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Implementation of a performance management system for environmental sustainability in an industrial organization

E.C. Rada[1], I.C. Nicolae[2], M.V. Zerbes[3], A. Tulbure[4], A. Karaeva [1], V. Torretta[1], R. Giurea[5,6]

[1]Department of Theoretical and Applied Sciences, University of Insubria, Varese, Italy
[2]Asociația Conexiuni, Sibiu, Romania
[3]Department of Industrial Engineering and Management, Lucian Blaga University of Sibiu, Sibiu, Romania
[4]Department of Food Industry and Environmental Protection, Lucian Blaga University of Sibiu, Sibiu, Romania
[5]Department of Industrial Engineering and Management, Lucian Blaga University of Sibiu, Sibiu, Romania
[6]Department of Communications, IT and Cyber Security Nicolae Balcescu Land Forces Academy, Sibiu, Romania

Corresponding author's: elena.rada@uninsubria.it

Abstract. The paper explores the implementation of process performance management systems in the automotive industry, specifically focusing on improving the assembly line of an organization within this sector thanks to the introduction of cobots in the line of manufacturing electronic modules used in car seat control systems. With an emphasis on environmental sustainability and circular economy (CE) concepts, the study investigates the positive effects of optimizing mechanical and electromechanical systems within the assembly line. Leveraging concepts such as KAIZEN and Gemba Kaizen, along with the guiding principles of Just-In-Time (JIT), Continuous Improvement and Automation with a Human Touch (JIDOKA), the research aims to elucidate the potential benefits of such enhancements. Key performance indicators (KPIs) including Overall Equipment Effectiveness (OEE), First Pass Yield (FPY), and scrap rates were considered. Rejects, primarily stemming from human error in part handling, emerged as the major challenge facing this assembly line. To address this issue, collaborative robots were introduced to automate part handling, replacing manual processes with precise and reliable automation. Before the implementation, the cycle time stood at 13.6 units, which was reduced to 12.5 units post-implementation, resulting in a significant increase in productivity equating to 3000 more parts produced per week. OEE increasing from 80% to 87.74%, FPY rising from 96.42% to 98.48%, and the scrap rate decreasing from 0.06% to 0.02%. By addressing inefficiencies at the assembly line level, organizations can achieve significant improvements in performance metrics while concurrently contributing to a greener and more sustainable future.

1. Introduction

In the landscape of automotive manufacturing, the production of electronic components stands as a cornerstone of technological advancement, driving innovation and efficiency in modern vehicle systems. The application of Circular Economy (CE) concepts to decrease the waste helps also to increase the environmental sustainability of the automotive manufacturing [1-6]. The fabrication of electronic modules used in cars has undergone a remarkable journey marked by transformative developments over the years. Beginning with the advent of automotive electronics, the landscape shifted from purely mechanical systems to the integration of electronic components, revolutionizing vehicle functionality and performance. From simple electrical circuits to sophisticated electronic modules controlling vital functions within vehicles, the manufacturing process has evolved to meet the growing demands of automotive technology.

The process of manufacturing electronic components for automobiles encompasses a diverse array of materials, technologies, and processes. Raw materials, including semiconductors, resistors, capacitors, and integrated circuits, are meticulously selected and assembled into intricate electronic modules tailored to specific vehicle functionalities. Similar to the tire manufacturing process, precision and consistency are paramount in electronic component production. Computerized systems govern material selection, blending, and shaping, ensuring uniformity and reliability in the final product. Layout modifications and assembly line optimizations are key strategies employed to enhance efficiency and streamline operations.

Enhancing environmental sustainability within the Industrial Sector refers to the strategic efforts aimed at improving the environmental performance of industries in agreement with CE concepts. This involves the implementation of sustainable practices and technologies to reduce environmental impact, including minimizing waste, reducing emissions, conserving resources, and promoting recycling [7,8]. The starting point is the citizen involvement at all ages and managers after a proper preparation for all the above-mentioned aspects [9-13].

As the automotive industry continues to embrace technological advancements, the demand for high-quality electronic components has surged. Manufacturers are compelled to analyse, monitor, and improve their production systems to meet stringent quality standards and performance metrics.

The present paper delves into the implementation of process performance management systems within the automotive industry, with a specific focus on enhancing the assembly line for manufacturing electronic modules. Leveraging methodologies such as KAIZEN and Gemba Kaizen, alongside principles like Just-In-Time (JIT) and Automation with a Human Touch (JIDOKA), the research aims to elucidate the potential benefits of such enhancements [14-24].

Identifying a targeted assembly line responsible for producing electronic modules used in car seat control systems, performance metrics such as Overall Equipment Effectiveness (OEE), First Pass Yield (FPY), and scrap rates serve as benchmarks for improvement. Challenges such as rejects due to human error in part handling prompt the introduction of collaborative robots to automate processes and bolster efficiency [25-30]. Before the implementation of improvements, the assembly line may face hurdles such as prolonged cycle times and suboptimal performance metrics. However, post-implementation, significant enhancements are observed, including reduced cycle times, increased productivity, and improved performance indicators [31-33].

The present paper underscores the transformative potential of integrating advanced methodologies and technologies to optimize assembly line processes, enhance manufacturing efficiency, and foster sustainability within the automotive industry. By addressing inefficiencies and embracing sustainable practices, organizations can not only improve performance metrics but also pave the way for a brighter, more innovative future in automotive manufacturing.

2. Material and methods

Process Performance Management (PPM) aims to ensure efficient organizational growth by continually enhancing personal skills and organizational parameters. Its application in the automotive industry, focus on optimizing mechanical and electromechanical systems on assembly lines to improve performance and minimize environmental impact but also from quality, productivity, and cost point of view.

A systematic PPM contributes to environmental sustainability by minimizing waste, optimizing resource utilization, and reducing energy consumption. By streamlining processes and eliminating non-value-added activities, PPM reduces the environmental footprint of automotive manufacturing operations. Moreover, proactive deviation management and continuous improvement initiatives ensure adherence to environmental regulations and promote sustainable production practices and circular economy concepts applications.

PPM incorporates a risk-based approach to categorize deviations based on their impact on product quality and environmental sustainability. Incidents, minor deviations, major deviations, and critical deviations are classified according to their severity, with critical deviations prioritized for immediate resolution [34]. This categorization enables organizations to allocate resources effectively and mitigate risks to product quality and environmental integrity.

Implementing PPM offers several benefits in automotive manufacturing as:

- *standardization:* Visual representation of performance indicators facilitates immediate recognition of deviations and simplifies communication [35].
- *efficiency:* Streamlined workflows and early deviation recognition enable rapid corrective action, enhancing process efficiency and quality [36].
- *communication:* Clear performance indicators and deviation reporting mechanisms promote effective communication and collaboration across organizational levels [34].
- *compliance:* PPM ensures adherence to environmental regulations and promotes sustainable production practices, minimizing environmental impact [37].
- *continuous improvement:* Deviation analysis and corrective action drive continuous improvement, aligning operational performance with organizational strategy [34].

The implementation of a PPM system in the automotive industry, particularly on assembly lines, requires careful planning and execution. One crucial element in this process is the Line Information Board.

The Line Information Board (LIB) serves as a dedicated tool for the line manager but is utilized by all levels of management to easily grasp the line's status and gain insights into risks and issues. It provides information on four major areas: Work Safety, Quality, Productivity, and Cost. The LIB consists of two distinct parts: the front and the back. The front part, with high-frequency usage, focuses on continuous management of deviations, while the back part, with lower frequency usage, is for daily management of deviations. The board's content includes critical information such as current line status, production graphics, 4M risks, escalation visualization, days without customer rejections, production plans, standard work routines, safety records, problem-solving agenda, OEE indicator, and action plans.

The primary responsibility for completing and updating the board lies with the line manager. They are tasked with various activities, including maintaining line standards, understanding line parameters, identifying improvement opportunities, ensuring safety, and monitoring deviations from standards. Additionally, the role of the leader of the line manager is crucial in supporting and reinforcing the process performance management system.

The essential information displayed on the front of the board includes current line status, production graphics, 4M risks, and escalated actions. This information aids in quick decision-making and problem-solving. Meanwhile, the back of the board includes information on work safety, problem resolution, 5S, Gemba standard agenda, OEE indicator with Pareto analysis, defect rate with Pareto analysis, and internal defect rate with Pareto analysis. The process of installing a process performance management system involves the following steps:

- Selecting a line for observation.
- Verifying cycle time, hourly production performance, and line standards.
- Defining a monitoring program capable of capturing 30 minutes of production.
- Involving relevant personnel in addressing immediate issues.
- Proactively adding all open points to the action list displayed on the Line Information Board.

The assembly line of electronic modules for seat control is part of the lines that have implemented the performance management system, namely Deviation Management (Line Information Panel) and was chosen as case-study because it has the lowest performance indicators relative to the target values that must be achieve. As a reference, the indicators reported in Table 1 for the three months were considered.

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Tabel 1. KPI's evolution

KPI	December	January	February
OEE (85%)	77.23%	79.98%	80.05%
FPY (98%)	97.80%	97.96%	95.55%
Scrap rate (0.1)	0.21%	0.18%	0.15%

Jishuken is an activity where leadership members identify areas needing continuous improvement and disseminate information throughout the organization to drive action [38]. The success of the improvement system implementation depends on the comprehensive understanding of all affected processes by the entire team and compliance with all internal and external regulations in force.

The analysis of the current configuration of the line reported in Figure 1 and the way the operators work, were the starting point for the development of the research presented in this paper. The current working mode consists of 4 operators doing the following activities:

- Operator 1: Plate Separation – Press Loading.
- Operator 2: Download Press – ICT – Load FLASH.
- Operator 3: Download FLASH – Laser – Assembly.
- Operator 4: EOL Testing – Packaging.

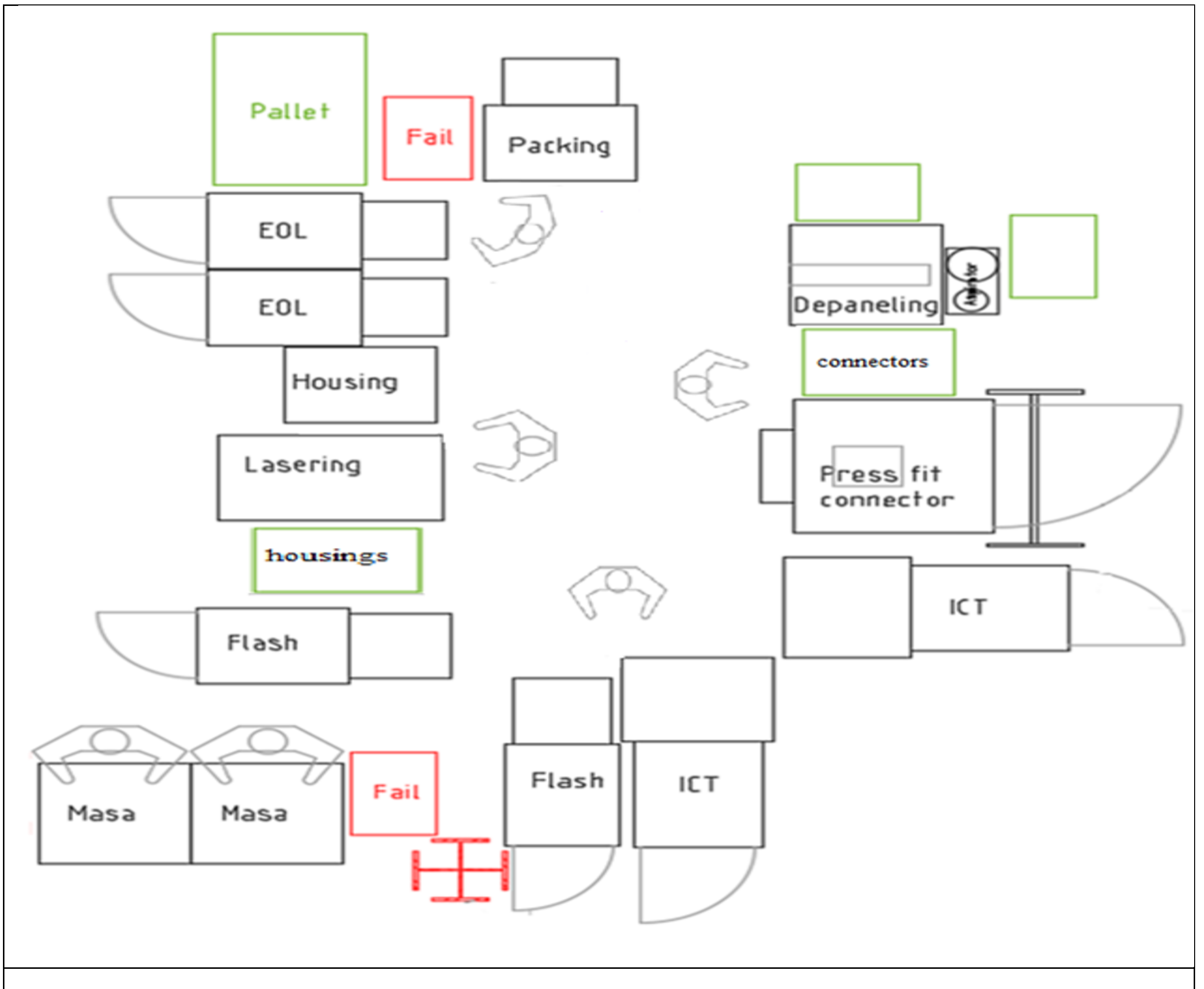

Figure 1. Current organization of the line

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The implementation of collaborative robots in the manufacturing process involves a comprehensive and structured approach encompassing project selection, team formation, space verification, impact assessment, planning, decision-making, implementation, validation, and customer approval. By following these stages meticulously, manufacturing processes can be enhanced, leading to improved efficiency, quality, and customer satisfaction.

After installing them, internal validation occurs, with the multidisciplinary team and quality representative conducting audits for validation. A test run of 300 pieces was conducted to test equipment functionality and optimize where necessary. Process and test reports generated from this run are sent to the customer.

Upon completion of the entire internal validation process, all reports, including process validation and product validation, along with additional documents requested by the customer, are submitted for approval. Production of parts in the current line configuration begins only after receiving customer approval.

3. Results and discussion

The implementation of collaborative robots (cobots) on the assembly line of electronic modules for seat control has brought significant improvements across various aspects of the production process.

Figure 2 presents the new configuration with 3 cobots introduction for the following activities:

- Cobot 1: Unload Press – Load/Unload ICT – Position part in intermediate nest.
- Cobot 2: Unload part from intermediate nest - Load/Unload FLASH - Place part in intermediate nest.
- Cobot 3: Load/Unload Laser.

One of the operators, more precisely operator 2, will be replaced by the 3 cobots, and the other 3 operators who perform the following steps:

- Operator 1: Plate Separation – Press Loading
- Operator 2: Assembly – EOL Loading
- Operator 3: EOL Download – Wrapping

The OEE (Overall Equipment Effectiveness) metric serves as a comprehensive measure of equipment utilization, and before the introduction of cobots, was 80%, indicating room for improvement. With the new configuration, OEE has risen to 87% having effects on:

- *availability:* cobots have contributed to increased equipment availability by minimizing unplanned downtime and streamlining production processes thanks to fewer interruptions and smoother operations.
- *performance:* the speed and efficiency of equipment utilization was improved thanks to faster cycle times and higher output rates.
- *quality:* product quality increased thanks to a more precise and consistent handling of components and the incidence of defects and rework has significantly decreased.

Another of the key benefits of cobots implementation was the substantial reduction in scrap rates as requested by CE concepts. By minimizing human errors and ensuring accurate assembly processes, cobots have effectively mitigated the occurrence of defective or non-conforming parts. As a result, the scrap rate has plummeted from 0.06% to a mere 0.02%, representing a considerable enhancement in manufacturing quality and cost savings. With their precision and efficiency, cobots perform tasks at a faster pace, reducing the time required for each production cycle. As a result, the cycle time has been slashed from 13.6 seconds to 12.5 seconds, enhancing overall productivity and throughput. In Table 2 the targeted KPI's improvement are reported.

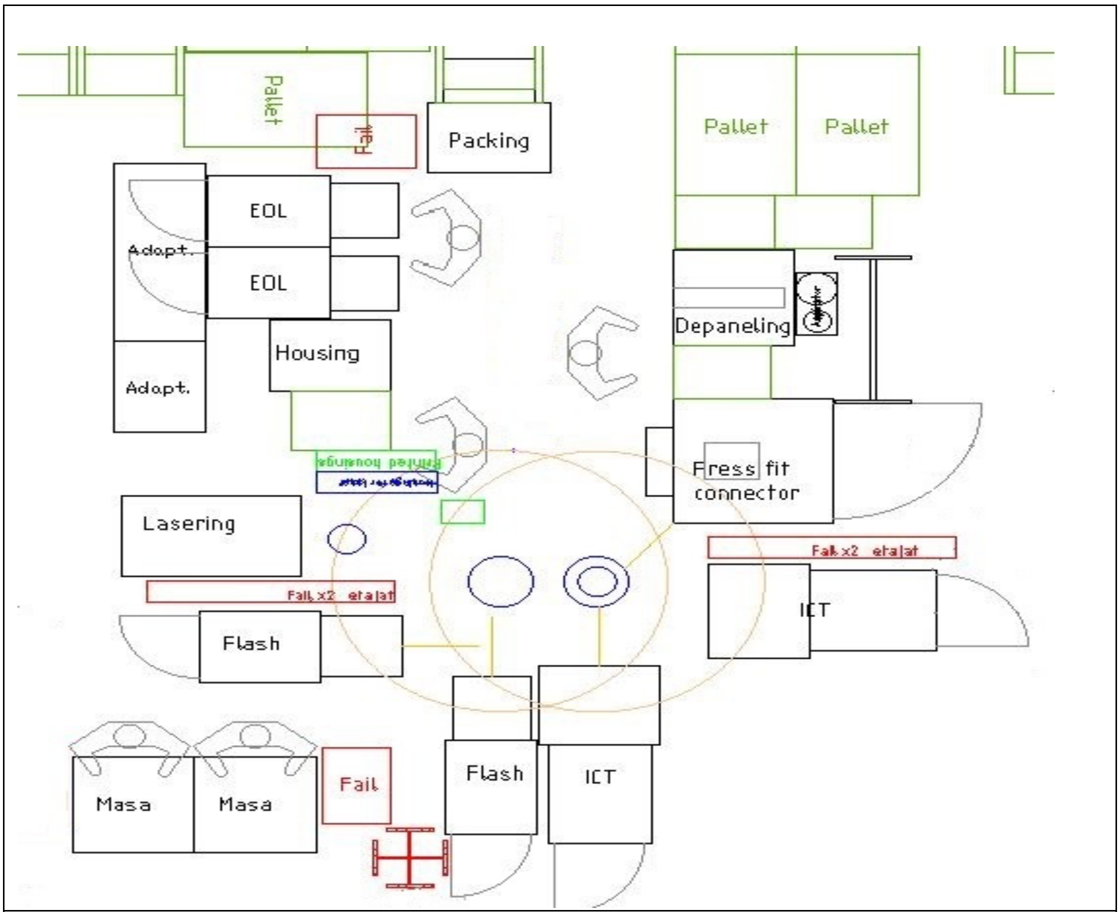

Figure 2. New organization of the line, cobots added

Table 2. Situation performance indicators before and after the implementation of cobots

KPI	Initial situation	Current situation	Improvement	Profit RON/day
OEE %	80.05	87.74	7.69	-
FPY %	96.42	98.48	2.06	-
Scrap rate %	0.06	0.02	0.04	500

Cobots implementation has also yielded substantial cost savings and operational efficiencies:

- *Labor Costs:* by automating repetitive tasks and reducing the reliance on manual labor, cobots have minimized the need for human operators on the assembly line. The reduction in labor requirements translates to significant savings in labor costs over time.
- *Productivity Gains:* the enhanced efficiency and throughput facilitated by cobots result in increased productivity gains. With more products manufactured within a given timeframe, the cost per unit decreases, maximizing profitability and return on investment.
- *Quality Improvements:* the reduction in scrap rates and the enhancement of product quality not only minimize material waste but also contribute to long-term cost savings. By producing higher-quality products, companies can reduce the incidence of returns, warranty claims, and associated costs, bolstering overall profitability.

The implementation of collaborative robots on the assembly line of electronic modules for seat control has had a transformative impact on production processes and outcomes. By improving performance indicators, reducing operational costs, and enhancing overall productivity, cobots have emerged as a game-changer in modern manufacturing. Their ability to augment human capabilities, optimize workflows, and drive efficiency underscores their significance as a strategic investment for companies seeking to thrive in a competitive marketplace. Other relevant benefits are highlighted in Table 3.

Table 3. Benefits of implementing cobots

KPI	Initial situation	Current situation	Improvement	Profit RON/day
No. of operators/shift	**4**	**3**	**-1**	**460**
Cycle time (sec)	**13.6**	**12.5**	**-1.1**	**1386**
Line capacity (pieces/day)	**4537**	**5369**	**+832**	**83200**

The successful implementation of the Performance Management System in the automotive organization highlights several key strengths. These include the active involvement of all managerial levels, the establishment of standardized management standards for each process, and the empowerment of production staff to contribute to problem-solving and innovation. Additionally, the system promotes a risk-based approach to decision-making, fosters interdisciplinary collaboration through the creation of multidisciplinary teams, and prioritizes addressing issues at their root cause. Furthermore, it is important to recognize the broader positive impact of these improvements on the environment. By implementing and optimizing mechanical and electromechanical systems on the assembly line, the organization can minimize waste, reduce energy consumption, and mitigate its environmental footprint. This commitment to sustainability not only enhances the company's reputation but also contributes to a healthier planet for future generations.

4. Conclusions

The implementation of a within the automotive organization plays a pivotal role in enhancing operational excellence and gaining a competitive edge in the industry. Through the careful definition of performance indicators and the engagement of production personnel, the company can effectively monitor the evolution of its processes and make informed decisions to drive efficiency and productivity.

In conclusion, this study emphasizes the ongoing importance of continuous improvement and innovation in the automotive manufacturing sector. As new systems and methods emerge, organizations must remain adaptable and proactive in their pursuit of excellence. By embracing Performance Management Systems and integrating sustainable practices into their operations, automotive organizations can drive positive change, enhance competitiveness, and contribute to a greener future.

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