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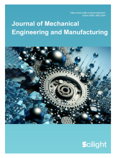

Article

Implementation of Assembly and Balancing Line Aiming at Operational Excellence in Pre-Hospital Transport Equipment

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How To Cite: Sebbe, N.P.V.; Sá, J.C.V.; Pereira, M.T.; et al. Implementation of Assembly and Balancing Line Aiming at Operational Excellence in Pre-Hospital Transport Equipment. *Journal of Mechanical Engineering and Manufacturing* **2026**, *2*(1), 7. https://doi.org/10.53941/jmem.2026.100007

Received: 5 August 2025
Revised: 29 September 2025
Accepted: 11 November 2025
Published: 7 January 2026

Abstract: In contemporary times, a corporation must provide rapid and faultless production to create differentiated, high-quality items that satisfy market need and standards, also taking into account the available industrial capacities. This study concentrates on optimizing the assembly line for pre-hospital transport equipment and instituting Standard Work across many workstations to enhance production efficiency. Consequently, operational excellence and strategies associated with continuous improvement were considered. Improvements in the assembly line and its edge facilitated a reduction in tasks, enabling a balanced workload among operators and optimizing the manufacturing process. A study was conducted on the durations and techniques employed in the different assembly processes and corresponding workstations for each product family. A comparison was conducted between the data reflecting the company's baseline state and the outcomes achieved in this project. The implemented adjustments and their influence on the entire production process were assessed.

Keywords: standard work; operational excellence; assembly line; balancing

1. Introduction

Nowadays, in order to be successful in the market, it is essential for companies to be competitive and efficient in terms of production. Therefore, it is essential to produce the quality products needed to satisfy customers, reducing production costs and eliminating processes that do not add value to the final product [1].

Balancing assembly lines provides an increase in production, with less effort and less space, reducing waste. Lean Manufacturing is a methodology used to reduce waste in the production process, consequently eliminating activities that do not add value to the final product [2]. With its implementation, it is possible to obtain a reduction in stocks and a reduction in lead time [3]. There is a set of specific Lean tools/techniques, most of which originate from the TPS system, which help in identifying problems, as well as in optimizing resources and controlling processes [4].

In turn, operational excellence refers to a company's ability to carry out its operations efficiently, effectively and consistently, seeking to continually improve its processes and results. It is a philosophy that aims to optimize all areas of a business, from production and logistics to customer service, with the aim of achieving higher levels of performance.

The project involved the design and implementation of a new assembly line for the production of stretchers, with the central objective of optimizing production flow. To this end, a functional layout and an efficient supply system were developed to improve the company's internal logistics. The project's main innovation lies in its methodological approach, which sequentially and synergistically integrated the continuous improvement tools Lean Manufacturing, Standard Work, and Kaizen. Standard Work was used to standardize tasks and ensure process consistency, creating a solid foundation for improvement. The Kaizen philosophy was then applied to promote continuous and sustainable gains in productivity. The combination of these tools resulted in the consistent exceeding of established production targets, validating the effectiveness of the implemented methodology. Based on this, the question arises about improving production flow by reducing production costs and eliminating processes that don't add value to the final product. The hypothesis is that balancing assembly lines and applying Lean principles will increase production with less effort and space, thus reducing waste. The study roadmap is shown in Figure 1.

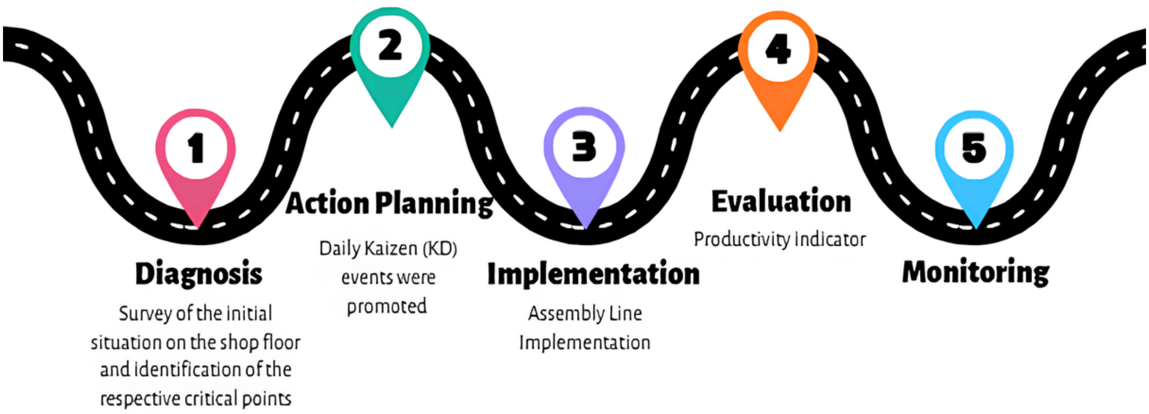

Figure 1. Stages of work carried out.

2. Literature Review

2.1. Tools for Production Evaluation and Optimization

Just-in-time (JIT) is a tool directly related to inventory and its main objective is to minimize unnecessary storage of parts, Work-In-Progress (WIP) and finished products. According to JIT, production should only be carried out when the product is requested, not before. By reducing stock levels, it is much easier to identify quality problems, which can be identified and corrected in advance. In order to implement this philosophy, there must be collaboration and responsibility throughout the entire production process, from the supplier to the operator responsible for quality control. Kanban supply and order scheduling will contribute to the existence of a pull system, that is, a system driven by needs in which only the right quantity and time is produced [5]. Using a Just-in-time model-based strategy, Cai et al. [6], proposed a new methodology to dynamically predict average Material Removal Rate (MRR) for the Chemical Mechanical Planarization (CMP) process. This methodology was named JIT-PF, which outperformed even dynamic models and static models. In turn, Agyabeng-Mensah et al. [7], evaluated the direct influence of Green Supply Chain Practices (GSCPs), JIT and Total Quality Management (TQM) on operational and business performance, which were positively influenced by the aforementioned criteria.

Using the Kanban system is a strategic operational decision to be applied to production lines. It contributes to increasing the company's productivity and, at the same time, reducing waste [8]. It is usually a printed form containing specific information with the identification of the part and its quantity. This methodology is one of the pillars of the JIT concept, allowing components to be replenished as they are consumed and, in this way, reducing the stock level and the space reserved for storing parts. Its application helps to maintain an organized flow of goods, materials and information throughout the production process [9]. Damij and Damij [10] applied the kanban methodology with a focus on determining the optimal relationship between replacement value, resource capacity and limits for work in progress to generate a sustainable workflow pace and minimize labor and people idleness. Weflen et al. [11], formulated an approach based on influence diagrams with the aim of estimating task delivery times for agile project management using Kanban in the software industry.

Standard Work (SW) is a tool that companies invest in to reduce production time and costs, and is essential to ensure a clear and safe work environment. With this approach to standardizing processes, defects in production can be avoided [12]. This standardization of processes and tasks throughout the production process defines the best practices to be taken into account by operators on an assembly line. The goal is to ensure that the work is carried out correctly, with the fewest possible errors. For this implementation, it is essential to apply the 5S and Visual Management methodologies. 5S is a Japanese tool that helps reduce times that do not add anything to the final product, guarantees increased production and improves its quality [13]. On the other hand, visual management is a concept that aims to create visual information in a coherent, timely and regular manner, with the aim of improving production processes and also optimizing all basic daily tasks [14].

In turn, Kaizen consists of implementing small changes to achieve a long-term objective, and thus ensure the continuous improvement of the organization, gradually and permanently. The main goal of this methodology is to increase the efficiency of the company, reducing costs and improving the quality of the service provided. To ensure the stability of the processes, it is necessary to implement some Kaizen tools to determine the causes of the problems, and then apply measures to reduce the inefficiencies of the organizational system [15]. For example, Berhe et al. [16] developed a framework and procedure for implementing Kaizen to be applied in industries to achieve long-term improvements in operational, innovation, business processes, performance-based and competitiveness. Implementation in 6 phases was required and resulted in significant improvement.

And, Value Stream Mapping (VSM) is a method used to approach production processes, thus creating a value stream from the supplier to the customer [17]. The objective is to have a flowchart for each type of product family, with information regarding its process and its material and information flows [18]. Ramani et al. [19], using value stream mapping, verified the improvement in productivity in a metal structure assembly project. The authors observed a substantial increase in productivity by reducing the project duration by 13 days. In turn, Ferreira et al. [20], combined VSM with hybrid simulation (HS) in the furniture and related products manufacturing sector in Quebec, Canada, to assist in the development of associated Industry 4.0 application scenarios.

2.2. Balancing Assembly Lines

The Assembly Line Balancing Problem (ALBP) is fundamentally concerned with assigning a set of assembly tasks to a minimum number of workstations, respecting precedence constraints and the cycle time. While the most basic formulation is the Simple Assembly Line Balancing Problem (SALBP), real-world industrial systems often involve more complex variants. These include the Mixed-Model ALBP (MMALBP), which handles multiple product types on the same line; the Multi-Manned ALBP (MMALBP), where multiple workers can be assigned to one station; and various formulations incorporating stochastic processing times or material restrictions.

There are some sources of line instability that can be controlled by minimizing unnecessary operator movements that, together with cycle time variation, negatively contribute to production line imbalance. Based on demand, the number of operators required to execute the final product can vary, increasing or decreasing in order to achieve the required production [15]. Balancing an assembly line consists of assigning assembly tasks to the various stations, following the sequence of operations. Minimizing the number of stations for a given cycle time will lead to increased line efficiency [21].

Balancing on lines where there is a wide variety of products requires the preliminary preparation of a line layout to ensure compliance with the desired cycle time. In this case, there are no individual lines for each model, that is, different models can be produced on a line. When balancing a mixed model line, the different characteristics of the assembly process and the different models cause problems, such as deviation in cycle time or task sequencing, problems that do not arise when dealing with a simple line that only produces a single model [21].

A concept commonly used to describe a set of analysis tools applied when beginning the process of evaluating the work performed by the operator is known as work study. This concept is broken down into the study of methods and the measurement of work (time study), and these two techniques are directly linked to each other. They work simultaneously, since, if the study of the feasibility of introducing new methods is carried out, it is essential to qualify them in terms of time saved. By measuring work, it is possible to identify times that do not add value to the final product, which can be eliminated by implementing new methods.

Therefore, in the context of assembly line balancing, variants pertain to the distribution of tasks among terminals, while maintaining constraints such as line cycle time and precedence relationships between tasks to prevent any station from being overloaded. In addition, the capacity of each workstation and the complexity of mixed lines, which involve the assembly of various products, may be considered as constraints. These lines necessitate mathematical models and heuristics for optimization.

The complexity of the ALBP problem has led to the development of various solution methodologies, which can broadly be categorized into three groups:

1. Exact Methods: These approaches (e.g., Branch and Bound, dynamic programming) guarantee the globally optimal solution but are computationally intensive and typically restricted to smaller problems.
2. Heuristics: These provide near-optimal solutions in a reasonable amount of time and are widely used for large-scale industrial problems. Popular examples include the Ranked Positional Weight (RPW) method and various task-oriented heuristics.
3. Metaheuristics: These advanced search techniques (e.g., Genetic Algorithms, Simulated Annealing, Ant Colony Optimization) are employed to tackle highly complex or non-linear variants of the ALBP, especially where finding the optimal solution is difficult.

2.3. OEE (Overall Equipment Effectiveness)

Overall Equipment Effectiveness is an index used to measure the performance of equipment [22]. Pereira et al. [23], focused their study on improving the productivity of an assembly line devoted to the manufacture of Bowden cables for the automotive industry, through the application of the A3 methodology. This resulted in a 49% increase in productivity and an 11% increase in the efficiency of assembly line balancing. In turn, Dias et al. [24], observed the optimization of a production line through line balancing, standardized work, visual management and 5S, resulting in a 22% increase in OEE. OEE specifies six sources of losses that impact equipment effectiveness [25]:

1. Machine failures/breakdowns;
2. Changes/adjustments/tuning;
3. Sudden stops/interruptions;
4. Reduced speed;
5. Defects/rework;
6. Start-up losses.

To understand the usefulness of OEE, it is important to perform an Equipment Time Analysis and take into account the impact of losses on total production time [9]. Haddad et al. [26], based on the single-minute exchange of dies (SMED) technique applied to extrusion line processes, reported an increase in OEE by 3.26%, as a consequence of increasing machine availability by 4.86%. Basak et al. [27], presented a framework to measure OEE within additive manufacturing (AM) operations, mapping the six production losses mentioned. On the other hand, Sunadi et al. [28] investigated the reason why the OEE in the company did not meet the expected standard, in one of the plastic manufacturing industries located in Tangerang, Indonesia. The authors applied Failure Mode and Effect Analysis (FMEA), Pareto's chart, Cause and Effect Diagram (CED) and six major losses, and obtained an increase in OEE from 26.43% to 78.87%. In turn, Vieira et al. [29], focused their investigation on increasing the availability of a deep drawing machine through the SMED technique, achieving a 7.7% improvement in OEE availability.

3. Research Methodology

There are many factors responsible for delaying the completion of products on the assembly line, which hinders the sequential development of work throughout the production process. Throughout the assembly process, tasks and processes used that do not add value to the product were observed, which directly influences the production flow and the entire sequence of necessary tasks. Problems were identified in advance, based on a thorough analysis of the entire process, so that it was possible to establish objectives and, in this way, achieve the expected improvements. The main problems identified at the workstations through-out the assembly process are described in Table 1.

Table 1. Problems identified in the Workplaces.

Problem	Consequence
Material	Poor control of supply and unnecessary operator travel
Space	Lack of organization in the stations and poorly managed space
Non-conformities	Rework, unnecessary tasks, and increased lead time
Standardization	Process variability, and quality control

3.1. Methodology

This study employed action research methodology, involving a sequential analysis of events and strategies through problem-solving, constituting research in action rather than research about the action. Martins et al. [30] assert that this methodology integrates academic knowledge with practical insights from the organization to enhance the production process and reduce losses. This methodology comprises five stages: Diagnosis; Action planning; Implementation; Evaluation; Monitoring. Table 2 delineates an overview of the action research cycle pertinent to this study, including the activities undertaken at each phase. In contrast to DMAIC, A3, and 8D, the Action Research methodology is a continuous and collaborative learning process that is employed to address intricate organizational issues. They are also frequently employed; however, they concentrate on resolving issues that are efficiency-oriented. Consequently, action research is research that is conducted in action, as opposed to research that is conducted about action.

Table 2. Summary of the action research methodology for this project.

Step	Action
Diagnosis	Data collection and analysis for problem diagnosis. An analysis was carried out of the factors responsible for delaying the timely completion of products on the assembly line, and which hinder the sequenced development of work throughout the production process. Thus, the equipment to be intervened was identified, considering the initial survey by timing, which is essential to analyze the critical points, their causes and their effects on the final production of each product.
Action Planning	Establish corrective actions by identifying necessary changes and the methods for implementation, taking into account the available resources. The answers derived from the analysis conducted during the Diagnosis phase are presented, and actions are delineated and scheduled.
Implementation	Actions are implemented according to the plans established in the preceding stage, taking into account all essential organizational members, as well as restrictions. Implement continuous improvement actions
Evaluation	Developing important metrics to evaluate performance, as the OEE.
Monitoring	Forcing consistency of the attained improvements which is crucial for realizing continual enhancement.

The main objective of this project was to balance the production line, aiming to improve the performance of a set of assembly lines. After the initial survey, it was essential to analyze the critical points, their causes and their effects on the final production of each product. Achieve continuous and leveled production, in order to reduce intermediate stocks and continuous improvement to optimize the production process. This complies with the first phase of the AR methodology.

The methodology applied was based on industrial rationalization, that is, at each stage of the production process the most effective method of carrying out the work was defined, in order to optimize existing human resources and improve the production flow. The configuration of the production line consisted of the entire process of dimensioning the line edge and supermarket, with the creation of new layouts for both, thus organizing the materials in the most appropriate places, and identifying all the shelves and structures that will serve as storage for the material necessary for the equipment assembly process.

In relation to the implementation of the kaizen philosophy, and based on the need to increase the efficiency of the production process, Daily Kaizen (KD) events were promoted, consisting of daily meetings held every morning to address quality problems, with a view to eliminating the associated causes. This constituted the second phase of the AR methodology. In addition, controls were created for visual management for each specific work area.

3.2. Assembly Line Implementation

This is the third phase of the AR methodology. The production line consisted of several workstations, whose positions were fixed and whose sequence was imposed by the logic of the successive operations to be carried out, based on their respective operating ranges. The load of the various operations was evenly distributed among the various stations, taking into account the sequence of tasks required to produce each product. Each station had idle time, since in practice it was not possible to achieve 100% efficiency. The company's production was subdivided into four production lines, adapted to the needs of each product (Figure 2):

Figure 2. Assembly Line Layout. • Line 1 (Trolleys, Monoblocs and Stretchers); • Line 2 (Chairs); • Line 3 (Tables, Ramps and Stirrups); • Line 4 (Platforms and Carts).

3.3. Balancing

In order to increase AR Equipment's productivity and, at the same time, reduce the production flow time of its equipment, the assembly lines were balanced. Initially, only the most produced and most sought-after equipment were addressed. To identify them, a study was carried out on the production history of previous years. With this, it was defined that the products were: M860 Stretcher; M860 Trolley; M760 Monobloc. Studies were then carried out on all the assembly tasks at each workstation, with the aim of balancing the lines correctly, taking into account the production needs.

A Mockup was carried out for each piece of equipment, where all the tasks required for the production of each piece of equipment were timed, arriving at a total production time called Mockup Acc. (accumulated time). At the same time, films were made of all the workstations, for later analysis of the various tasks, taking into account all the movements made by the operators. This way, it was possible to detect tasks that do not add value to the product.

Monitoring production time is crucial to optimizing the process and ensuring efficiency. OEE is one of the most comprehensive KPIs, as it measures the overall effectiveness of production equipment. It is calculated by multiplying three factors: Availability, Performance, and Quality, as shown in Equation (1).

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (1)$$

Availability (Equation (2)) is the proportion of time that the assembly line is operating in relation to the total time available.

$$\text{Availability} = \frac{\text{actual operating time}}{\text{planned production time}} \quad (2)$$

Performance (Equation (3)) is the actual production speed compared to the theoretical speed.

$$\text{Perfomance} = \frac{\text{Real production rate}}{\text{Ideal production rate}} \quad (3)$$

And quality (Equation (4)) is the proportion of good products in relation to the total number of products produced.

$$\text{Quality} = \frac{\text{Number of good units}}{\text{Total number of units}} \quad (4)$$

In turn, Throughput (Equation (5)) is a direct measure of the production rate of an assembly line.

$$\text{Throughput} = \frac{\text{Total number}}{\text{Time}} \quad (5)$$

WIP (Work in Progress) measures the amount of inventory that is in the production process at any given time (Equation (6)). It's not a rate, but a count. It's the inventory being processed between the start and end of the assembly line.

$$\text{WIP} = \text{Number of Unfinished Units} \quad (6)$$

Lead Time (Equation (7)) is the total time it takes for a unit to be produced, from the entry of the raw material to the output of the finished product.

$$\text{Lead time} = \text{Processing Time} + \text{Inspection Time} + \text{Movement Time} + \text{Waiting Time} \quad (7)$$

Balance loss (Equation (8)) measures the inefficiency caused by the difference in cycle times between workstations.

$$\text{Balancing loss} = \frac{\sum_{i=1}^{n}(\text{Ideal Cycle Time} - \text{Cycle Time}_\text{i})}{\text{Workstations} \times \text{Ideal Cycle Time}} \quad (8)$$

The rework rate (Equation (9)) measures the percentage of products that need to be repaired. A high rework rate indicates quality problems in production, which increases cycle time and cost.

$$\text{Rework rate} = \frac{\text{number of reworked units}}{\text{Total number of units}} \quad (9)$$

The problem of assigning assembly tasks to the minimum number of workstations while respecting the calculated cycle time (CT) was addressed using a heuristic approach. Specifically, the Ranked Positional Weight (RPW) method was employed due to its proven efficacy in achieving near-optimal solutions for Simple Assembly Line Balancing Problems (SALBP) with low computational overhead, making it suitable for practical industrial application. The RPW heuristic was implemented and solved iteratively using a computational environment based on Python (with optimization libraries) / Microsoft Excel Solver. The process operated under the following criteria (Table 3):

Table 3. Parameters and criteria used for the implementation of the Ranked Positional Weight (RPW) heuristic in balancing the assembly line.

Parameter/Criterion	Description
Cycle Time (CT)	Maximum allowable time per workstation.
Task Selection Rule	Tasks were prioritized for assignment based on their Positional Weight
Constraints	All precedence relationships and task times were strictly maintained.
Stopping Criterion	The algorithm ceased execution upon achieving the primary objective: minimizing the number of workstations.

4. Results and Discussion

4.1. M860 Trolley/Stretcher

The total processing times were distributed among the various stations for the M860 trolley/stretcher set. Tables 4 and 5 show the cycle times (TC), which is defined as the slowest of all the stations presented.

Table 4. Distribution of times between PTs—Stretcher M860.

Position	Time (hh:mm:ss)
1	00:13:55
2	00:13:59
3	00:13:45
4	00:13:20
5	00:13:40
6	00:14:00
7	00:14:00
8	00:14:30 TC
9	00:13:10
10	00:11:58
Total	02:16:17 = 136.28 min

Table 5. Distribution of times between PTs—Trolley M860.

Position	Time (hh:mm:ss)
1	00:20:21 TC
2	00:19:46
3	00:18:04
4	00:18:17
5	00:18:57
6	00:19:47
7	00:19:36
8	00:18:56
9	00:18:23
10	00:20:05
Total	03:12:12 = 180.2 min

The demand value was initially defined as 22 units per day. All downtime was deducted from the total time. This generated a takt time of 20.91 min. In addition, 7 workstations are required for the stretcher and 9 workstations for the trolley. The target cycle time (CT) (Equation (10)) for the new assembly line was calculated based on the required production rate. This value serves as the maximum allowable time for any single workstation.

$$\mathrm{CT} = \frac{\text{total operational time}}{\text{demand}} \tag{10}$$

4.2. Monoblock M760

Table 6 shows the distribution of processing times across the different workstations. The demand value was initially defined as 18 units per day. Which generates a takt time of 25.56 min and 14 workstations required.

Table 6. Distribution of times between PTs—Monoblock M760.

Position	Time (hh:mm:ss)
1	00:25:10
2	00:25:13
3	00:25:03
4	00:24:41
5	00:22:38
6	00:24:40
7	00:25:20 TC
8	00:25:14
9	00:25:05
10	00:22:23
Total	4:05:27 = 245.45 min

4.3. Productivity Indicator

To analyze the productivity indicator, the equivalent units method was used, as shown in Table 7.

Table 7. Production time and equivalent stretchers.

Equipment	Production Time (min)	Equivalent Stretchers
M860 Trolley	180.2	1.32
M860 Stretcher	136.28	1
M760 Monobloc	245.45	1.8

Based on the data relating to the average monthly production in equivalent stretchers on line 1 and the remaining lines, it was possible to arrive at a value for the initial state of the project. The project objective value was obtained, assuming a production increase of 33%. Figure 3 shows that in both weeks the objective value was reached and that production was always higher than the value defined as the project goal. This complies with the fourth phase of the AR methodology, monitoring.

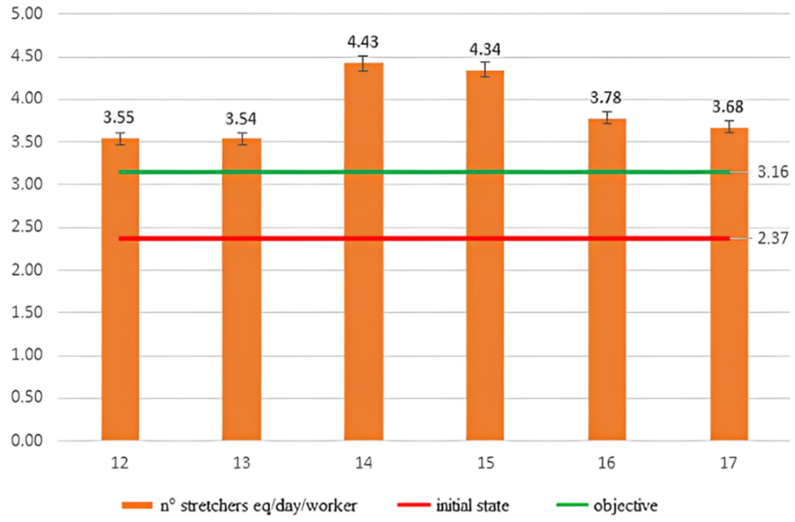

Figure 3. Initial State vs Project Objective Analysis.

4.4. Overall Equipment Effectiveness (OEE)

The OEE values were calculated for the three pieces of equipment under study in order to monitor the performance of the production process. To make this possible, it was necessary to analyze all production records and their stoppages. Table 8 presents the results.

Table 8. OEE for each equipment analyzed.

Parameter	M860 Trolley	M860 Stretcher	M760 Monobloc
Availability	89%	91%	75%
Performance	90%	85%	80%
Quality	95%	97%	95%
OEE	76%	75%	57%

After calculating the values, it can be seen that the Monobloc M760 equipment will need to be improved in the future. This corresponds to the fifth and last phase for the AR methodology. Since it is the equipment with the highest number of operations, the number of stops is more frequent, and this is reflected in a lower number with regard to Availability and Performance. Rosa et al. [31] demonstrated that OEE as a quantitative metric to enhance assembly line production resulted in a 43% increase in production rates and a 30% reduction in assembly line utilization. This improvement was achieved by eliminating non-value-adding tasks and minimizing waste related to equipment robustness and reliability, operator movements, task balance, and the definition and standardization of work methods. An additional study conducted by Rosa et al. [1], focused mainly on VSM analysis and desertification mitigation, resulted in a productivity gain of 41%. Consequently, it can be stated that the methodology followed, employed and implemented in this investigation resulted in obtaining consistent results regarding the optimization of production lines, with good results in OEE, with only Monobloc M760 being below expectations. However, there was an increase in production volume of 33%, which makes the methodology effective and viable, being only slightly below the studies cited.

4.5. Supply

Once the line balancing process was complete, the kanban tool was applied throughout the supply chain. The components were stored in boxes with standard dimensions, with only the large parts being stored in specific structures. All components were duly identified, with an article code and a fixed quantity per box. Supply was then managed by visually monitoring each empty box that was removed from the line edge and transported to the supermarket, where it was returned with the quantity defined on the kanban card (Figure 4). Minimizing movements that did not add value to the final product was just as important as reducing the movements of the operators responsible for supplying the production line. In this way, the quantity of each component to be supplied became fixed and immediate. The design of an effective Kanban system relies on a rigorous determination of the required number of cards, which dictates the maximum allowable stock level and ensures the line operates as a true pull-system. To achieve operational excellence and prevent both stockouts and excess inventory, the sizing procedure must be based on the established relationship between demand, lead time, and safety stock. The calculation of the Number of Kanban Cards (*N*) is central to the implementation methodology and is determined by the following well-known formula:

$$\mathrm{N} = \frac{\mathrm{D} \times \mathrm{L} \times (1 + \mathrm{S})}{\mathrm{C}} \quad (11)$$

where the variables are defined as follows:

N: Number of KANBAN cards (or containers).
D: Demand rate (units per time period).
L: Lead time/Replenishment time (time period).
S: Safety Stock factor (dimensionless, representing a percentage buffer).
C: Container capacity (units per container).

Applying this theoretical model to the assembly line for pre-hospital transport equipment required precise quantification of each parameter, derived from operational data and process mapping conducted on-site. The specific values used for the Kanban sizing are detailed below, ensuring the system is optimized for operational efficiency and robustness. The average daily Demand Rate (D) was established at 22 units/day, calculated from the historical three-month average production requirement, aligned with the operational planning. The Lead Time (L) was determined through value stream mapping, including internal ordering, processing, and transportation delays, resulting in a value of one week. Crucially, the Safety Stock factor (S) was set at 15% to mitigate supply chain and process variability, reducing the risk of stockouts to a management-acceptable level. Finally, the Container Capacity (C) was standardized at 20 units/container, balancing material handler ergonomics with the supplier’s packaging constraints. For high-value, bulky components, the Container Capacity (C) was constrained by safety and space limits, set at 5 units/container. Substituting these values into the Kanban formula yielded a requirement of 7 final cards for effective inventory control.

Production or movement of material is only authorized when a Kanban card is returned to the production or supply area, indicating consumption at the downstream station. In the event of a stockout, a supervisor contacts the supplier for an expedited delivery, but the system must not bypass the standard card circulation to prevent accumulation of excess inventory. Cards are always attached to containers, and the number of cards (N) remains fixed unless a formal review of demand or lead time dictates a resizing. This ensures that the system works as a pull-system.

(**a**) (**b**)

Figure 4. Kanban Card (a) and Kanban Card Application Example (b).

The implementation followed these steps:

- Material Mapping: All critical line components that would be managed by Kanban were identified, focusing on high-consumption items (such as screws, nuts, bushings, etc.).
- Defining Supply Zones: Parts supermarkets were created at workstations. Each item had two containers (bins).
- Creating Kanban Cards: Each container was labeled with a Kanban card containing essential information, such as the item code, description, and quantity.

The system works with the following Control Rules: The operator uses the first container (bin 1). When the first container is empty, the operator moves their Kanban card to a collection bin and begins using the second container (bin 2). The logistics team collects the cards from the bin and uses them to replenish stock. The reserve stock is replenished, and the first container is returned to the line.

4.6. Line Edge and Storage Area

To define the line edges, an in-depth study of all the necessary workstations was carried out, after the balancing of the assembly lines had been completed. To this end, the layout of the various line edges was defined, based on the sources of waste identified previously, with a view to eliminating unnecessary movements in the supply to the lines that do not add value to the final product. The boxes at each line edge and each station contain only the parts necessary for the tasks performed there and are subdivided into four standard types, based on the size and volume of the components:

- Type A box (200 × 150 × 120 mm^3);
- Type B box (300 × 200 × 120 mm^3);
- Type C box (400 × 300 × 120 mm^3);
- Type D box (600 × 400 × 120 mm^3).

Fixed quantities were defined for each box, which were small in order to minimize the stock on the lines. It was decided to place the line edges on both sides of the lines, thus minimizing the movements of the operator and those supplying them. The position of each box on the line edge was influenced by its weight and quantity requested, following the existing sequence of operations. New work benches were designed and built, with an area with sliding rails reserved for the return of empty boxes from the line edge. Figure 5 illustrates how the organization was achieved.

Figure 5. Trolleys/Monoblocks/Stretchers Line.

After creating the line edges and defining the boxes to be used, it became essential to create a storage area that would facilitate the work of the operator responsible for supplying the lines. And, similarly to what was done on the line edges, all shelves and boxes were identified with a code. Similar to what was developed on the line edge, the identifications contain information regarding the position of the box on each shelf, the number of pieces with which each box must be replenished on the line edge and its location. With this implementation, it is possible to ensure that the FIFO (First-in First-out) system is complied with in the supply and the operator has optimal visual management of all existing boxes.

4.7. Standard Work

To begin the creation of standard operations, a standardized sequence of operations required to produce each item was defined. The wide variety of manufacturing operations and the lack of a detailed sequence of work procedures meant that it was not possible to improve the efficiency of the line. Therefore, and together with the operators, documents were drawn up with images representing the work instructions for the various assembly phases, also including references to the components required for each operation.

The development of these standard work documents, with work instructions, aims to simplify the understanding of all the tasks throughout the production process and, in this way, help operators in carrying out all tasks, with a particular emphasis on the provision of visual information (photographs). To make this possible, it was essential to apply Poka Yoke devices to detect errors at the exact moment of the operation being carried out. As used herein, Antoniolli et al. [32], primarily utilizing standard work tools, facilitated a 16% enhancement in OEE. This shows the importance of using management tools to improve business productivity.

5. Conclusions

This work involved an approach based on operational excellence by balancing the assembly line and organizing and distributing tasks. The following conclusions could be drawn:

- Action-Research methodology was successfully applied to this case and it was effective in solving the identified problems.
- Opportunities for improvement were identified to eliminate waste and reduce stock levels. Standardizing processes and focusing on training operators proved to be essential for improving the company's production capacity.
- Various tools and techniques were used to evaluate and optimize processes, which helped in analyzing the initial situation.
- Balancing line 1, as well as the others, helped reduce the total cycle time of the process and increase the production levels of the operators.
- The kanban tool helped create a continuous flow of work on the assembly line and improve the company's internal logistics, making the process more efficient and effective.
- The solution presented for the lack of balancing in the global production line and the implementation of continuous improvements in its process, provided better visual management in the various areas of the line.

It is important to acknowledge the inherent limitations of this applied industrial study, which focused on the practical implementation of operational excellence principles. Firstly, regarding data constraints, the initial Assembly Line Balancing Problem (ALBP) solution was highly reliant on estimated and standard task times. Similarly, the Kanban utilized historical demand data for a previous facility setup, introducing inherent uncertainty regarding future demand variability. Secondly, concerning external validity, the optimized line configuration and the specific Kanban parameters (e.g., container size and safety stock) are highly specific to the physical dimensions and assembly sequence of the pre-hospital transport equipment. Therefore, the results represent a successful internal validation for this specific product and facility layout, but their direct external generalization to different product lines or industries may be limited. Finally, we recognize potential biases in the data collection phase. A potential observer bias may exist in the measurement of task times, as the workers were aware of the time study. Furthermore, the selection of the safety stock factor (S) and the lead time (L) for the Kanban calculation was influenced by management's risk tolerance and established vendor relationships, which represents a selection bias based on non-optimization criteria.

In short, it is concluded that the objectives of this work were achieved and, therefore, the implemented modifications were successful and the applied tools proved to be quite beneficial for the optimization of the entire production process. The increase in production volume of 33% is visible through the analysis of the productivity indicator, having exceeded the value predefined as the project objective. For future work, it is suggested to carry out a study in relation to the economic impact of the project, as well as to apply the methodology to other areas of the company.

Author Contributions

N.P.V.S. and A.J.V.: conceptualization; A.J.V., J.C.V.S. and A.B.: methodology; N.P.V.S., M.T.P. and A.B.: data curation, visualization; I.M.P.: writing—original draft preparation; N.P.V.S.: investigation; A.J.V.: supervision; A.B.: validation; A.J.V. and J.C.V.S.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Funding

The work is developed under the "DRIVOLUTION—Transition to the factory of the future", with the reference DRIVOLUTION C644913740-00000022 research project, supported by European Structural and Investments Funds with the "Portugal2020" program scope.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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