PROCEEDINGS OF THE TECHNICAL UNIVERSITY OF SOFIA, ISSN: 2738-8549, 2738-8530 VOL.76, NO. 1, YEAR 2026

Transformation from Manual to Automated Assembly in Automotive Industry

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***Abstract*—This paper presents a case study on the transformation of a manufacturing process in the automotive industry by automating an existing manual assembly process in order to increase efficiency, quality and productivity. The study focuses on a real industrial case related to the assembly of three components into a single Pivot Part assembly unit. A comparative analysis was performed between the manual process and a fully automated production station, using the OEE (Overall Equipment Effectiveness) indicator to assess the effectiveness. The results show a significant improvement in productivity with the automated machine – an increase in production at the automated station. By moving to a fully automated process, the impact of PLC systems (programmable logic controllers) and machine vision systems was taken into account. The integration of automatic part feeding systems was also considered. The main challenges accompanying the transition to full automation were examined: high initial investments, the need for staff training and adaptation to new technologies. The main advantages and disadvantages of the manual and automated assembly process in the context of the automotive industry are described.**

***Keywords*— The transformation of the production process, increasing efficiency, OEE, assembly.**

I. INTRODUCTION

The automotive industry is one of the most dynamically changing sectors in global manufacturing. In recent decades, the industry has moved from traditional manual assembly methods to hybrid models combining human labor with machine support, and ultimately to full automation. This transformation is driven by the need to meet growing demand, higher quality requirements, and the pursuit of higher efficiency. Partial automation allows for greater repeatability and reduced physical strain on operators, while full automation almost completely eliminates human intervention, especially in risky and repetitive processes. Technological advances in robotics, artificial intelligence, and cyber-physical systems make it possible to achieve high levels of production flexibility and traceability. One of the key indicators of the effectiveness of these processes is the overall equipment effectiveness (OEE), which includes three main components: availability, productivity, and quality. Through (OEE) analysis, companies can objectively measure the impact of automation on the production cycle and identify potential losses. Despite the desire to eliminate the human factor and fully automate the production and control process, this has not yet been possible, and humans remain the primary factor in creating and controlling processes.

A. *Evolution of production processes*

Traditional and modern methods

Manual processes provide flexibility, but are susceptible to human error and quality fluctuations. Gradually, companies are moving to semi-automated and fully automated systems that increase efficiency [1].

In the early 20th century, automobile production moved from manual manufacturing to the assembly line, introduced by Henry Ford in 1913. This innovation significantly increased productivity and reduced costs, allowing mass production of cars. However, the assembly line had limitations in terms of flexibility and product customization. [2].

In the 1960s, industrial robots began to be deployed in the automotive industry, initially for tasks such as welding and painting. Over time, robots have taken on more and more functions, improving the accuracy and safety of manufacturing processes. [3].

B. *Digital technologies and automation*

The implementation of PLC systems, artificial intelligence (AI), and machine vision have enabled automated inspections, minimizing human intervention and improving precision. The integration of Lean philosophy with digital technologies of the Fourth Industrial Revolution (such as the Internet of Things, artificial intelligence, and cyber-physical systems) creates a new model of manufacturing efficiency that builds on traditional approaches through real-time data and adaptive automation. [4]. Successful implementation of Lean in manufacturing requires not only structural changes, but also a significant transformation in employee thinking and behavior. Commitment at all levels of the organization is necessary to achieve sustainable results [5].

C. *Collaborative robots (cobots)*

Cobots work together with operators, performing tasks such as assembly and inspection. They increase the flexibility of production lines and adaptability to market needs [6]. Some companies, such as Audi, are moving from traditional assembly lines to modular production islands that allow customization and optimization of production processes. The implementation of automated systems leads to a significant reduction in production cycle times. The integration of PLC systems and machine vision allows for the management of processes and systems from a remote desktop, which leads to a reduction in response times when production processes are stopped.

II. METHOD OF ANALYSIS THROUGH OEE

The effectiveness of production equipment is assessed using the OEE (Overall Equipment Effectiveness) indicator, which takes into account availability, productivity and quality. The method allows for a quantitative assessment of the real efficiency of a given production system.

OEE=AxPxQ [7].

A is Availability – measures the percentage of time actually used compared to planned production time (Availability = (Actual operating time) / (Planned production time)).
Influencing factors: Unplanned downtime (accidents, breakdowns). Planned downtime (tool changes, machine setup).

P is Performance – compares the actual production rate with the theoretically possible (maximum) rate (Productivity = (Actual number of units produced × Ideal time for 1 unit) / (Actual operating time)).
Influencing factors: cycle delay, micro-downtimes, working below optimal speed

Q is Quality – measures the percentage of suitable (defective) products out of all products produced.
Quality = (Goods) / (Total Products Produced)
Influencing Factors: Defects, Scrap, Rework
Overall Equipment Effectiveness (OEE) is a well-established indicator in the mechanical engineering industry and is often used as the primary method for assessing manufacturing efficiency. Its popularity is due to its relative simplicity and broad applicability, supported by standardized methodologies. However, the current scientific literature points out a number of limitations related to OEE, including problems arising from the choice of time base and difficulties in correctly measuring speed efficiency [8]
Summary data on overall equipment effectiveness (OEE) at different levels of automation in manufacturing systems are presented in Table I. The values are synthesized based on empirical observations and published studies, including Hopp & Spearman (2011) [9], as well as industrial case studies described in various sources. The data shows a clear correlation between the degree of automation and key production metrics such as cycle time, production efficiency and quality variation [10].

TABLE I
AVERAGE OEE VALUES IN DIFFERENT PROCESSES

Process	OEE (%)	Average time per cycle	Production efficiency	Variations in quality
Manual	45-55	900 s.	Low	High
Semi-automated	67-75	600 s.	Average	Average
Fully-automated	58-95	300 s.	High	Low

III. TRANSITION PROCESS FROM MANUAL TO AUTOMATED ASSEMBLY

A real industrial case is considered, related to the assembly of three components into one assembled unit Pivot Part (hinged element), serving for automatic switching off of traffic lights, Fig. 1.

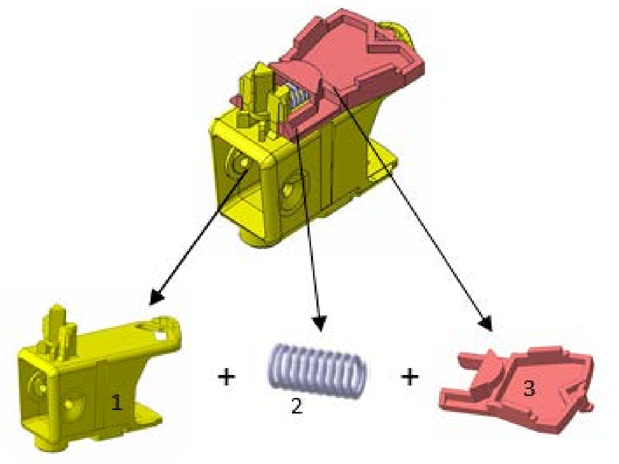

Fig.1 Assembly process of an assembled unit (Pivot part): base (1), spring (2) and slider (3).

A workstation for manual assembly of the base, spring and slider elements to an assembled unit (Pivot Part) is shown in Fig. 2 and Fig. 3. A rate of 316 pcs. per hour is realized.

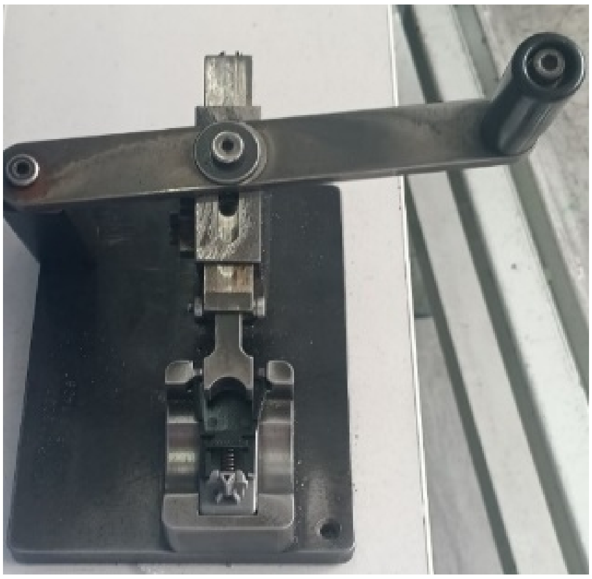

Fig.2 Manual working station position 1.

Fig.3 Manual working station position 2.

The benefits of manual assembly are: lower cost compared to full automation; flexibility – human intervention when needed; faster implementation.

Disadvantages of manual assembly are: lower productivity; risks of human errors; limited repeatability and accuracy; higher operating costs in the long term; difficulties in scaling; dependence on human resources; higher requirements for training and quality control. A 3D model of an automated station for assembling an assembled unit (Pivot Part) is presented in Fig.4. Automatic loading systems (vibrating hoppers) are used to load the three elements. An assembly position is designated. Machine vision systems and automatic part feeding systems are integrated. The drives are pneumatic and electric. Cameras and various types of sensors are used for quality control. The station is controlled by a PLC (programmable logic controller). The maintenance, loading and control of the station is performed by a setter. A connection has been made with IO-Link (intelligent communication protocol). The set rate of the production process is 444 pcs. per hour.

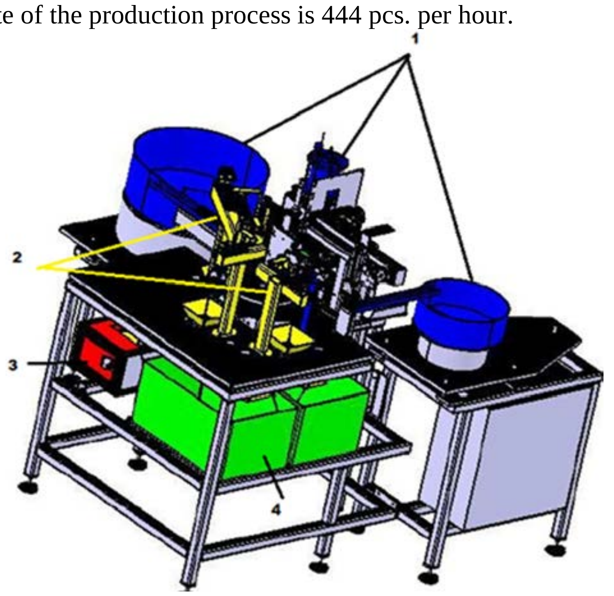

Fig.4. 3D model of an automated assembly station (Carousel-automatic): 1- Vibro-hoppers for loading. 2-assembly systems. 3- position for rejected parts. 4- positions for suitable parts.

The advantages of automating the process are: increased efficiency and speed; the ability to work without breaks or vacation; long-term cost reduction; fewer errors, leading to lower costs for corrections; process quality tracking; repeatability and stability of the process; easy to increase the capacity of work with additional hardware/software without the need for additional personnel; increased safety; the ability to graphically analyze and monitor the process in real time (downtimes, delays, stops, causes).

Disadvantages of automated assembly are: high initial investment; limited flexibility; high maintenance and repair costs; specialized equipment requires qualified technicians, spare parts and regular service; risk of damage or software errors; limited opportunity for human judgment; machines cannot intuitively detect non-standard defects or adapt without prior logic; longer return on investment (ROI) period.

IV. EXPERIMENTAL RESULTS

Studies were conducted for a manual process and a fully automated production station for the assembly of an assembled unit (Pivot part), and the OEE (Overall Equipment Effectiveness) indicator was used to assess the effectiveness.

A graphical representation of the data for a manual process for a period of seven months is shown in Fig. 5, Fig. 6 and Fig. 7

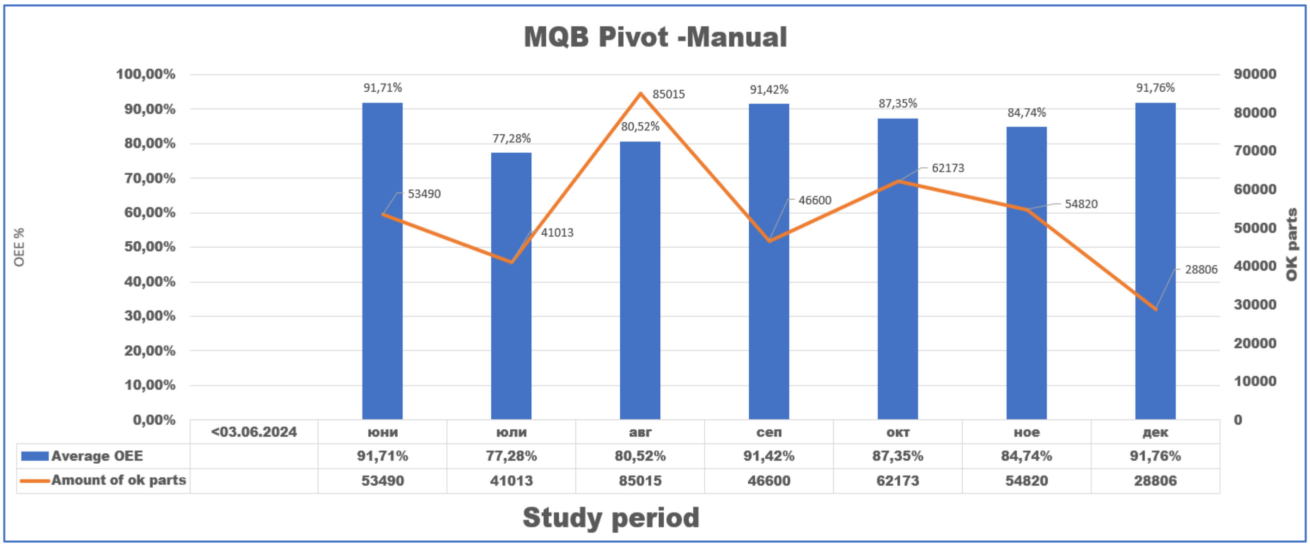

Fig.5 Number of usable parts / OEE MQB pivot manual for a period of 7 months with a manual assembly process.

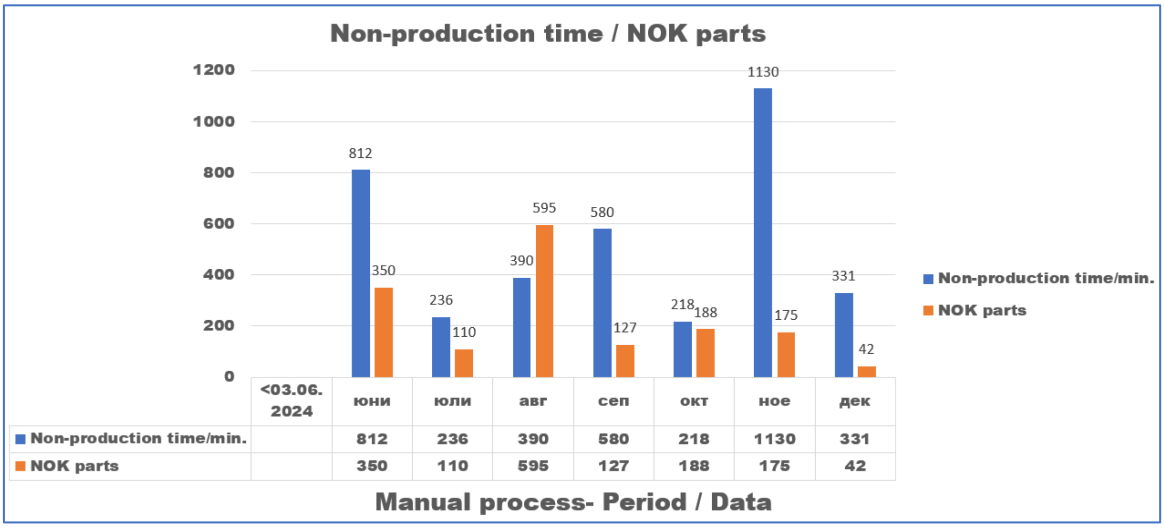

Fig.6 Breakages/Defects for a period of 7 months during a manual assembly process.

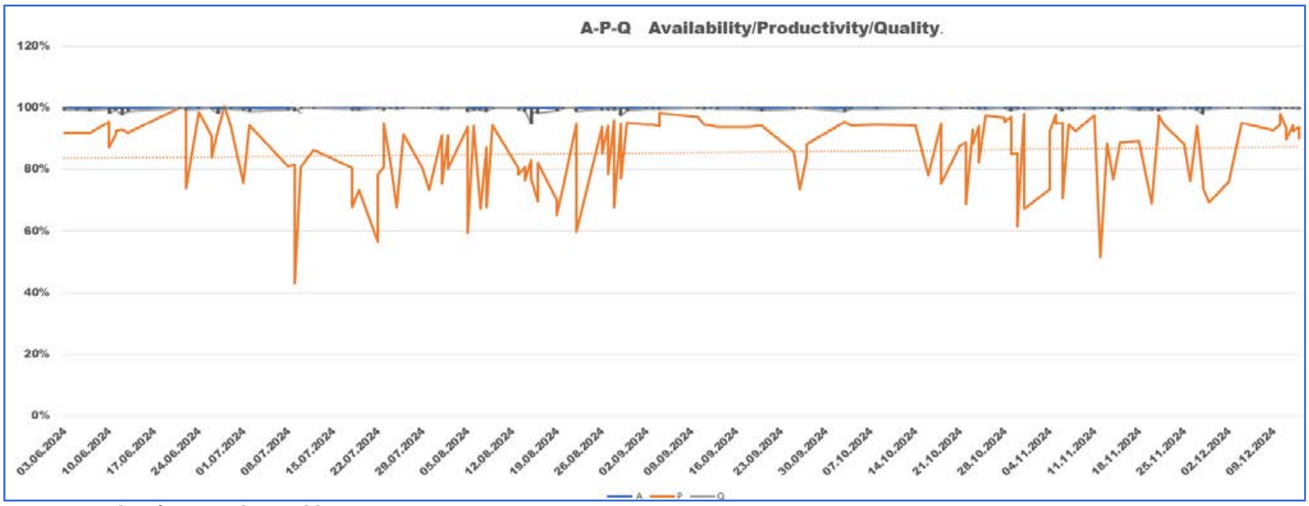

Fig.7 A-P-Q data for manual assembly process

A graphical representation of the data for an automated assembly process over a period of seven months is shown in Fig. 8, Fig. 9 and Fig. 10.

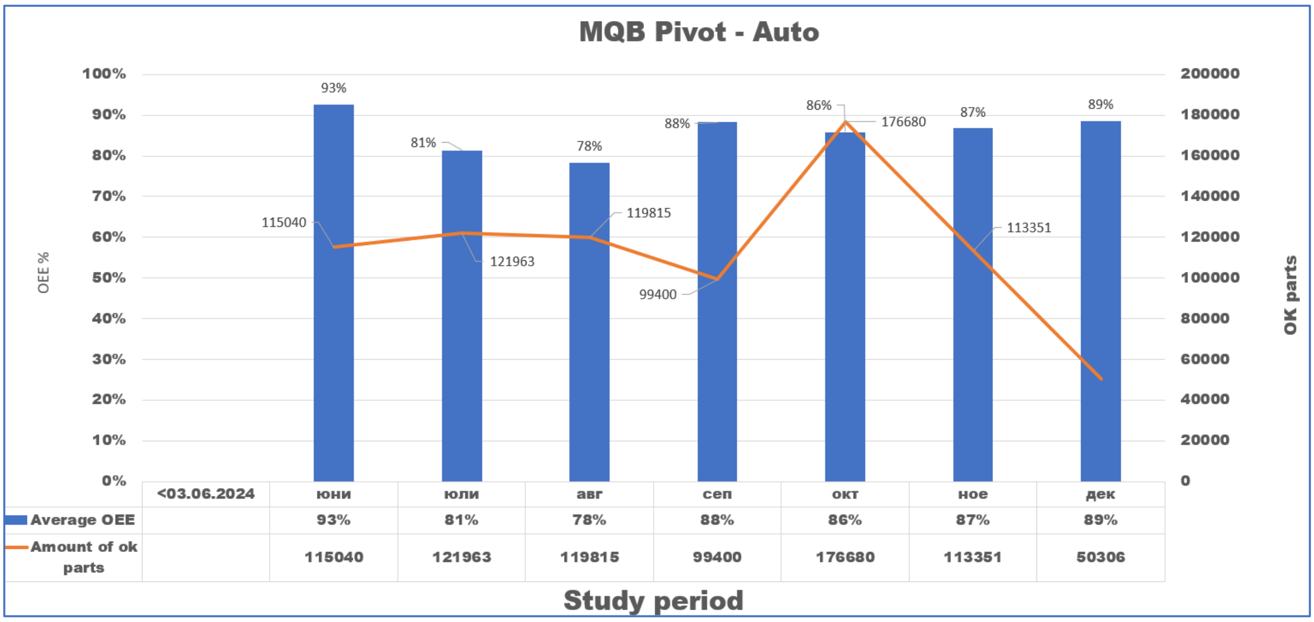

Fig.8 Number of usable parts / OEE MQB pivot part for a period of 7 months with an automated assembly process

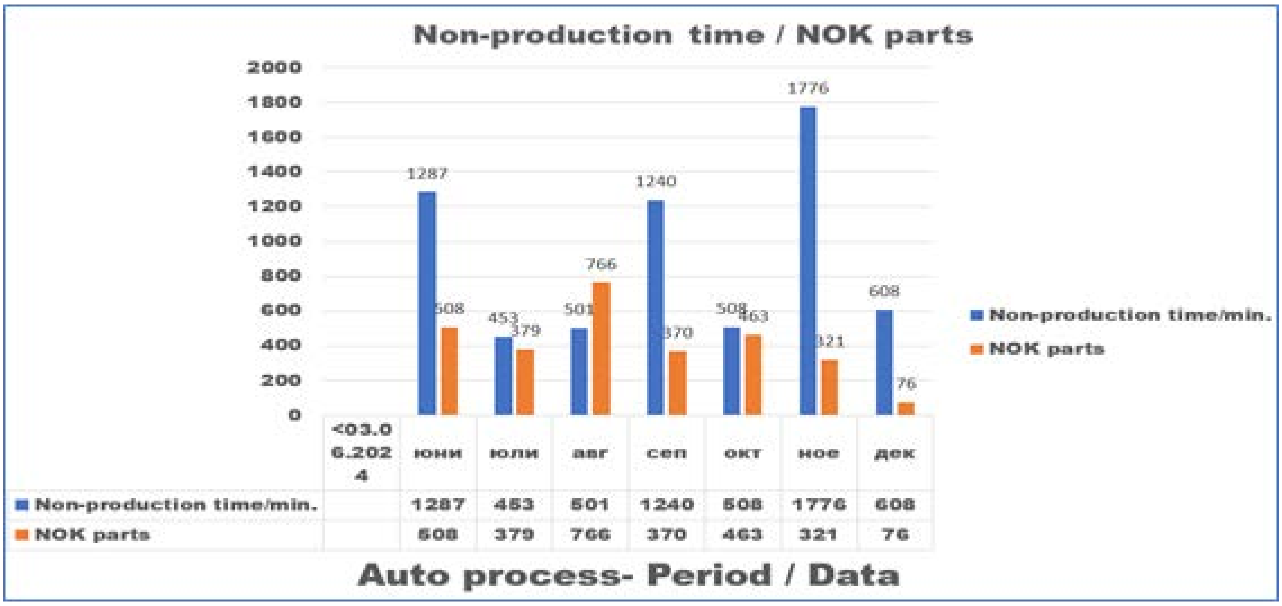

Fig.9 Breakdowns/Defects for a period of 7 months in an automated assembly process.

Fig.10 A-P-Q data for an automated assembly process.

V. Analysis Of OEE Data During The Transformation Of The Process From Manual To Automated

The efficiency of the manual process is lower, with OEE values varying between 70% and 85%, and fluctuations from month to month create instability. The high frequency of non-productivity and significant scrap compared to manufactured parts of over 100 pieces per month have a negative impact on Availability and Quality, which leads to lower indicators: Availability ~80–95%, Performance ~40–85%, Quality ~85–88%. Unlike the manual process, the automated approach guarantees higher efficiency and stability, the automated process shows 51.9% higher productivity than the manual one. OEE values reach 85–93%, and the productivity level is stable. The frequency of stops is greatly reduced, with the number of scrapped parts being below 0.44% compared to the manual 0.7%, and equipment downtime is minimal.

Automation leads to significantly better indicators – Availability over 90%, Performance peaks ~60%, Quality over 97%. In comparison, the Performance peaks of the manual station reach levels of ~40%. The comparison between the two methods clearly shows that automation is superior to the manual process in every respect. It improves productivity, reduces losses and guarantees high and stable quality. Investing in automated systems is highly recommended, as it ensures more efficient and reliable production with optimal use of resources. Also, the possibility of integrating real-time process monitoring systems and data recording allows for process analysis and investment in improvements.

VI. Conclusion

The transition from manual to automated assembly in the automotive industry brings significant advantages: higher productivity, more consistent quality, increased safety, and also high investments in skilled labor for: repairing, operating and modifying machines. Despite the challenges associated with capital costs and the need for training, the long-term benefits of integrating digital technologies guarantee a sustainable and competitive production process.

However, the human factor and thought are an indispensable part in every area of the production cycle. Presents real data from a seven-month study of two types of production (manual and automated), which provides a solid practice-based justification of the effects of process automation. Demonstrates a methodological application of the OEE indicator as a reliable tool for comparing production processes. Examines investment costs, necessary personnel training and ROI, giving a comprehensive picture of the transformation from manual to automated production.

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