starting point, worked on jointly by both operators, and then each operator proceeds sequentially through their respective task sequences. The positional weight of each element is calculated by summing the time of that element with the time of all subsequent elements.

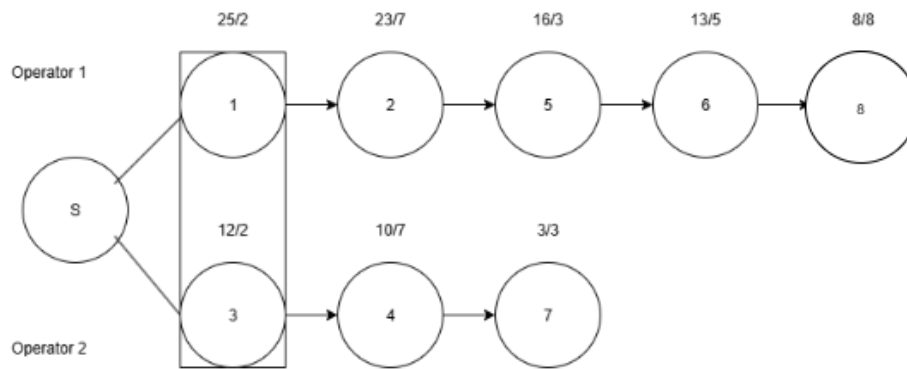


Fig. 4. Precedence Diagram

Figure 4 illustrates the grouping of activities into two clusters or workstations. Activities 1 and 3 are assigned to Group 1 and Group 2, respectively, with subsequent activities following the established process relationships. Group 1 comprises the activity sequence 2–5–6–8, while Group 2 consists of the sequence 4–7. This allocation reflects an effort to distribute work based on precedence relationships and workload, aiming for a more balanced process flow. Such grouping reduces the number of workstations compared to the initial setup and serves as a basis for line balancing evaluation to enhance efficiency and minimize idle time. The calculated positional weights are then sorted from largest to smallest to determine the priority of element placement within a workstation, as shown in Table 2.

Table 2. Rank Position Weight

Ranking	Operation	Time (min)
1	1	25/2
2	2	23/7
3	5	16/3
4	6	13/5
5	3	12/2
6	4	10/7
7	8	8/8
8	7	3/3

This order serves as the primary basis for grouping work elements into more balanced workstations. The RPW approach was chosen because it has been proven to provide the highest efficiency results compared to other heuristic methods.

3.3. Task Redistribution: From Unbalance to Balance

Based on the RPW sequence and cycle time constraints, the work elements are then regrouped into five workstations. The most significant change was the transfer of stamp inspection duties from the first operator to the second, which directly reduced the workload of the first operator while increasing the contribution of the second operator. The grouping results, along with the efficiency levels of each workstation, are presented in the following Table 3.

Table 3. Workstation Efficiency

WS	Workstation Grouping	Time (min)	Efficiency (%)
I	1, 2	9	100
II	3, 4	9	100
III	5, 6	8	88
IV	7	3	33
V	8	8	88

This grouping resulted in a new, more proportional precedence diagram, where the first operator handles WS I and WS III, while the second operator handles WS II, WS IV, and WS V. A complete overview of the workflow after the improvements can be seen in the following figure.

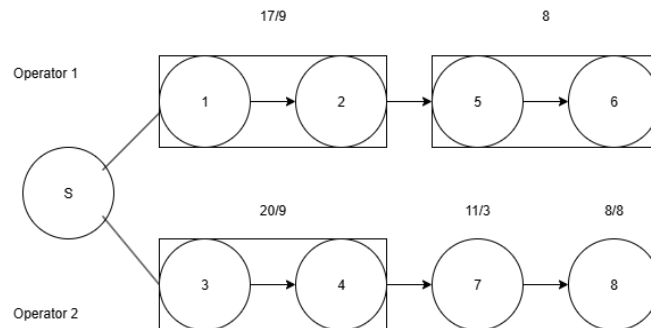


Fig. 5. Precedence Diagram After

The figure illustrates the division of activities into two work groups based on precedence relationships. Operator 1 handles the sequence of activities 1–2–5–6, while Operator 2 handles activities 3–4–7–8. This division demonstrates a more structured work distribution that takes the process sequence into account. Grouping activities also has the potential to reduce movement and simplify workflow. The results of this grouping can subsequently be used to calculate line efficiency and balance delay.

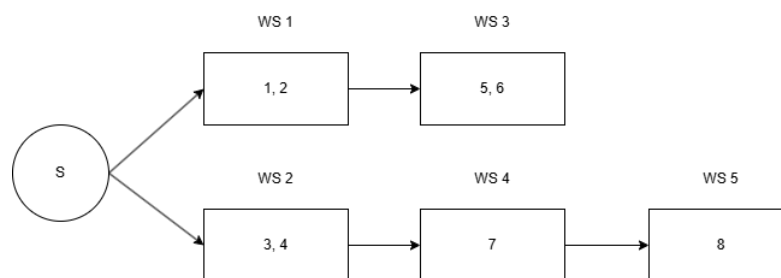


Fig. 6. Workstation

With this new configuration, the first operator's work time decreased from 25 minutes to 18 minutes, while the second operator's work time increased from 12 minutes to 21 minutes after rounding. This much more even distribution demonstrates that the RPW approach is capable of producing practical solutions that can be immediately implemented without requiring additional labor or changes to the physical layout of the production area.

3.4. Line Efficiency Calculation: Concrete Evidence of Improvement

One indicator of successful line balancing is an increase in line efficiency. In this study, line efficiency was calculated by comparing the total process time to the product of the number of workstations and the cycle time. The results are as follows:

$$\text{Line Efficiency Before} = (25 \times 100\%) / (8 \times 8) = 39.06\%$$

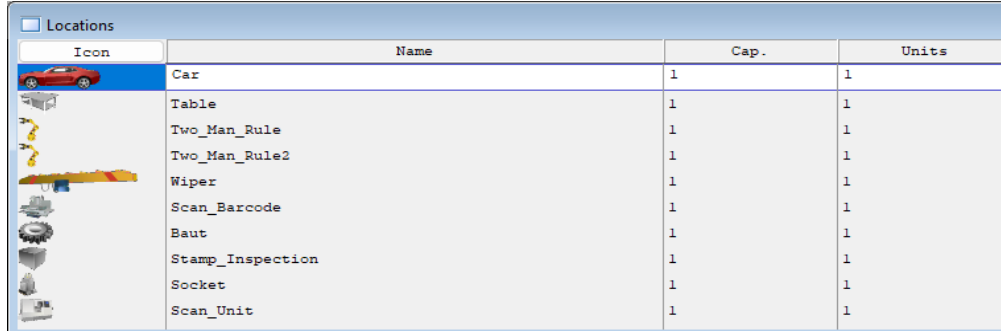
$$\text{Line Efficiency After} = (21 \times 100\%) / (5 \times 9) = 55.55\%$$

The increase in efficiency from 39.06% to 55.55% is a significant achievement, considering that this improvement was achieved without any additional resources. However, this study recognizes that the 55.55% efficiency figure is still far from ideal. This occurs because in line balancing practice, there are precedence constraints that cannot be ignored, differences in duration between work elements, and cycle time

determination that affect how tightly work elements can be combined. This condition aligns with the theoretical explanation that 100% efficiency is nearly impossible to achieve in real conditions due to the inherent idle time in every production line [11].

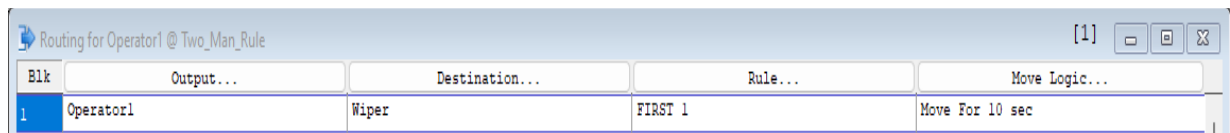
3.5. Validation Through ProModel Simulation

To ensure that the designed task redistribution is truly feasible to implement, this study conducted simulations using ProModel software. The simulation is built by defining four main elements: Locations, which represent each process point; Entities, which represent the two operators; Processing, which contains the sequence and duration of each process; and Arrivals, which regulate the entry time of entities into the system.



Icon	Name	Cap.	Units
	Car	1	1
	Table	1	1
	Two_Man_Rule	1	1
	Two_Man_Rule2	1	1
	Wiper	1	1
	Scan_Barcode	1	1
	Baut	1	1
	Stamp_Inspection	1	1
	Socket	1	1
	Scan_Unit	1	1

Fig. 7. Locations in ProModel



Blk	Output...	Destination...	Rule...	Move Logic...
1	Operator1	Wiper	FIRST 1	Move For 10 sec

Fig. 8. Processing in ProModel

The simulation shows that the average time spent by the first operator in the system is 17.50 minutes, while the average time spent by the second operator is 20.50 minutes, which is close to the results of manual line balancing calculations. This confirms the validity of the model. Furthermore, the Single Capacity Location graph shows that each process location operates sequentially without significant queue buildup, while the Entity States graph shows that both operators now have a much more balanced proportion of active time compared to the initial conditions.

Scoreboard		
Name	Total Exits	Average Time In System (Min)
Operator1	1,00	17,50
Operator2	1,00	20,50

Fig. 9. ProModel Simulation Results

Based on the scoreboard, Operator 1 and Operator 2 each produced one unit. The average time spent in the system was 17.50 minutes for Operator 1 and 20.50 minutes for Operator 2. Thus, Operator 2 took 3 minutes longer than Operator 1, representing an increase of approximately 17.1%. This difference indicates a variation in processing time. The time difference between Operator 1 and Operator 2 is utilized to inspect all components, ensuring their completeness and conformity to established standards.

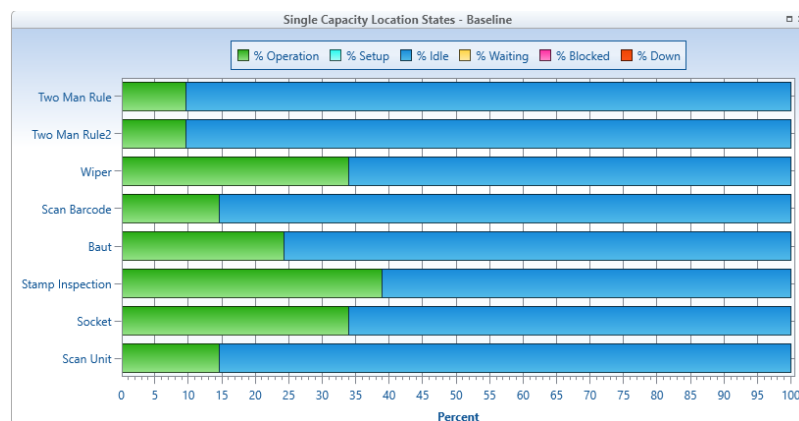


Fig. 10. Single Capacity Location

Based on Figure 10, the baseline conditions reveal that the utilization of each activity at the Single Capacity Location varies. The Stamp Inspection activity exhibits the highest operational percentage approximately 40%, followed by Wiper and Socket activities at around 35%, and the Bolt activity at roughly 25%. Meanwhile, the Two Man Rule, Two Man Rule 2, Scan Barcode, and Scan Unit activities account for relatively low operational proportions, ranging from 10% to 15%. The significant blue-shaded areas indicate that a large portion of the time for each activity is spent in an "Idle" state, signifying that capacity is not being optimally utilized.

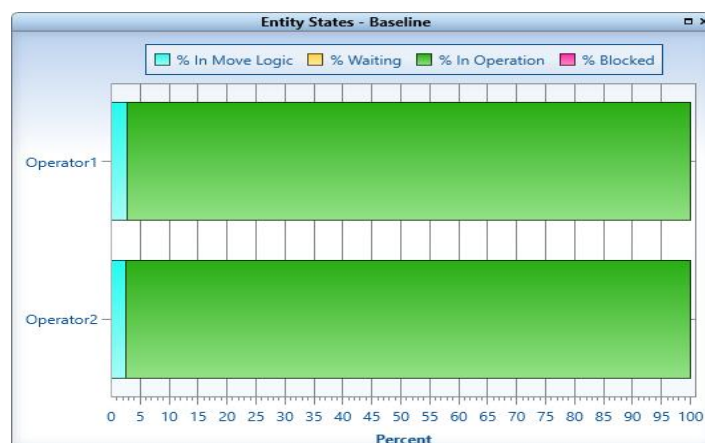


Fig. 11. Entity States

Based on Figure 11, regarding entity states, Operator 1 and Operator 2 show predominantly operational activity approximately 97–98%, while "Move Logic" accounts for only about 2–3%, with virtually no time spent in "Waiting" or "Blocked" states. This indicates that both operators are actively engaged in the process. However, the high idle time associated with certain location activities points to an imbalance between process capacity and facility utilization. These baseline conditions can serve as a foundation for evaluating workload balance, reducing idle time, and enhancing process utilization during the subsequent improvement phase.

These findings strengthen the argument that combining line balancing and ProModel simulation is a complementary approach [20]. Line balancing provides analytical task redistribution solutions, while ProModel dynamically validates these solutions before they are implemented in the field. A similar approach is also applied to analyzing production capacity, where ProModel simulations have been shown to identify inefficiencies that are difficult to detect through direct observation alone [21].

3.6. Discussion

Overall, the improvements made in this study resulted in measurable changes in several production line performance indicators. The table 4 clearly shows that although cycle time increased slightly from 8 to 9 minutes, this change was offset by significant process simplification and a much more proportional workload distribution. The absence of additional manpower also demonstrates that efficiency improvements do not always require additional resource investment, but rather simply require structured, data-driven restructuring.

Table 4. Comparison Before and After Improvement

Indicator	Before	After
Cycle Time (min)	8	9
Efficiency (%)	39.06	55.55
Process (activity)	8	5
Man Power (people)	2	2

Based on Table 4, the comparison between before and after improvement states reveals an increase in process efficiency, despite a rise in cycle time. The cycle time increased from 8 to 9 minutes or increase 2.5%, indicating a slightly longer duration for completing a single cycle. However, line efficiency rose from 39.06% to 55.55%, an increase of 16.49 percentage points, demonstrating more optimal utilization of working time. This improvement was driven by a reduction in the number of activities from eight to five or 37.5% decrease. This reduction reflects the simplification, consolidation, or elimination of activities that offered little added value, thereby streamlining the process flow. Meanwhile, the workforce remained constant at two personnel, meaning the efficiency gains were achieved without adding human resources. Overall, the improvements successfully enhanced efficiency and simplified the process while maintaining the same workforce size.

4. Conclusion

This research successfully addressed the problem of workload imbalance in the final assembly area by implementing a line balancing method with a Ranked Positional Weight (RPW) approach, validated using ProModel simulations. The redistribution of tasks, specifically the transfer of stamp inspection work from the first operator to the second, proved effective in balancing the work time imbalance of 25 minutes versus 12 minutes, to a more proportional 18 minutes for the first operator and 21 minutes for the second operator. This improvement also resulted in a streamlined workflow from 8 processes to 5 workstations and an increase in line efficiency from 39.06% to 55.55%, without requiring additional labor or changes to the physical layout of the production area. The ProModel simulation results, which showed an average system time of 17.50 minutes for the first operator and 20.50 minutes for the second operator, further confirmed the feasibility of the designed solution for direct implementation in the field.

The limitation of this study is that the line efficiency of 55.55% is still not optimal, considering that there is still idle time that cannot be completely eliminated due to the limitations of precedence constraints and differences in duration between work elements. In addition, this study only focuses on two operators in one production area with an observation period of six months, so the generalization of the results needs to be done carefully. Therefore, further research is recommended to integrate the lean manufacturing approach to identify and eliminate remaining waste in the production system, as well as expand the scope of analysis to other production areas so that a more comprehensive picture of overall line efficiency can be obtained.

Declarations

Author contribution.

Abdilah Putraman Septianto: data collection, data analysis, final report.

Indra Setiawan, Tringudi Wiyatno: data analysis, interpretation and evaluation.

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