Internal Logistics Process Improvement using PDCA: A Case Study in the Automotive Sector

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Abstract

Background: The Plan-do-check-act (PDCA) cycle methodology for a continuous improvement project implementation aims for the internal logistics upgrade, which is especially important in the industrial context of a component manufacturing company for the automotive sector. **Objectives:** The goal is to quantify the gains from waste reduction based on the usage of the PDCA cycle as a tool in the implementation and optimisation of a milk run in an assembly line of a company in the automotive sector by determining the optimal cycle time of supply and the standardisation of the logistic supply process and the materials' flow. **Methods/Approach:** The research was conducted through observation and data collection in loco, involving two main phases: planning and implementation. According to the phases of the PDCA cycle, the process was analysed, and tools such as the SIPOC matrix, process stratification, 5S, and visual management were implemented. **Results:** Using Lean tools, it was possible to reduce waste by establishing concise flows and defining a supply pattern, which resulted in a reduction of movements. The transportation waste was reduced by fixing the position of more than half of the materials in the logistic trailers. The developed Excel simulator provided the logistic train's optimal cycle time. **Conclusions:** The assembly line supplied by milk-run was fundamental to highlight a range of improvements in the process of internal supply, such as better integration of stock management systems, greater application of quality, or the adoption of better communication systems between the different areas and employees.

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Introduction

Developed between 1940 and 1950, Lean quickly became a strong and dominant management reference in the industrial context (Garza-Reyes et al., 2018). It represents a philosophy focusing on value creation by employing continuous improvement tools and waste elimination (non-added value) of the production system along the supply chain (Boateng, 2019). Lean practices allow the continuous flow of a company's processes in an integrated way, contributing to its higher performance. The concept of Lean reflects the idea of 'creating more with less, enabling cost reduction, increased quality, and improved delivery times (Abreu et al., 2017).

Lean thinking is associated with the Toyota Production System (TPS). The automotive industry was a pioneer in applying this system, which originated in Japan, at the Toyota car plant, just after the Second World War. At that time, the Japanese industry had very low productivity and a considerable lack of labour, which prevented the adoption of the mass-production model (Chiarini et al., 2018; Ohno, 1988). The goal is to make it right the first time, seek effectiveness in the production process, use the minimum necessary resources, reduce lead times, improve productivity and meet the customer requirements (Santos et al., 2015). Since value creation requires pressure on processes over time, the quality of services and products is a derivative of the quality of processes.

In contrast, improvement cannot be regarded as a one-time project. Thus, systematic attempts to seek opportunities to eliminate defects' causes and use new ways to conduct and introduce changes actively must be preconised (Brajer-Marczak, 2014). The Lean approach focuses on reducing or eliminating waste, mainly overproduction, overprocessing, transport, movements, waiting, defects, and stock, which leads to product quality and productivity improvement (Oliveira et al., 2019). This methodology is supported by theoretical and empirical evidence from increasing the competitiveness of organisations through the application of tools such as Kaizen, Kanban, 5 S methodology, Poka-Yoke and Andon systems, visual management tools, value stream mapping, supply flow balancing of parts and products, and many others (Bragança et al., 2013; Garza-Reyes et al., 2018; Puchkova et al., 2016; Randhawa & Ahuja, 2017; Veres et al., 2018).

In the manufacturing environment, internal logistics is essentially responsible for the operations that affect the performance of assembly lines (Alnahhal et al., 2014) and guarantee efficient material flow (Goldsby & García-Dastugue, 2003). This requires important decisions due to the need to predict what, how much, by whom, where, when, and how to transport the materials, considering the supply and demand requirements (Kluska & Pawlewski, 2018).

Several logistic solutions can be implemented to ensure the internal supply of materials in factories. The Milk-run system is a profitable management strategy that uses a logistic vehicle (or logistic train) to meet supply demands in a supply chain. It is a solution commonly used in production systems due to its successful results in providing waste reduction and transport efficiency (Kluska & Pawlewski, 2018; Nemoto et al., 2010). It's a relatively easy and cost-effective solution to minimise the covered distances between the storage locations and the workstations (Gyulai et al., 2013). When these vehicles' capacity is maximised, their application's advantages directly contribute to implementing one-piece flow production systems (Gotthardt et al., 2019; Kluska et al., 2018).

For its implementation, it is required to study the supply process, defined by the production cycle time and materials management. It is necessary to determine how often and in what quantity is necessary to transport the materials from the warehouse (or a storage place, e.g., an intermediate supermarket) to a different point in a factory, attending the routes that provide consumable items in time to production.

Following the idea that only consumed materials can be replaced, the principal goal of the milk-run process is to make materials flow faster through the production area, making deliveries in different locations within the same route and the same service period. Thus, milk-run systems are aligned with implementing Lean tools, contributing to reducing the seven wastes, mainly in transport, waiting for time, and stocks (Ivanov et al., 2018; Vicente et al., 2016).

There are several methodologies that, when implemented in an integrated way, lead to increased performance outcomes. One of those methodologies is the Plan-do-check-act (PDCA) cycle. Developed by Edwards Deming in the 1950s, the PDCA cycle is a quality tool, especially useful for promoting continuous improvement (Isniah et al., 2020). It has been used to improve production systems and work management applications and to enhance business organisation. It has also offered the steps as drivers of continuous improvements and the key to a learning culture (Lerche et al., 2020).

Four steps define the method - *Plan*, *Do Check,* and *Action*. In the *Plan* phase, the improvement opportunities are identified and then prioritised. Also, the goals are established, and the processes to achieve specific results are planned (Isniah et al., 2020; Realyvásquez-Vargas et al., 2018). In the second phase (*Do*), the action plan previously developed is implemented, putting in action all the data collection, measurement techniques, and tools for data analysis. Afterwards, all the results are analysed (*Check*) through a before-and-after comparison to verify the achieved gains. The last step is the *Action* stage, where the plan is created to improve and standardise the achieved results (Isniah et al., 2020; Realyvásquez-Vargas et al., 2018).

According to Jagusiak-Kocik (2017), the PDCA cycle is a very adaptable methodology. It can be successfully used In continuous improvement processes, during the implementation of changes and innovative solutions, or even during a process improvement review. Mantay de Paula & Feroni (2021) applied the PDCA cycle and a milk-run system in a reverse logistics project in the food industry sector. According to the authors, the PDCA methodology reduced the customers' dissatisfaction with reverse logistics processes, facilitating the identification of the problem's root causes. The study describes the milk-run system efficiency as a solution in the goods returning process. The application of PDCA methodology and the milk run conduced to a faster process with increased levels of customer satisfaction since the product reuse rates and reverse costs of freight were optimised (De Paula & Feroni, 2021). In the automotive sector, for example, Rahim *et al.* (2016) used the PDCA cycle to improve the quality of the electrodeposition painting process, to reduce operating costs and lead time. By applying the PDCA cycle, the authors identified the most frequent defects and the implemented tools to improve the method quality. The cycle time was reduced by reducing the duration of a few work processes, resulting in less than 33% of direct person-hours and less than 50% in material consumption and consequent cost savings (Rahim et al., 2016). PDCA methodology is usually applied with the resort to visual management practices, 5S methodology, standard work, checklists application, and Six Sigma tools. With this approach, supplier–input–process–output–customer (SIPOC) matrices and control charts can be generated for further analysis (Oliveira et al., 2019; Realyvásquez-Vargas et al., 2018; Uluskan, 2019).

The PDCA cycle has proven efficient in many industrial processes (Aichouni et al., 2021). This allows structuring the problem in several steps, making it possible to analyse the root causes of the problem in more detail and create corrective measures to mitigate them.

In the literature, several processes are used to study the PDCA cycle with the continuous improvement process. These case studies are reported in a wide range of industrial areas. Antunes Junior & Broday (2019) applied the PDCA cycle in a food company in southern Brazil to solve the problem of excessive waste of sauce used in frozen meals. It was possible to reduce waste by 86.75% by implementing improvements in the operation and sauce dispensing equipment.

The PDCA was applied in a company's case study that assembles a set of keys, locks, and handles (Malega et al., 2021). The authors introduced measures to correct the long-term problems and made changes to individual and production control documents. Through the statistical analysis, the authors confirmed the effectiveness of the continuous improvement processes implemented in the first month. Milosevic et al. (2021) implemented the PDCA cycle with Lean tools to ensure the sustainability of the production process of welded excavator frames. The authors refer that the process had a significant performance improvement (10.67%).

Due to a growing demand for electronic components, a manufacturing company in Mexico began to detect defects in the electronic board welding process (Realyvásquez-Vargas et al., 2018). The PDCA cycle was applied to three double production lines of the boards, where defects decreased by 65%, 79%, and 77%.

The case study presented in this article represents the need to improve an internal process within the company, so it cannot be directly compared with other cases in the literature. However, similar to this case study, the studies above highlight the positive aspects of applying the PDCA cycle and using continuous improvement tools. This way, it is possible to normalise work processes, minimise waste that does not add value to the product, and allow for more efficient and healthy production workflow management.

The main purpose of this paper is to explore the use of the PDCA cycle as a tool in the implementation and optimisation of a milk run in the assembly line of a company in the automobile sector by determining the optimal cycle time of supply and the standardisation of the logistic supply process and the materials' flow. Also, it aims to demonstrate that Lean and Logistics can contribute to improving the internal supply process with simple and cost-effective approaches. The present research is in line with the work reported in the referred literature: applying continuous improvement tools to an industrial context, aiming to reduce cycle times and minimise labour and resource wastes. In addition to the PDCA approach, this paper is focused on applying current tools such as the SIPOC, milk-run systems, and simulators to identify the material needs in industry 4.0. Therefore, this paper falls within the field of applied research. Despite the particular context of the paper application, the study provides an important scientific contribution since the methodology and the developed simulator can be easily adapted to other assembly lines, not only in the electronic components production for the automotive sector.

The paper was organised into six sections. After the introduction, section two describes the methodology framework, and section three characterises the case study. The Lean logistics tools implemented in the project were described in section four, mainly milk-run, Kanban, and visual management. The results validation and main conclusions are presented in sections five and six.

Research Methodology: PDCA

This study is classified as a case study and developed through observation and data collection in loco (Saunders et al., 2007). The continuous improvement project was developed within a company dedicated to producing electromechanical components for vehicles.

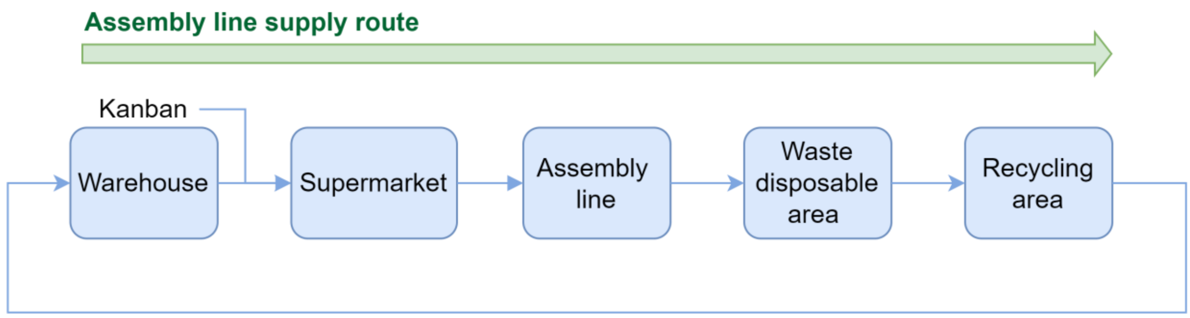
PDCA cycle was used as the reference method for the continuous improvement project implementation, which included different Lean tools: SIPOC matrix, Chart Control, 5S, and Visual Management. Thus, the wastes from the materials' flow of the assembly line were effectively identified and measured to formulate and undertake suitable methods to optimise the supply strategy.

In the Plan phase, the assembly line was selected as the study object (called from now on line Y), and the supply processes were assessed to identify improvement opportunities. The main problem was the lack of an adjusted cycle time for the internal supply process of the line. Thus, strategies were defined for the optimisation of the milk-run process. In the second stage, phase Do, the data needed to estimate the optimal cycle time were collected, and the defined strategies were developed to improve the milk-run supply process. In the Check phase, the milk-run supply process was again analysed to confirm and evaluate the results obtained by implementing the previous phase's improvements. To validate the implementations, a brief satisfaction survey was developed to evaluate the impact of the changes from the operators' perspective and the assembly line productivity. In the last PDCA stage, the Act phase, an action plan was created to maintain the obtained results regarding the continuous improvement of the supply process for assembly line Y.

Case Study Description

The case study was carried out for seven months, focusing on analysing the company's internal supply process (Figure 1). The company uses a milk-run system for the internal supply to deliver different materials in small batches from a central warehouse to the assembly lines, with standard routes and predetermined cycle times.

Figure 1
Milk-run supply process circuit



Source: Authors' work

The assembly line supply process occurs continuously during the three 8 hours shifts. The logistic operators are responsible for supplying the train and the assembly lines, ensuring that the required components are provided following the production orders. Material management is attained through a Kanban system between the warehouse and the supermarket.

Only the materials that have been consumed are replaced. This enables higher vehicle loading rates, low inventory levels, and delivery accuracy, maximising the efficiency of manufacturing continuous flow.

The logistic train is also responsible for properly collecting and disposing of wastes from the assembly line and forwarding reusable materials to the recycling area. Thus, the milk-run system is simultaneously used to supply the assembly line and, in the reverse logistic processes, transport materials, such as plastic boxes and other packaging items, as well as reusable materials that have an internal flow (e.g., injected plastic parts trays). Despite the well-defined logistic train route and the use of the supply vehicle, a detailed analysis of the line Y supply process showed discrepancies between the theoretical and effective cycle time.

Implementation of Continuous Improvement Tools

Different Lean tools were applied during the project development, according to the PDCA cycle steps and considering a continuous improvement approach.

Milk-run supply process optimisation

The strategy was to effectively identify improvement opportunities for optimising the milk-run process. To do so, a SIPOC matrix was developed. As shown in Table 1, two main improvement opportunities were identified: (1) the methodology to supply the logistic train and the assembly line; and (2) the management of both waste and reusable materials.

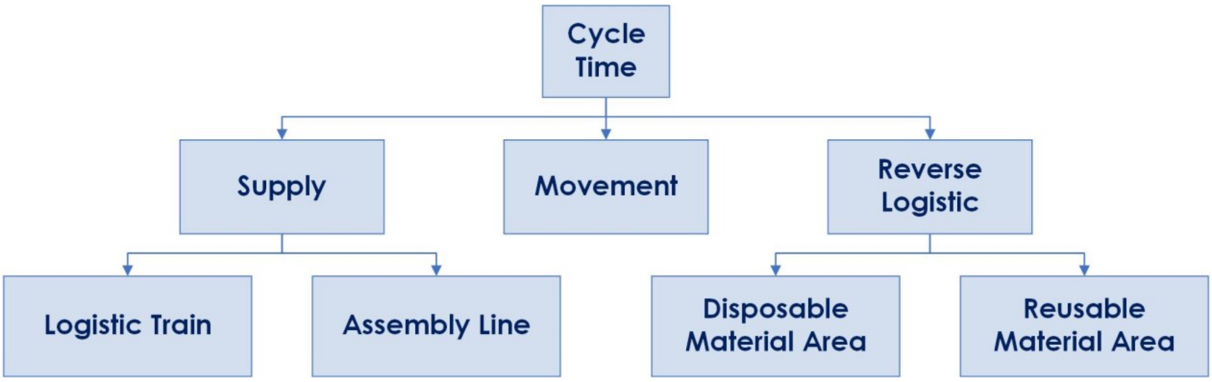
Table 1
SIPOC matrix to identify improvement opportunities

Suppliers	Inputs	Process	Outputs	Customers
Supermarket	Materials to transport	Supply the logistic train with material	Stocked logistic train	Logistic train
Logistic train	Availability of materials to the assembly line	Supply the assembly line	Stocked assembly line	Assembly line
Assembly line	Residual materials and reusable materials	Supply the logistic train with residual and reusable materials	Logistics train loaded with residual and reusable materials	Logistic train
Logistic train	Residual materials and reusable materials	Discard residual materials and return reusable materials	Discarded waste materials and returned reusables	Availability of waste and reusable materials

Source: Authors' work

To determine the optimal cycle time for the milk run, it was decided to stratify the process by dividing the cycle time into supply activities, reverse logistic activities, and movements (Figure 2). The assembly line operations' data were collected using a Radio-Frequency Identification (RFID) controller. Data collection was based on a sample of 30 observations, randomly performed during the morning and afternoon shifts.

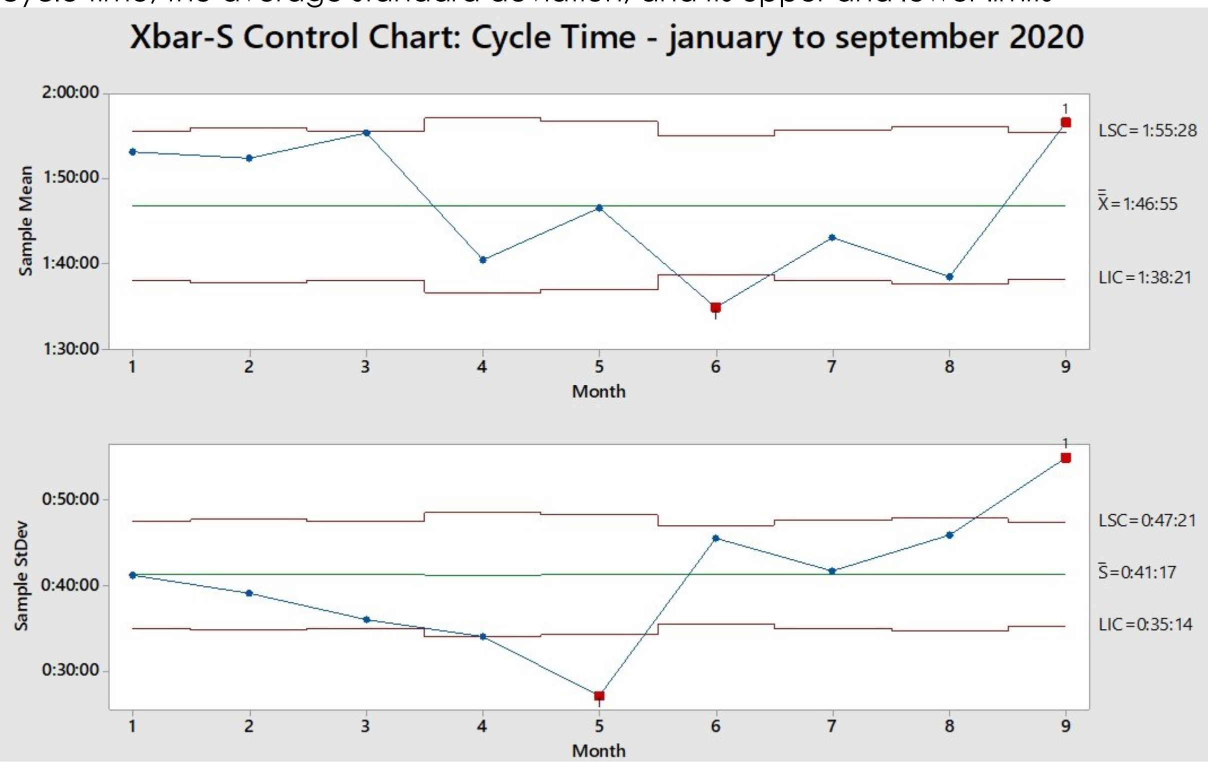
Figure 2
Stratification of cycle time in the milk-run supply process



Source: Authors' work

With the collected data, a control chart was prepared (Figure 3) to compare the monthly average cycle times with the theoretical value predetermined by the company managers, a cycle time of 1 hour. The control chart was developed with the historical data from the nine previous months, providing insight into the instability of the milk-run process. There is a discrepancy of 76.7% between the theoretical cycle time (1 hour) and the average calculated value, which corresponds to approximately 1 hour and 47 minutes. This assessment reflects the complexity of the assembling process and the urgent need to study the supply method because different products require managing between 40 to 70 different materials per cycle.

Figure 3
Control chart of the milk-run process before improvements, considering the average cycle time, the average standard deviation, and its upper and lower limits



Source: Authors' work

It was also necessary to perform a motion study analysis based on the movement diagram of the assembly line to identify possible wastes during the supply process. With this data, a simulator in MS Excel was developed (Figure 4). This simulator considered the assembly line settings, specifying the batches of materials transported by logistic train at each cycle. To do so, several steps were taken into account:

1) Separate materials that are supplied in bags but must be supplied in tubes or carton boxes on the logistic train and assembly line;
2) Sum of all the different materials quantities that are supplied per cycle by the logistic train;
3) Calculate the time for milk run and assembly line replenishment, indicating the daily average restocking activity time.

From the simulation program and the defined cycle time, a new work pattern could be determined according to the line needs, promoting process normalisation and movement waste reduction. In addition, labels were developed to identify packaging materials, respecting the quantities necessary for the assembly line to minimise reverse logistics flows.

Figure 4
Representation of MS Excel simulator interface for 10 of the 24 simulated cycles for the logistic train

Logistic Train:		Cycles										Average
		1	2	3	4	5	6	7	8	9	10	
Tube / Bag / Roll		10	4	11	14	3	11	11	13	0	12	9
Plastic Box (1) / Plastic Box (2)		1	7	2	2	3	5	2	4	1	5	4
Plastic Box (3)		3	3	2	5	3	3	4	3	2	5	4
Carton Box ESD (1)		4	5	3	4	4	5	3	5	5	4	5
Carton Box ESD (2)		1	0	1	0	1	0	1	0	1	0	1
Batch / Blister (2)		6	8	5	5	7	7	4	6	7	7	7
Tray (1) / Blister (1)		35	34	35	34	35	35	34	35	35	34	35
Blister PCB		31	30	31	30	32	29	31	30	32	29	31
Bag	00:24	04:01	01:36	04:25	05:37	01:12	04:25	04:25	05:13	00:00	04:49	03:34
Plastic Box (1)	00:14	00:14	01:42	00:29	00:29	00:43	01:13	00:29	00:58	00:14	01:13	00:46
Plastic Box (3)	00:26	01:20	01:20	00:53	02:14	01:20	01:20	01:47	01:20	00:53	02:14	01:28
Carton Box ESD (1)	00:25	01:40	02:05	01:15	01:40	01:40	02:05	01:15	02:05	02:05	01:40	01:45
Carton Box ESD (2)	00:25	00:25	00:00	00:25	00:00	00:25	00:00	00:25	00:00	00:25	00:00	00:12
Blister (2)	00:17	01:43	02:18	01:26	01:26	02:00	02:00	01:09	01:43	02:00	02:00	01:46
Blister (1)	00:03	02:14	02:11	02:14	02:11	02:14	02:14	02:11	02:14	02:14	02:11	02:13
Blister PCB	00:10	05:10	05:00	05:10	05:00	05:20	04:50	05:10	05:00	05:20	04:50	05:05
Time to supply - Logistic Train		16:49	16:13	16:19	18:38	14:57	18:09	16:52	18:35	13:14	18:58	16:52
Movement		6:19	6:19	6:19	6:19	6:19	6:19	6:19	6:19	6:19	6:19	6:19
TOTAL:		**23:09**	**22:32**	**22:38**	**24:57**	**21:16**	**24:28**	**23:11**	**24:55**	**19:33**	**25:17**	**23:12**

Source: Authors' work

Visual management

Visual management and 5S methodology were applied to the assembly line and the logistic train to guarantee process standardisation.

On the assembly line, the excess material that contributed to waste was removed through the implementation of 5S. When implementing this methodology, the maximum batch quantities of materials can be estimated by considering the requirements of each workstation. Also, different positions were defined for support material in the assembly line.

In the logistic trailers, the 5S was implemented to facilitate visual management and vehicle restocking, resulting in a more agile shift change, reducing wastes of overproduction, transport, movements, and the stock itself.

The most used materials in the production line and the necessary quantities per supply cycle were then allocated in fixed positions for those most frequently used. The materials allocation in the milk-run trailers and the different fixed positions were validated with the operators, so the last trailer could always be available for transporting disposable and reusable materials. Considering the new specifications of the line supply process, the operators received specific training to absorb the new procedures and practices to meet the expected cycle time. The new procedures were properly documented to instigate standardisation.

Results and Discussion

The development of this project brought direct contributions to the company. The results from the line supply cycle standardisation, implementation of 5S, and visual management tools are presented.

Milk-run supply process optimisation

First, developing a simulation tool to define the cycle time for milk-run supply processes allowed us to determine the optimal cycle time of 1h10min for supplying the assembly line Y. The tool was based on the assembly line configurations, identifying which parts and the respective quantities the milk run should transport per cycle. Thus, the time cycle considered the average time spent on the assembly line supply, waste disposal, and recycling tray filling. The picking time for all materials was also included.

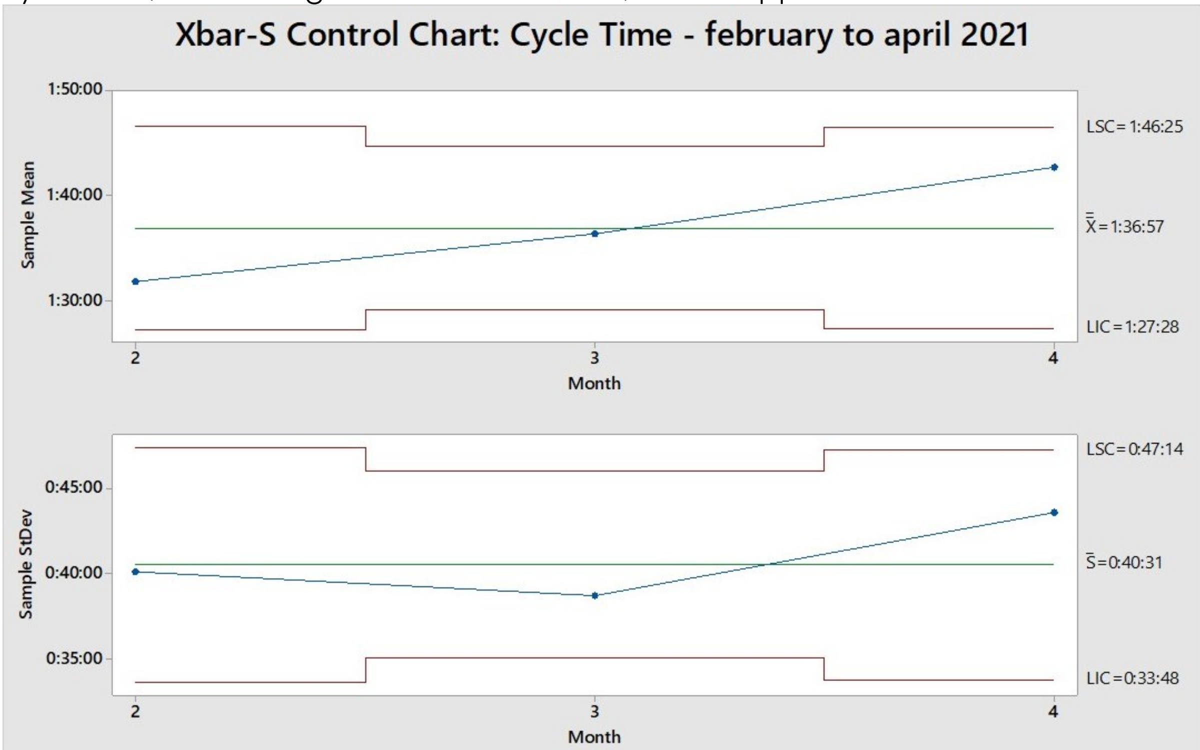
The standardisation of the supply process and the development of documentation for operators' training have represented a reduction of 9%, on average, of the cycle time practised by the milk run (new average calculated value of 1 hour and 37 minutes). This result can be observed by comparing the control chart of Figure 5 for the milk-run process after the continuous improvement tools implementation with the one presented in Figure 3. The control chart was developed with the data collected three months after the improvement tools implementation. Results showed that reducing the cycle time and keeping the average standard deviation within the lower and upper limits is possible.

In this study implementation, it was observed that there were differences in the time of carrying out the supply activities between the different work shifts. Generally, the morning shift had longer cycle times when compared to the afternoon shift. On average, the cycle time of the morning shift was 5.6% higher than the afternoon shift time cycle.

The activities where there is a greater discrepancy are: supplying the train according to Kanban, line supplying at stop 1 (P1), and line supplying at stop 3 (P3). To overcome these differences, training was prepared for the line supply employees of both shifts to standardise the internal logistic process.

Some critical points were raised during the new work plans implementation. One of them is related to production plan change since such change can cause variable supply time cycles and consequent lack of available materials. In addition, without an effective exchange of information between the production planning and the logistic sectors, the production orders may not be concluded.

Figure 5
Control chart of the milk-run process after improvements, considering the average cycle time, the average standard deviation, and its upper and lower limits



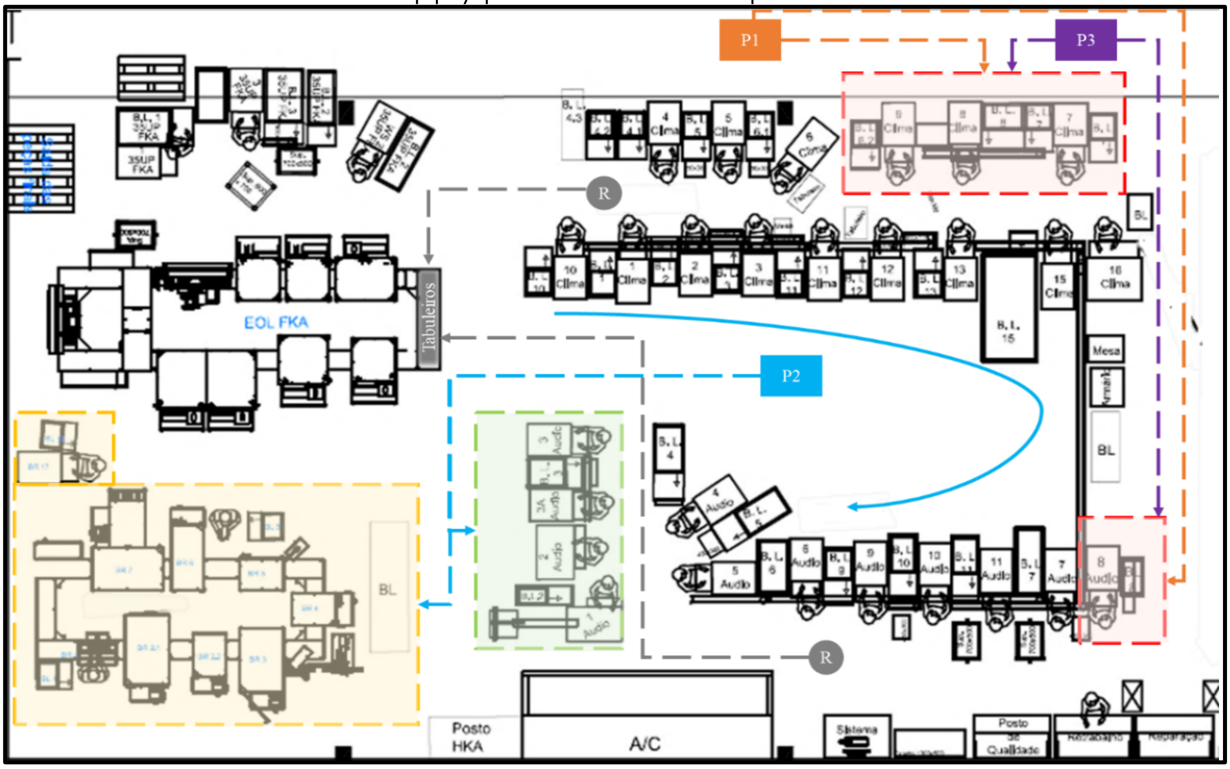
Source: Authors' work

To ensure adequate working conditions for logistics train operators, it was defined that the exchange of references must be communicated to logistic workers at least one hour in advance, giving them time to complete the current logistic cycle and prepare to fully meet the needs of the line when it starts to produce another product reference. After defining the cycle time, a fixed route for the milk run was proposed according to the assembly line needs. The fixed route proposal also aimed the movement reduction.

The supply route was defined considering the optimisation of materials flow and using tags and Kanban cards for visual management. The proposed route includes three stops (Figure 6) because some workstations require two supplies per cycle. At the first (P1) and third stops (P3), the operator must supply the line, picking and returning electronic boards whenever necessary. During the second stop (P2), the operator must proceed with the trays recycling and return to replenish the line that presents such a need. The picking of electronic boards and other parts must be carried out whenever necessary. The maximum quantities to directly fill up the supply bays were delimited.

It was verified a reduction of transportation and stock waste, mostly due to the enhanced visual management provided by new guidelines for managing materials in the milk run. Also, the excess material that contributed to extra processing, unnecessary movements, and transportation was removed from the supply area.

Figure 6
Fixed route for the milk-run supply process on the shop floor

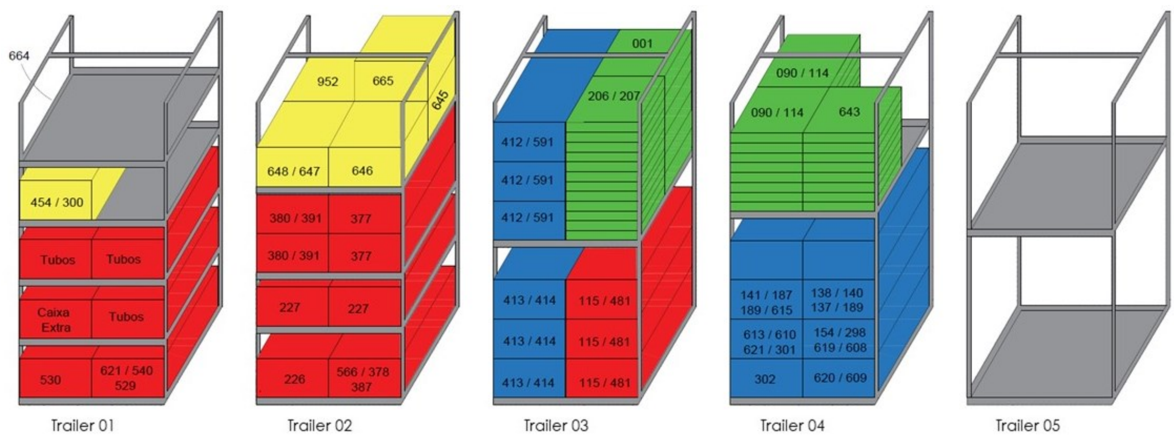


Source: Authors' work

Visual management

As can be observed in Figure 7, the employment of fixed storage positions allowed the release of storage capacity for trailer five. Assuring a maximum occupancy of 80% of the milk run, materials in the logistic trailers represent 68%, and remaining space for the waste transport (12%), thus reducing the movement and transport on the factory floor. The colour coding establishes the different dimensions of the boxes in which different materials are placed. The free spaces of the milk run are intended for materials that are not frequently used, and the last trailer is reserved for the collection of waste produced on the line and for materials of reverse logistics flows.

Figure 7
Fixed positions on milk-run



Source: Authors' work

In the assembly line, the application of 5S resulted in the reduction of stock waste by eliminating 2 856 parts in intermediate stock, which corresponded to 9 220 € savings and a gain of 1.92m^2 in the available supply area, as well as improvements in the visual management level and other packing materials. The comparison between the initial state and the state after implementing these visual management tools can be seen in Figure 8.

Figure 8
Comparison between the initial state (a) and after (b) the implementation of visual management tools to the logistic train

(a) (b)

Source: Authors' work

It was also estimated a reduction in terms of wasted movements on the production floor, which corresponded to a decrease of about 24%. In addition to the consequent improvement in productivity, this outcome had implications for minimising the impacts of excessive movements on the operator's health.

To guarantee the organisation and maintenance of the established supply procedures, through the reduction of the time cycle, the weekly control of the process via RFID was defined, as well as the implementation of regular audits of the line and logistic train.

Discussion and Final Considerations

Lean and quality tools allow a broader view of internal logistics by applying simple, economical, and efficient solutions to improve the process, generating direct and indirect gains for the company.

The objective of the current research was to optimise a milk-run supply system from one of the assembly lines of an automotive sector company by implementing the PDCA methodology. In this sense, an optimal time for the supply cycle was determined, and the internal logistics process was standardised. The different phases of the PDCA approach were used to implement the materials flow and provide better project management. The goals of this study were achieved after collecting data in loco, analysing the supply process, combining quality tools with Lean tools, and following the project according to the phases: Plan, Do, Check, and Action.

A simulator was developed to determine the optimal cycle time for the assembly line supply process, and the ideal time for the milk-run cycle was calculated as 1h10min. Integrating the simulation in MS Excel, 5S, and the visual management was decisive for the good results obtained in the milk-run supply process. With the implementation of 5S and visual management, it was possible to reduce waste, optimise materials supply and adjust the reverse logistics within the company by defining a fixed position for the materials and a fixed route for the milk run.

Implementing new supply rules reduced wasted movements, freed up the storage area capacity, and avoided unnecessary intermediate stocks. This better organisation, both in the assembly line and in the logistics train, resulted in a total occupancy rate of 80% in the production area and less movement of the operators. At managerial levels, the PDCA cycle for continuous improvement reinforced the benefits of staying on the factory floor, teamwork, and a good relationship between managers and employees. These aspects significantly contributed to the project's success and the full internal logistics chain's development, with positive impacts outside the assembly line. These results agree with (Garza-Reyes et al., 2018; Gyulai et al., 2013). Both works used prototypes and software to solve the milk-run planning problem considering real-life industrial data and obtaining the reduction of cycle times.

In addition to the direct gains, the project made it possible to demonstrate the potential of using Lean Logistics methodologies, showing improvements in working conditions, standardising internal processes, and creating procedures or work instructions within the company.

For the automotive company, the study represented a learning mechanism that generated know-how for future projects in the company's internal supply processes. The assembly line supplied by milk-run was fundamental to highlight a range of possible improvements in the process of internal supply, such as better integration of stock management systems, greater application of quality, or the adoption of better communication systems between the different areas and employees.

Due to the size of the company under study and the quantity and complexity of the production lines, it was necessary to focus the research work on a single line that presents several points of similarity with the other production lines of the company. This can be considered a limitation of the work since (at the moment) the developed simulator only works for the line mentioned in the case study. However, adopting this simulator to other lines is relatively easy, having to parameterised the characteristics that are variable between different lines of production.

As a future work, and to overcome these limitations, it would be interesting to adapt the simulator to all production lines, carrying out a quantitative study that would allow an economic evaluation of the milk-run implementation in the global context of the company's production lines. Through a preliminary theoretical analysis, it is predicted that the impact will be even more significant. It is also suggested to implement studies that aim to extend the use of logistic trains so that tasks such as the internal supply of packaging for final products (activity until then performed by line assistants) might be covered by the improved supply chain methods.

Finally, ensuring the continuous analysis of the processes, the PDCA approach can be used to identify other problems and new opportunities in the context of Lean Logistics.

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