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ARTIFICIAL INTELLIGENCE IN QUALITY CONTROL WITH LEAN MANUFACTURING IN THE AUTOMOTIVE INDUSTRY

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Abstract

Lean is an efficient and proven system of cutting operating expenses and eliminating wasteful activities on the manufacturing companies. The lean principles are established for the growth and continued existence of the industries connected to production and sector in service. The automotive industry is experiencing a change at its fundamentals due to the adoption of Artificial Intelligence (AI) and Lean Manufacturing. Drawing from relevant literature this paper is a discussion of the roles that AI can have in improving manufacturing techniques, product quality, and customer satisfaction. Predictive analytics and automated inspection from the AI technologies help manufacturers to reduce wastage, cut on defects and improve efficiency. Lean manufacturing means reduction of waste, and, when integrated with AI, it enables manufacturers to optimize their operations by using robust and relevant information. The paper also explores more specifically areas of integration between AI and Lean process; many principles where AI been shown to increase Lean practices within the automotive industry are discussed. Through real-time monitoring, empowered employees, and a customer-focused approach, the integration of AI into Quality Control fosters a culture of innovation, leading to superior automotive products that meet and exceed customer expectations. This paper examines the synergies between AI and lean manufacturing, highlights the benefits of implementing these strategies in the automotive sector, and discusses the key challenges and solutions in quality control.

Keywords: Artificial Intelligence, Quality Control, Lean Manufacturing, Automotive Industry.

I. INTRODUCTION

First of all, Most lean concepts have their roots in Japanese corporations, namely in Toyota. Lean manufacturing maximizes the value of the product by minimizing waste, despite the misconception held by many authors that it is a waste reduction strategy. Value added (VA) and non-value added (NVA) activities are distinguished in order to ascertain the client's perceived value of the good or service. Then, in order to cut waste, lean principles define this value and pursue perfection through ongoing improvement. The primary causes of NVA activity wastes include transportation, inventory, motion waiting, overproduction, over processing, and faults. The debris left over by NVA operations is a significant barrier to VA action. These wastes are eliminated when lean ideas are successfully implemented.[1][2].

Moreover, the advent of Industry 4.0 and smart manufacturing technologies has further enhanced Lean Manufacturing's ability to maintain stringent quality standards in automotive production[3]. Technologies like IoT[4], AI[5], and machine learning [6]enable predictive maintenance, real-time data analysis, and automation in quality control, allowing manufacturers to foresee potential

defects and prevent them before they occur. This integration of Lean and digital technologies guarantees the quality of products produced with less defects and optimum rework[7][8].
Further, machine learning and AI have added as new dimensions of quality control in terms of performance by paving the way for predictive quality. In the automotive industry, that concept is known as predictive quality where manufacturers are able to predict the quality of a product using data and analysis of both process and product[9][10]. Process parameters may be used by the machine learning models to predict possible quality problems in future and this help the manufacturers to seek corrective measures early in the manufacturing process to guarantee that the goods fulfil the strict required quality[11].

Last but not least, quality control is the last application of Lean Manufacturing, where supplier quality shall also manage. Since automotive manufacturing involves numerous other suppliers, quality from one supplier to another must be maintained. JIT production and TQM therefore enable supply chain activities to co-ordinate by making sure suppliers deliver a quality product, free from defects that may affect the overall final product.[12].

The purpose of this study is to investigate how lean manufacturing principles and quality control (QC) can be used to enhance productivity and product quality in the automobile sector. It focusses on how current QC techniques, waste reduction, and continual improvement lower variability and defects. Moreover, the study investigates the function of cutting-edge technology like AI and machine learning in optimizing quality management in automotive manufacturing.

1. Structure of the paper:

The paper is structured as follows: Section II provide the role of AI in Automotive Industry; Section III discussed the lean manufacturing practices within the automotive industry. Section IV provide the integration of AI with LM, Section V and VI gives the QC in Automotive Industry with in LM, Section VII Integration of AI in Quality Control. Section VIII presents a literature review of relevant studies. Finally, Section IV concludes with insights and future recommendations for the field.

II. ARTIFICIAL INTELLIGENCE IN AUTOMOTIVE INDUSTRY

A multitude of elements characterize this era of technological advancement, rendering every aspect of human existence reliant on consumer technology. The manufacturing technology of the 4.0 industrial era has enabled automation and data sharing, which has led to the classification of human demands as relatively high. domains where AI stands for artificial intelligence, which is used to try and reduce risk. As technology develops, it must be able to manage and disperse all components and data associated with each contact between humans and self-governing robots [13].

Figure 1: Use cases of Artificial Intelligence In Automotive Industry

Figure 1 illustrates the use cases of artificial intelligence in the automotive industry. The function of artificial intelligence (AI) in the automobile sector has expanded significantly in recent years, influencing various aspects from manufacturing processes to end-user experiences. Here are some key areas where AI is making an impact:

1. Manufacturing and Production

AI optimizes automotive production through timely prediction of machines breakdown hence reducing periods of production halt. It also uses object recognition for checking flaws in parts, for tracking demand and ensuring proper supply chain management for stock.

2. Autonomous Vehicles

Self-driving cars are built using artificial intelligence that receives information from the car's sensors and cameras to drive without involving humans. Machine learning enables perception to check for obstacles and learn to predict behavior making it perfect suitable for complex environments.

3. Driver Assistance Systems

ADAS is where Artificial intelligence assists drivers with systems such as lane departure warning and automatic speed regulation. These systems improve safety because they monitor the road conditions then adapt the vehicle response and also set preferences unique to each driver.

4. Connected Vehicles

Intelligent vehicles apply artificial intelligence for such aspects as telematics and data analysis giving information about the automobile's functioning and required servicing. Annually, customers also adopt the use of Artificial intelligence in optimizing driving patterns for insurance rates.

5. Customer Experience

AI enhances customer relations by dealing with client enquires and assistance with vehicle purchase through chatbots and virtual assistants. Moreover, AI improves presentation and features of infotainment with natural speech and orders understanding and more suitable content.

Research and Development

AI facilitates rapid research and development in the automotive sector through advanced simulations, allowing manufacturers to test new designs virtually. It also aids in discovering new materials to improve vehicle performance and safety.

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III. LEAN MANUFACTURING IN THE AUTOMOTIVE INDUSTRY

Lean production, also referred to as lean manufacturing, is a set of techniques and procedures used to run a manufacturing and services company effectively. Depending on the application, different techniques and steps are taken, but they always adhere to the same basic idea: the elimination of all wasteful and non-value-adding activities from the business[14], Regardless of Figure 2 lean manufacturing structure.

A conceptual framework called lean manufacturing aims to maximize customer value. by eliminating or minimizing waste, defined as any element that does not contribute value to the customer. Contemporary automobile production is defined by the necessity for reduced lead times, diversification of current product lines, expedited launch of new products, and swift market entry. Consequently, automotive manufacturers must effectively execute lean manufacturing across multiple tiers to endure and prosper against intense market competition. Lean manufacturing emphasizes the minimization of various forms of waste that result in value loss, including inefficiencies in motion, waiting times, inventory, production, rework, and others. According to the principles of lean manufacturing, the reduction of costs, effort, time, labor, and equipment-related waste inherently enhances the productivity of a manufacturing enterprise. Efficient administration of industrial flexibilities is essential for attaining these objectives. This subsection presents manufacturing flexibilities within lean manufacturing.[15][3].

1. Principles of Lean Manufacturing

The core principles of lean manufacturing, often referred to as the 5 Lean Principles, guide the implementation of lean strategies in various industries, including automotive:

A. **Value Definition:** The first principle involves identifying value from the customer's perspective. In the automotive industry, value can be defined in terms of the quality, safety, and performance of vehicles, as perceived by customers [16].
B. **Value Stream Mapping**: This refers to mapping out the entire production process to identify areas where waste occurs. In automotive production, waste can be excess inventory, defects, overproduction, and unnecessary transportation or handling of parts [17].
C. **Continuous Flow:** This principle focuses on ensuring that production flows smoothly, with minimal interruptions or delays. Manufacturers of automotive products strive to improve the efficiency by reducing cycle time and guaranteeing the flow of components on the assembly line.
D. **Pull System:** A pull-based system means that the company's production depends on the actual number of customers out there, and not on how many cars it can produce at a given period. In automotive industry one of the most famous lean techniques is just-in-time production that implies the manufacturing of parts and cars in required quantities.
E. **Pursuit of Perfection**: Lean manufacturing demands a work culture of continual progress or what is referred to as Kaizen. In the context of the automotive industry this refers to permanently checking for inefficiencies and constantly revisiting procedures to make small improvements to its final efficiency and quality [18].

2. Benefits of Lean in Automotive Production

The automotive industry has gained numerous benefits from the adoption of lean manufacturing practices, which have helped manufacturers maintain competitiveness in a global market:

A. **Reduction of Waste:** Many types of wastes get eliminated with lean practices, including, inventories, unnecessary movements, overproduction and defects. This results in even a more efficient manufacturing process and the overall save on materials.
B. **Improved Quality:** Integral to lean manufacturing is the continuous integration of quality control in the production process so that any defects are only had at an early stage and corrected [20]. This means that the improvement of the quality of the final product is accomplished since defective products are few in the assembly line.
C. **Enhanced Efficiency**: Lean manufacturing entails eliminating of wasteful activities and shortening the cycles. In automotive production, this results in increased production line velocities but with the quality of the end product being well maintained to enable efficient delivery of automobiles to serve the market demands [19][20].
D. **Cost Savings:** Lean manufacturing assist the automotive organization to decrease the cost of manufacturing as it eliminates waste costs including the costs of used materials, man-power and energy consumed in the firm. They make the utilization of resources productive because they support a high level of productivity that achieves more with less.
E. **Increased Flexibility**: In addition to JIT and continuous flow, used in automotive manufacturers, they are now able to react more quickly to the fluctuating markets. This gives them a flexibility that they can build a car to meet a specific client demand or build fewer or more depending on demand.
F. **Enhanced Customer Satisfaction**: Lean manufacturing guarantees products meet customer requirements to a larger extent. The following shows how automotive manufactures can enhance customer satisfaction and loyalty through high quality cars which are free from defects [21].

IV. INTEGRATION OF AI WITH LEAN MANUFACTURING

In the following section, details of how lean manufacturing and artificial intelligence are combined shall be discussed.

1. Synergies between AI and Lean Manufacturing

AI is used in Lean Manufacturing to boost its performance by the application of analytics and reduction of costs and wastage. For that purpose, it is possible to integrate sale techniques based on machine learning and predictive analytics, highly associated with Lean processes, which are designed to discover defects during the performance of other processes continuously. By allowing the implementation of actual production systems that are adaptable to change AI tools take Lean to the next level by allowing organizations to automate the work involved in optimization.

2. AI for Process Optimization in Lean Manufacturing

Manufacturing process efficiency is enhanced by AI platforms that are able to gather data from the manufacturing floor to look for inefficiencies. Techniques like machine learning and computer vision enhance precision, reducing human error, and increasing operational speed. Predictive maintenance through AI helps maintain equipment reliability, a critical factor in Lean's waste reduction objectives.

3. Enhancing Productivity and Quality with AI

AI increases productivity and quality in Lean manufacturing by automating tasks, detecting defects earlier, and ensuring consistent output. For example, AI-driven robotic systems can perform quality control checks faster and more accurately than manual inspections, enhancing throughput while maintaining high quality standards[22][23].

V. QUALITY CONTROL IN AUTOMOTIVE INDUSTRY

Various industrial sectors employ distinct production techniques. These distinct process characteristics impose varying requirements and instruments for quality control [24]. The automotive industry, akin to other sectors, possesses distinct characteristics. The welding process, the most prevalent method, is quite intricate. Projects are of moderate duration and costliness [25]. Furthermore, several operations are interconnected and reliant upon one another. Moreover, the manufacturing quantities are substantial, and all expenses are minimized to the lowest possible level or below. The expense associated with malfunctioning components is typically very substantial[24]. These attributes lead to numerous issues in automobile quality assurance. Since the inception of the automotive industry, dating back to Henry Ford, a perfect de facto solution for quality control has yet to be established.

1. Sampling & SPC

Sampling inspection refers to the evaluation of a limited segment of production, such as every thousandth unit or one unit each day. The process's behavior is assessed using statistical analysis of these samples. This methodology is referred known as SPC, or statistical process control, has been widely used in the automotive sector since the 1940s. Currently, it is prevalent for a coordinate measuring machine (CMM) will be utilized for the inspection of samples. The CMM's measuring duration typically precludes the inspection of additional parts within a single day.

2. Non-or-all Inspection

For more than fifty years, there has been a vigorous discourse—both practical and scholarly—regarding the sample technique in quality control through sampling inspection. Augmenting the sampling rate elevates inspection expenses. Decreasing the sampling rate diminishes the quantity of information.
[26].

A. Challenges in Quality Control

The significant issues identified through the analysis of existing works are deliberated as follows:

- **Limited data availability:** Labeled data for training AI models in semiconductor production can be insufficient. Future studies should concentrate on developing methods to generate synthetic data or evaluate TL (Transfer Learning) approaches to utilize data from related domains [27].
- **Scalability:** Executing AI-based quality control systems in large-scale semiconductor production facilities can present difficulties. Future efforts should concentrate on developing scalable architectures and AI algorithms capable of dealing with the substantial velocity and volume of real-time generated data [28].
- **Interpretability and explain ability**: AI models applied in quality control must deliver

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interpretable and explainable outcomes for establishing reliability among the stakeholders and operators [29][30].

- **Adaptability to process variations:** Semiconductor production processes can exhibit variations due to material differences or equipment disparities. Future research should explore AI techniques that can adapt and generalize effectively across diverse process variations, ensuring robust quality control.
- **Ensuring cost-effectiveness:** Adopting AI-based quality control systems encompasses substantial expenses, including data acquisition, infrastructure, and model development. [31].

VI. QUALITY CONTROL (QC) WITHIN LEAN MANUFACTURING

Quality Control (QC) within Lean Manufacturing focuses on ensuring product quality while minimizing waste and maximizing efficiency. Lean Manufacturing is a methodology aimed at streamlining production processes by reducing waste, improving workflow, and optimizing resource utilization. Here's a detailed overview of how QC integrates with Lean Manufacturing principles:

A brief discussion of each key concept of Quality Control (QC) in Lean Manufacturing:

- **Waste Reduction**: In Lean Manufacturing, waste reduction is vital, focusing on eliminating non-value-added activities. This involves making a detailed analysis of inspection procedures with an aim of either eliminating or simplifying other procedures to increase the quantity of work completed in a given length of time. One of the usual philosophies is the continuous improvement or known as Kaizen, which give power to the employees in a way that they are encourage making various assessments of the procedures and creating a culture of steady improvement.
- **Empowering employees**: This is another requirement as you mentioned empowering employees. An effective approach implemented to enhance quality is the Quality at the source where a worker is taken through a process where they are able to take individual responsibility and rectify the quality problem on their own without passing the substandard product to other departments. These personnel bring a wealth of experience and broad focus, which arises from cross-training within the manufacturing unit, to a team that can better address difficulty at Craven Mills.
- **Standardization:** This is because standardization is always crucial in maintaining consistency on the kind of products produced. In addition to that, well written SOP facilitates identification of non-conformities and facilitate implementation of corrective measures since there is always a laid down way of doing a particular activity. Visual control tools raise visibility of improvement data and organizational delivery, making key control metrics more proactive.
- **Real-time monitoring and feedback**: In monitoring and communicating the Lean initiatives, data collection and feedback are used in real time. This makes it possible for organizations to get real-time feedback to quality indicators, and help intervene when necessary. With the help of IoT devices, and automation, the quality check can be done all the time, and thus if there are deviations they can be immediately corrected.
- **Customer Focus**: Last but not the least; customer centricity is the core of Lean Manufacturing. Customer requirements to be understood to ensure that quality checks in the organization meet the expectations of the customer which increases satisfaction. Another best practice when giving feedback to customers encompasses practices that provide the manufacturer with

helpful feedback regarding the quality of products that are being delivered to the market so that its QC processes can be improved on as time progresses while at the same time holding customers' loyalty through good end user feedback.

VII. INTEGRATION OF AI IN QUALITY CONTROL

The following two are very used in lean manufacture for integration of AI in AC;

1. Automated Inspection:

Artificial Intelligence employs high image samplings and training of higher algorithms to analyze picture information from sensors and cameras. This automation contributes to a higher speed and precision of defects comparison with typical manual inspections[34][35]. Since it becomes easier and faster to detect anomalies from the set manufacturing parameters, manufacturers can resolve quality issues as they emerge, result in better quality products throughout the manufacturing process. This method markedly enhances the speed and accuracy of defect detection compared to traditional human inspection methods.

- **Speed:** Machines are capable of analyzing images and data much quicker than man and so production lines can be observed continually. This eliminates time wastage in defining what is wrong with a product, which in turn reduces time wastage.
- **Accuracy:** Many kinds of defects could be defined with a high level of accuracy by training machine learning models. They are convergence to various product forms and defect types hence minimize the chances of both false positive and false negative.

Therefore, there will be an opportunity for the manufacturers to rectify customer complaints regarding the quality of their respective-made products, and hence enhance the quality of their products and gain the trust of the customers.

2. Predictive Analytics:

Consequently, quality data is studied by machine learning algorithms in order to derive patterns and trends about it, which leads manufacturers to detect future quality issues. It also helps the companies to take corrective action before the problems occur, hence minimizing on the times that have to be lost and maximizing on the productivity of the production line.

- **Proactive Problem-Solving:** Through the identification of potential problems before they arise, the manufacturers are in a position to correct them. For instance, if a model establishes that one certain machine is likely to develop faults then maintenance can be arranged to prevent the development of the faults before they occur.
- **Increased Efficiency**: This contingency approach of preventive and planned measures minimizes as much time as possible that can be lost due to defects and rework. It also facilitates proper handling of stocks, since manufacturers will occur, when need arises where such issues are most probable to happen.

Overall, both automated inspection and predictive analytics significantly contribute to enhancing quality control processes, enabling manufacturers to produce higher-quality products with greater efficiency.

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VIII. LITERATURE REVIEW

A survey of the literature on lean manufacturing frameworks and techniques, particularly as they relate to the automotive sector, is presented in this section. It examines many strategies that have been used to increase production processes' effectiveness, cut waste, and raise their quality.

In this study Perico and Mattioli, (2020), presents a Accelerated technology advancement has unveiled new company prospects, compelling organizations to perpetually implement increasingly sophisticated solutions to maintain competitiveness. Following the definition of Lean 4.0, which seeks to offer valuable insights for the amalgamation of lean principles and Industry 4.0 within manufacturing enterprises, artificial intelligence is then introduced as a pivotal enabler. This study examines the integration and enhancement of AI inside Lean 4.0, primarily exploring process and control challenges through improved utilization of data and knowledge [32].

This paper Ramakrishnan et al. (2024), the Kano two-dimensional quality model was proposed. Both SPSS and MATLAB are used in the data analysis process. Based on the results of the analysis of two software programs, the most efficient method was identified. The average risk assessment value is predicted by this method to be a high-risk factor. In the SPSS model, the supply chain convergence speed varies between 1.89 and 4.25 seconds, while in MATLAB, the implementation time is associated with 16.83 seconds. The findings indicate that MATLAB can develop the most effective prediction model utilizing the given methodology with the questionnaire data [33].

In this work Kötter et al. (2023), to evaluate the effectiveness of the augmented reality user interface, a survey with people working alongside the cobot equipped with the visualization-system is conducted. The survey assesses the perceived usefulness, ease of understanding, and overall satisfaction with the user interface. The result of the survey indicates that the user interface significantly improves the comprehension of cobots actions. Participants working with this visualization system report enhanced situational awareness, reduced ambiguity, and increased efficiency. The qualitative feedback highlights the effectiveness of the visual cues in conveying information and the ease of integration into existing production processes [34].

Some of the studies Zope, Swami and Patil, (2023), offer a new way by employing real-time data to analyze the barriers with a view of ranking them. Following a thorough review of the literature, four primary obstacles impeding the assembly process were found: conveyance as well as designing, palletizing and conveyance, line production, EV construction merging, and staff recruitment and education. In order to improve the evaluation and ranking process, the current paper presents a procedure by employing TOPSIS methodology. Compared to the previous approach, this approach provides a more real-time and precise estimation of the barriers. These set solutions can serve as a guide for policy maker in auto manufacturing to channel more resource on the areas that were a concern in this study for effective assembly of Evs [35].

This study Kapse et al. (2021), proposes the construction of a specialized machine to perform sensor hole punching and bracket adhesion operations. This system supersedes the manual approach, which is time-consuming and produces only 60 components daily. The proposed technology is cost-effective, conserves significant time, and facilitates the production of 200 pieces daily. This paper presents a comprehensive design The creation of a special purpose machine with mechanical, pneumatic, electrical, and PLC components for sensor hole punching and bracket pasting elements [36].

In this paper Ferreira and Teixeira, (2023), A case study will be undertaken on the utilisation and application of Lean, a digital technology that regularly supports an organization's production lines in the automobile sector. Because mean is digitally orientated, it can create settings that are less

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complex and more dynamic, which improves industrial quality, flexibility, and productivity. Sector, corroborating the findings of this study [37].
This paper Dacal-Nieto et al. (2020), presents a particular instance of digital transformation at an automotive plant, detailing a roadmap, an architecture, and initial studies concerning quality, dependability, as well as proactive upkeep in the paint shop. Additionally, covered are statistical control, data visualization, and data collecting. Success stories encompass diminished defect rates, process optimization, and early identification of parameter deviations through the application of algorithms using artificial intelligence on datasets of hundreds of thousands of produced cars and thousands of variables. These activities have resulted in cost reductions for the factory, alongside enhancements in productivity and efficiency, demonstrating the feasibility of achieving quick wins while implementing a long-term plan. The entire plant is currently using this method, which includes the assembly line, body in white, and stamping. The table 1 shows the Related work summary for the Lean manufacturing within AI and Quality Control [38].

Table 1: Related work summary for the Lean manufacturing within AI and Quality Control

Reference	Title/Focus	Key Findings/Methodology	Applications	Outcomes/Impact
[32]	Lean 4.0 Integration with AI	Introduces Lean 4.0 as a framework integrating lean principles with Industry 4.0; AI as a key enabler for process and control issues.	Manufacturing companies looking to enhance competitiveness.	Improved data utilization and knowledge management in production.
[33]	Kano 2-D Quality Model Analysis	Utilizes MATLAB and SPSS for data analysis to predict high-risk factors in quality assessment.	Quality improvement in production processes.	Identified optimal predictive model; MATLAB showed superior performance.
[34]	Augmented Reality User Interface for Cobots	Conducted a survey assessing the effectiveness of AR interfaces on cobots, focusing on usability and efficiency.	Collaborative robotics in automotive assembly lines.	Enhanced situational awareness and increased operational efficiency.
[35]	Real-time Data Analytics for Assembly Process Barriers	Identifies barriers in EV assembly; proposes TOPSIS methodology for dynamic assessment and ranking.	Decision-making in assembly process improvements.	Provides insights for prioritizing resource allocation in EV assembly.

[36]	Design of a Specialized Machine for Sensor Hole Punching and Bracket Adhesion	Develops a machine to automate processes, increasing throughput from 60 to 200 parts per day.	Automation in assembly processes.	Cost-efficient solution with significant time savings.
[37]	Implementation of Lean Digital Tools (mean)	Case study on mean's impact on production lines; emphasizes digitization for improved quality and flexibility.	Automotive industry production line management.	Improved productivity and reduced complexity in operations.
[38]	Digital Transformation in Automotive Factory	Case study focusing on digital transformation in Paint Shop; highlights data analytics for quality and predictive maintenance.	Quality control and maintenance in automotive manufacturing.	Reduced defect rates and improved overall productivity.

IX. CONCLUSION AND FUTURE WORK

Lean production is a prevalent philosophy aimed at waste elimination and continual improvement in manufacturing; yet, the need for a supporting software solution remains a contentious issue.

In this study, the significance of implementing both lean manufacturing systems and improved quality control techniques in the manufacture of automobiles. Considering the principles like the elimination of waste and its constant minimization, the quality of products will be improved along with other manufacturing processes. The automotive industry is under great pressure when it comes to both product quality and efficiency of production lines. Given that, automotive manufacturers are aware of the growth of comforts, and rising of intensiveness, it will be the successful effect to put the AI and Lean principles into practice. Advanced automation of surface inspection increases the speed of defect detection and accuracy of results; meanwhile, advanced usage of predictive analysis allows for fewer unexpected breakdowns. The features of Lean Manufacturing, including waste minimization and constant enhancement, are empowered via AI that shapes a culture of high quality and creativity. When supply-side production processes mirror demand-side consumption, satisfaction and loyalty increase and the overall competitive advantage in today's global automotive industry improves. Hence, the future operation of the automotive industry will be founded on the collaboration between Lean Manufacturing and AI, thus setting the new bar in quality control and operation improvement.

The future research work should aim at: Mitigating the challenges highlighted in this study with regard to cultural resistance, supply chain and the scalability of AI technologies. To better understand how to implement AI within production and to improve quality control the methods of making models for AI more flexible in a variety of settings must be studied. Further, using synthetic data generation and transfer learning could help avoid shortcoming associated with limited availability of labeled data. Moreover, it urges for further investigation of human-AI working relationship in order to optimize the quality control results as well as the proper use of data. Possible directions for future research might also be to conduct a series of investigations to

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compare and measure quality improvements and productivity gains in the context of the automotive industry, after the implementation of the aforementioned integrations.

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