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Innovative solutions for warehouse logistics: improving efficiency with RFID and IoT integration

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Abstract: This research summarises the results of the scientific discussion on the possibilities of improving logistics flow in industrial practice. The objective of the paper is to introduce an exploratory case study aiming at streamlining production logistics flow through the implementation of automatic identification technology (RFID) and new storage solutions in warehouses in industrial enterprises. The main aim of the paper is to introduce an innovative solution regarding implementation of the Internet of Things (IoT) in the warehouse operations to eliminate waste of time and material guided by Plan –Do-Check- Act (PDCA) cycle verified both by observation and statistical methods. The results of this research propose and realise new innovative solutions to reduce waste in logistics processes in warehousing. The key improvements include the elimination of waste and innovative solutions to increase the efficiency of tracking kitting trucks, improving the clarity of the sequencing of kitting carts, and creating standards for the unification of boxes that result in time savings, optimisation of the workplace and scrap minimisation, and increased quality of the logistics processes. The article concludes future recommendations to streamline logistics flow and implement an innovative lean solutions in industrial enterprises.

1 Introduction

Lean logistics is an approach to supply chain and logistics management based on the principles of lean management. Key ideas in lean management include minimising waste, optimising processes, and increasing efficiency. The lean logistics considers possibilities and new solution including Industry 4.0 for minimizing inventory, times, reducing movements, and costs throughout the supply chain, while maintaining the ability to respond quickly to changes in demand and other factors (legislative, economic, ecological, ergonomic and social).

The adoption of lean and green logistics practices brings synergies and improvement to industry [1]. Lean logistic principles, derived from lean manufacturing, are applied throughout the logistics chain, including warehouse and distribution [2]. Essential elements include continuous process improvement, inventory minimisation, and optimisation of material and information flow in logistics [2,3].

Recent studies in scientific papers emphasize elimination of waste in logistics processes, while the emphasis is on the system's contribution, continuous improvement, and enhancement of quality attributes. Several authors [4,5] discussed new opportunities for logistics flow, technical elements in logistics and supply chain management.

Given rapid industrial growth and increasing demands for efficiency, optimising production logistics has become a key concern for many companies. Integration of advanced technologies such as automatic identification systems, including Radio Frequency Identification (RFID), is emerging as a crucial tool to improve the management of warehousing and logistics operations.

Despite numerous studies highlighting the potential of RFID in supply chain management, there remains a notable gap in published contributions addressing its implementation in the specific context of industrial warehouses in the automotive industry. This gap extends to the lack of case studies that combine RFID with new storage solutions and systematically evaluate the results using a continuous improvement methodology.

The objective of the paper is to introduce an exploratory case study aiming at streamlining production logistics flow through the implementation of automatic identification technology (RFID) and new storage solutions in warehouses in industrial enterprises. Specifically, this study explores how the integration of the Internet of Things (IoT) into warehouse operations can eliminate waste in time and materials. Furthermore, by implementing the PDCA cycle, this provides practical insight into how IoT solutions can create more efficient, responsive, and sustainable logistics processes.

For this case study-based article, the research question and hypothesis can be formulated as follows:

Research Question: How can the implementation of automatic identification technology (RFID) and new storage solutions, integrated with the Internet of Things (IoT), streamline production logistics and reduce waste of time and materials in automotive industry using the continuous improvement by PDCA cycle?

Hypothesis: The implementation of RFID technology and IoT-based storage solutions in industrial warehouses, guided by the PDCA cycle, will significantly reduce time and material waste in the automotive industry, leading to more efficient and sustainable production logistics processes. This hypothesis reflects the assumption that RFID and IoT technologies, when systematically applied, can improve logistics operations by improving real-time tracking, inventory management, and overall efficiency.

2 Literature review

The concept of lean thinking helps eliminate logistics activities that do not add direct added value to the company. Many authors discuss the implementation of digitalisation and the Internet of Things as potential for eliminating waste, improving efficiency [6-11] and sustainability [12-15]. In the theory of logistics and production, waste is, as understood, often anything that adds cost to a product or service without increasing its value. Everything that the customer does not want to recognise as value and pay for is considered as waste. Therefore, every company strives to produce without waste. This issue might be very difficult to achieve, but by constantly reducing waste and combining several methods of industrial engineering, it can be possible to eliminate waste to a minimum level.

In terms of waste definition, it can be specified as waste of time (waiting for a trolley, for work assignment), non-conformity (scrap, wrong assignment of work), unnecessary stocks (excess stocks of finished products, work in progress), overproduction (production of more pieces than the next process consumes), not necessary transport (redundant transport, lengthy transport) and not necessary movements (redundant movements).

Katayama, H. [9]characterised conceptual legends of lean management as follows: perfect elimination of Muri (Strain), Mura (Variegate), and Muda (Waste) on the Plan, Do, Check, and Action Cycles (PDCA).

MURI: That is, a massive resource overload. This is the opposite case to MURA. In the short term, this type of transport can have a positive effect, but as time increases, the wear and tear of the transport machines increases, their performance decreases, and the entire logistics system becomes overloaded.

MURA: Translated in English means unevenness. It deals with under-utilisation of resources; that is, we cannot effectively fill the capacity of our transport machines, which transport material half-empty.

MUDA: The meaning is translated in English as waste, uselessness or purposelessness, which is contrary to the creation of added value. Value-added work is a process that increases the value of a product or service so that the customer is willing to pay for it.

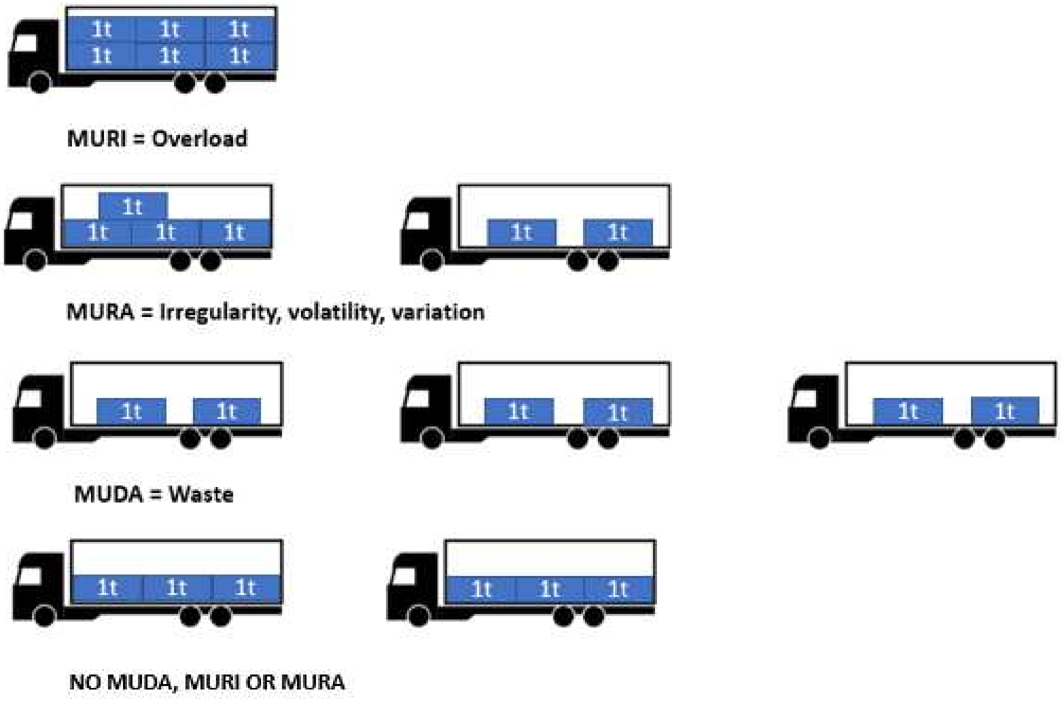

Figure 1 Types of waste in production logistics: mura, muri, muda

Two types of Muda can be defined, namely type 1 and type 2 (Figure 1). Muda type 1 includes activities in processes that do not add direct value to the final product, but are necessary to ensure the quality and safety of the product for the customer. An example can be inspection and safety tests, which do not provide value in themselves but are necessary for the safety of the product. Muda type 2 includes activities in processes that do not add value to the product and are not needed by the customer. These activities should be completely eliminated, ideally, because they do not contribute to improving the quality or value of the product to the customer. The ideal point is to reach the state described as zero muda.

The key principles of the strategic approach Industry 4.0 include the Industrial Internet of Things, cyberphysical systems, vertical and horizontal software integration, augmented reality, predictive manufacturing, logistic and maintenance, autonomous robots, additive technologies, mass individualisation, innovative methods for collecting and processing big data, and many other real-time data analysis techniques utilising the potential of cloud computing [12]. The Internet of Things creates an industrial system that combines intelligent machines, advanced predictive analytics, and machine-human collaboration to promote efficiency and reliability [16]. The IoT is a system composed of heterogeneous devices and organised as networks. Each device (a thing) is equipped with unique identifiers and the capability to share information or transmit data using a wireless or cable network without the need for human interaction.

RFID (Radio Frequency Identification Technology)is a major prerequisite for the Internet of Things (IoT), which, as part of Industry 4.0 connects physical objects to the Internet [12]. Radio frequency identification is a wireless communication technology that uses radio signals to identify specific targets and read and write related data without the need for mechanical or optical contact between the system and a specific target to determine. RFID is an efficient means of identification and one of the main sources of data in the supply chain [7].

The implementation of radio frequency identification is a very interesting and widespread solution in industry to implement IoT systems or distributed sensor networks [9]. RFID represents an innovative tool in warehousing that enables automation of the identification and tracking of materials and products. When combined with lean principles, RFID can significantly improve inventory accuracy, reduce errors in storage and dispatch, and thus improve the efficiency and transparency of logistics operations [3].

By combining lean principles with RFID's tracking capabilities, enterprises can achieve a higher level of efficiency, minimise waste, and ensure timely delivery of products. For example, RFID can provide real-time data that supports JIT inventory systems, enabling companies to reduce excess stock and associated costs. Furthermore, the continuous improvement culture can drive the effective implementation and use of RFID technology, ensuring that the technology is used to its full potential. The wide use of RFID in logistics flow and its potential are presented in [17,18].

Nowadays, RFIDs are relatively cheap, provided by unique identifiers and can be equipped with a variety of sensing capabilities [9]. The advantage of RFID is its extremely low price and its simple methods of production. However, there are definitely limitations that need to be noted, such as the amount of information required during implementation. On the other hand, Katayama [9] considers this limitation to be much less serious or irrelevant.

Data volumes in each supply chain can be generated from various sources of data, business processes, and IT systems, including enterprise resource planning (ERP) systems; order and transport logistics; customer purchasing patterns; and technology-driven data sources such as global positioning systems (GPS), radio frequency-based identification (RFID) tracking, mobile devices, and others [7].

The application of bar code and RFID technologies in logistics, as the most common forms of auto-ID technology, enables fast and enables product identification and supports the logistics flow, including production logistics, transport, handling, warehouse and sales operations, thereby reducing lead time, operational costs, and transaction costs [10,19,20].

3 Methodology

The proposed solution is based on an analysis of the literature, including case studies and previous practices and research. Following the main aim is increasing elimination of waste in the industrial enterprise and continuous improvement the PDCA cycle was applied.

The PDCA methodology can be applied to all processes, including logistics. The Demings cycle, also called the PDCA cycle consists of four phases as follows:

- **Plan** requires the setting of the objectives and processes necessary to achieve the desired results in accordance with the customer requirements.
- **Do** means implement the action plan to achieve the objectives.
- **Check** means monitor and measure processes and products, compare it with stated objectives and indicators.
- **Act** is taking action to improve process performance.

In a study conducted in industrial enterprise using the idea of continuous improvement by the PDCA cycle, the three most significant deficiencies and waste were identified in the logistics flow in an a kitting warehouse in industrial company.

- **Plan:** First, during the planning phase, processes were identified. The task was to increase the efficiency of tracking the kittling trucks in the warehouse and to improve the clarity of the kittling trucks.

- **Do**: The introduction of the selected innovation took place: RFID technology in the warehouse. This solution included the selection of suitable devices (RFID tags and readers), the design of an implementation plan (taking into account time and financial constraints), and the defining the implementation schedule of the solution itself, including the budget. The realisation includes activities necessary for the purchase of RFID tags and readers, the installation of RFID antennas, and reading devices.
- **Check**: During this phase, the performance of the RFID system was monitored and data about the use of the RFID system in logistics were collected and analysed. The focus was mainly on the identification of specific areas for improvement in this project.
- **Act:** During this phase, corrective measures were implemented based on previous actions, and opportunities for standardising these new measures were identified to facilitate continuous improvement.

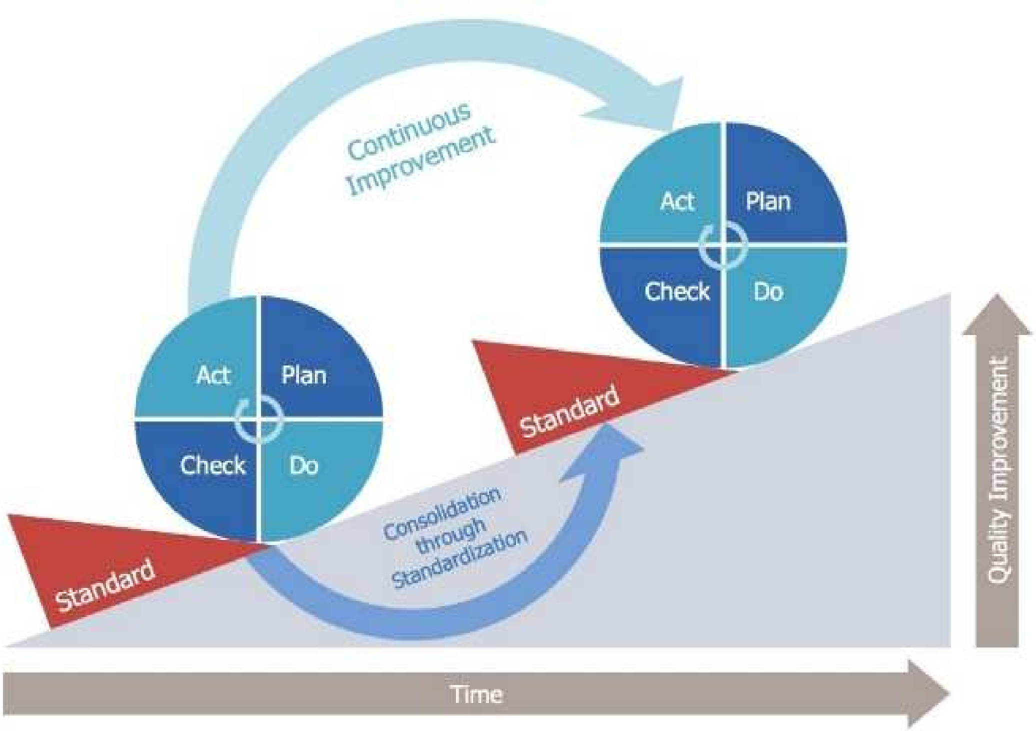

Figure 2 PDCA cycle (https://www.cems-en.com/article/820-pdca-cycle)

The implementation of the PDCA cycle (Figure 2) for identification of shortcomings, planning and realisation of corrective measures to eliminate waste (time, material) in logistics process and verification of implemented solutions result in time savings, workplace optimisation, and scrap minimisation and improving of logistics processes. The solutions themselves were implemented, and their effectiveness was verified by measurement.

4 Results and discussion

This part of the paper focusses on the presentation of an innovative logistics solution in an a case study in industrial enterprise and validation of the research. The object of the analysis was an industrial company that produces interior components for the automotive industry. The organisation was chosen for improvement due to its use of innovative approaches to production and its strong commitment of management to quality and innovation.

4.1 *Identification of deficiencies in terms of material flows in the industrial enterprise*

Based on the concept of lean philosophy and the analysis of logistics processes, specific steps were implemented to optimise movement flows and the arrangement of warehouse spaces, which could contribute to further increasing the efficiency and overall success of the company within the competitive automotive industry.

The main focus was to plan the improvement of logistics processes in the pilot project in the Kitting area with several innovative technologies. During the workplace, some innovative technologies and also some opportunities for improvement were identified, as well as potential shortcomings. The use of innovative solutions, e.g. the pick-to-light system, was considered to be an effective tool, increasing the accuracy and speed of the work used during the selection of parts from the warehouse. The use of smart gloves to scan the cable enables easier handling of small parts and a reduction in unnecessary movements. Subsequently, several areas of production logistics were identified where improvements could be made.

First, one of the main problems was the inefficient movement of operators when retrieving parts from the racks as the actual layout of the racks was inappropriate, often causing time delays.

Second, there was a need to replace cardboard boxes. Standardizing the packaging could enhance process efficiency in terms of time

The third challenge was inadequate waste management during the work process. Empty packaging thrown by operators on the ground slowed the process and posed a safety risk.

Fourth, the last problem to be solved was the impaired identification of specific kitting tracks due to their uniform construction, design and colour design. It was a challenge for the operators to recognise the kitting trolley.

4.2 Measures for streamlining and innovative solutions in logistics

The first technology introduced to streamline the logistics workflow and avoid waste and waste of time and material in the workplace is radio frequency identification. In this case, this method of automatic data collection using radio waves would be used directly in the kitting warehouse to simplify the identification, tracking, and movement of kitting carts, which serve to assemble the door panel. The main reason for this IoT technology is to prevent waiting times and to prevent blocking of primary production batches.

The problem that might be prevented is where the assembled door does not pass the final quality control due to a defect. Subsequently, such doors cannot be stored in the final container that is intended for final delivery to the customer. Setting up is consider as a waste because the faulty door has to be reassembled with new parts. The line transmits the information to the warehouse, where a new document with identical components is reprinted. The problem occurs at the moment when these priority components are mixed into another batch of kitting carts. As a priority, it is necessary to produce this door in required quality, amount and on time so that the final container can be closed, scanned and handed over to the customer. If this priority kitting cart is mixed with another batch among several different kitting carts, it is problematic for warehouse operators to find this priority cart and immediately send it to the assembly line. The proposed solution is the application of RFID led tags. Using RFID for monitoring, the desired kitting truck can be found and selected from the rest in seconds. The RFID led tag might be placed on the visible top of the kitting cart using a magnetic mount. At the beginning of the process, the warehouse worker scans the QR code in the documentation. Using IoT technology, this information is transferred to the reader and, by subsequent attachment of the RFID led tag, this information can be transferred to a specific tag.

The advantage of implementing the RFID led tag would occur during a specific search for the truck. The LED light built into this device, together with sound signalling, reduces the search for kitting carts to a minimum. It is also an advantage that the worker can search for several carts at the same time or the entire production batch. The battery life of an RFID led tag is stated to be 40 months, and the battery can be replaced. The assumed range of the RFID tag is set at a distance of 30 metres.

The second measure to improve logistics flow was the introduction of a drop rack to avoid used empty packaging. By implementing this measure, the prevention of waste in the form of accumulated empty boxes that warehouse operators place on the ground. When empty packaging and boxes are placed freely on the ground in this way, there is a risk that operators may stumble while working and an accident will occur. The second aspect is as an obstacle in the movement of operators when filling the kitting carts and it affects their handling space in the warehouse. Drop rack are a special type of racks that is used to collect and then remove unnecessary boxes from the workplace without the energy supplied. They are designed with a slope between the beginning and end of the rack, through which the empty boxes can move forward independently. The most useful type of drop for this solution shelf is one with rails. For the solution, a total of six flow racks with dimensions of 280 x 60 x 106 cm (length, width and height) were needed each. For efficient movement at workplace, three pieces of flow rack were needed, each on the right and left sides. After the implementation of these storages, it became easier for logistics operators to handle empty packaging.

In the introduction of the unification of containers, this measure was directly related to the one described previously. The main identified problem was the complicated handling of packaging operators. We found that non-standardised packaging increases significantly handling time. Such cardboard packaging tears and breaks during use, with the risk of damage to the stored material. Operators usually cut a hole in the front of the cardboard box to improve access.

The proposed measure to streamline logistics flow is the purchase of plastic containers with a cutout on the front part. Such packaging would be regularly filled by logistics operators from the original cardboard boxes. The main advantages of the proposed solutions are their strength, accessibility, and low weight. At the same time, these new standardised containers can be stored on racks so that the components stored in them would have a logical connection and continuity in cooperation with the implemented pick-to-light system. This would prevent unnecessary walking between the left and right shelves.

The dimensions of the plastic container are 200 x 310 x 500 millimetres (height, width, and depth). The advantage is the possible stack ability and the possibility to reuse for a long time.

4.3 Verification of innovative solutions

After the introduction of automatic identification with RFID led tags, the efficiency of finding the right kitting truck has increased. For the verification phase, first the measurement of five operators were conducted followed with five measurements with five purchased RFID tags were in the workplace. The data clearly demonstrate significant reductions in time demand across all operators, reflecting the effectiveness of the applied measures. The Table 1 provides a comparative analysis of the time demand for five operators before and after the implementation of improvement measures aimed at optimizing the efficiency of logistics operations.

Table 1 Comparative analysis of the time demand after implementation of measures

	Time demand before [s]	Time demand after measures [s]	Saved time [s]
Operator 1	154	10	144
Operator 2	145	12	133
Operator 3	136	11	125
Operator 4	160	9	151
Operator 5	141	12	129
Total	736	54	682

After statistical analysis of data (Table 2), we can state that the mean time demand of five operators before was 147.2 seconds, with a standard error of 4.35 seconds, indicating moderate variability in the sample. The median time, 145 seconds, suggests that half of the operators completed their tasks in less than this time, while the other half took more time. Notably, there was no mode, indicating no repeated values among the operators' time demands. The standard deviation of 9.73 seconds shows a moderate degree of variability in the times before the measures, with a sample variance of 94.7 confirming this spread in the data. The range of 24 seconds (with a minimum of 136 seconds and a maximum of 160 seconds) further reflects the spread in time demand among the operators. The skewness of 0.34 suggests that the distribution was slightly positively skewed, with a longer tail on the right, indicating that a few operators took considerably longer to complete their tasks. The negative kurtosis value of -1.56 reveals that the time demand distribution is flatter than a normal distribution. The 95% confidence level of 12.08 seconds suggests that the true mean of the population lies within this range, highlighting the precision of the sample mean.

On the other hand, the time demand after the implementation of the measures was reduced, with a mean time of only 10.8 seconds, reflecting the significant improvement in operational efficiency. The standard error also decreased to 0.58 seconds, indicating much greater precision in the post-intervention time measurements. The median time demand was 11 seconds, closely aligned with the mean, demonstrating consistency in the time improvements across the operators. The mode of 12 seconds suggests that this was the most frequent time recorded after the intervention. The standard deviation after the measures was reduced to 1.30 seconds, indicating lower degree of variability compared to the pre-previous measurement. This reduction is further confirmed by the sample variance, which dropped from 94.7 before the measures to just 1.7 after. This suggests that the time demand was much more uniform after the improvements. The range of 3 seconds (with a minimum of 9 seconds and a maximum of 12 seconds) shows a minimal dispersion in time demand following the intervention, reinforcing the notion of enhanced consistency among operators. The skewness value shifted to -0.54, indicating a slight negative skew, where the distribution is now slightly left-skewed, with most time demands being on the lower end. Additionally, the kurtosis value of -1.49 is similar to the pre-intervention kurtosis, indicating that the time demand distribution remained somewhat flat even after the measures were applied. The 95% confidence level after the measures was 1.62 seconds, significantly narrower than the confidence level before the measures.

In summary, the descriptive statistics presented in the Table 2 demonstrate improvement in the efficiency of the operators following the implementation of the measures. The mean time demand decreased from 147.2 seconds to 10.8 seconds, and the variability in time demands significantly reduced as evidenced by the lower standard deviation and variance. The skewness and kurtosis values, along with the narrower confidence intervals, suggest that the improvements were not only effective but also consistent across the operators, resulting in more uniform performance outcomes. These findings provide strong empirical support for the effectiveness of the intervention in optimizing the logistics processes within the industrial setting

In the presented case for logistics, for the complex solution, 40 pieces of RFID tags have to be purchased, one for each kitting trolley used at the workplace. Subsequently, two RFID readers are required to use RFID technology. After the introduction of automatic identification using RFID led tags, the efficiency of searching the kitting trucks has been significantly increased.

At the same time, the realised measures contributed to optimising the removal of empty boxes and packaging from the warehouse. The operator's work is easier, and potential safety risk is avoided with removal of empty boxes on the ground, and simple solution for storage in the flow racks works eliminated waste of time in logistics. The costs for one drop shelf are 335 euros. In the Kitting warehouse, six flow shelves were purchased for total costs of 2010 euros.

Table 2 Descriptive statistical analysis of the time demand after improvement

	Time before measures		Time after measures
Mean	147.2	Mean	10.8
Standard Error	4.352011029	Standard Error	0.583095189
Median	145	Median	11
Mode	no	Mode	12
Standard Deviation	9.731392501	Standard Deviation	1.303840481
Sample Variance	94,7	Sample Variance	1.7
Kurtosis	-1.55800176	Kurtosis	-1.487889273
Skewness	0.342570225	Skewness	-0.541387051
Range	24	Range	3
Minimum	136	Minimum	9
Maximum	160	Maximum	12
Sum	736	Sum	54
Count	5	Count	5
Confidence Level (95.0%)	12.08311972	Confidence Level (95.0%)	1.618931785

Replacement of the original cardboard boxes will bring many benefits to warehouse operators. Operators will not waste move in the form of cutting access to the box. The handling in the logistics flow will also be improved due to the fact that their original cardboard will no longer tear and. get stuck on the shelves. The stack ability of containers is also an advantage for storage. For the workplace, 54 containers need to be purchased for the amount of 6.7 euros, with estimated costs of 368.1 euros.

In summary, the results presented in this case study are consistent with objective and validate the stated hypothesis, showing that RFID technology and new storage solutions significantly improved logistics efficiency and reduced waste.

5 Conclusions

The study focused on an innovative logistics solution considering the improvement of current state of digital transformation in Industry 4.0 and its technologies in the logistics processes in automotive industry, focussing on a case study of an industrial enterprise. The aim of the study was to promote a more efficient solution in logistics by implementing automatic identification technology (RFID) and innovative warehouse management solutions.

By integrating the Internet of Things (IoT) into the PDCA cycle, the research highlighted implementation of s innovative methods for reducing time. The mean time demand decreased dramatically from 147.2 seconds to 10.8 seconds, and the variability in time demands significantly reduced as evidenced by the lower standard deviation and variance. Key improvements observed and measured included increased efficiency in tracking kitting trucks, efficient organisation and sequencing of kitting trucks, and standardization of box unification. These improvement resulted in significant time savings, improved workplace conditions, reduced scrap, enhanced quality control, and overall advancements in logistics performance. which led to significant time savings, workplace optimisation, minimization of scrap, increased quality and overall improvement of logistics processes.

The findings indicate the potential of future innovative lean solutions to increase the efficiency of logistics in industrial enterprises. Several authors emphasize the importance and relevance of sustainable solutions, new technologies, and the digitisation of industrial practice [21-26]. In future research, we will contribute to [27] and continue to explore IoT development, using advanced data analytics, application of emerging technologies applications in logistics, such as blockchain for supply chain transparency and security, while focussing on sustainability . Specifically, future research directions will be essential to maintain and multiply the added value and efficiency achieved through current innovative solutions in context of sustainable development goals, ensuring the continuous optimization of industrial logistics and fostering both economic, social and environmental benefits in the long term.

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Review process

Single-blind peer review process.