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Lean Manufacturing through Karakuri Kaizen: Implementation of a Nut Dispenser Mechanism Using Poka-Yoke in the Automotive Industry

Kartikaey[1], Gurpreet Singh[2], Vikas Salotra[3], D K Bhalla[4]

[1,2,3] UG Student, Department of Mechanical Engineering, Lingaya's Vidyapeeth, Faridabad, Haryana, India
[4] Professor, Department of Mechanical Engineering, Lingaya's Vidyapeeth, Faridabad, Haryana, India

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Abstract – *This research explores the application of lean manufacturing techniques in the automotive industry through the development of a Nut Dispenser Mechanism that enhances manual assembly accuracy. Designed using Karakuri Kaizen principles and incorporating Poka-Yoke features, the mechanism addresses common issues associated with manual nut picking, such as incorrect quantities and loose fasteners. The system operates without external power, using a magnet-assisted rotating wheel and guided slope to dispense exactly two nuts per cycle.*

After implementation, the average nut picking time reduced from 3 seconds to 1.5 seconds, and loose nut defect cases dropped from four per month to zero. These improvements demonstrate the mechanism's effectiveness in streamlining workflow, reducing variability, and enhancing product quality. This case study validates the potential of simple, cost-efficient mechanical solutions in achieving lean objectives, offering valuable insights for similar manual assembly processes across industries.

Key Words: **Lean Manufacturing, Karakuri Kaizen, Poka-Yoke, Manual Assembly, Automotive Industry, Nut Dispenser**

1.INTRODUCTION

In the context of a highly competitive global marketplace, manufacturing industries—especially those in the automotive sector—are under constant pressure to enhance production efficiency, minimize waste, and improve the overall quality of their products. Lean manufacturing, rooted in the Toyota Production System (TPS), provides an effective framework for achieving these objectives. Lean manufacturing is centered on eliminating waste, optimizing processes, and fostering a culture of continuous improvement (Kaizen), all while empowering employees to participate in the enhancement of operational systems [1]. Numerous recent studies have demonstrated that the successful adoption of Lean principles not only boosts operational efficiency but also helps in reducing costs and improving product quality [2].

A significant aspect of Lean manufacturing is Karakuri Kaizen, which involves employing simple mechanical systems to improve production processes without the need for costly automation. This technique emphasizes the use of low-cost, high-impact solutions to streamline workflows and reduce operational inefficiencies. By incorporating simple mechanical devices, Karakuri Kaizen facilitates substantial productivity gains and error reductions within the manufacturing process [3]. It has been especially beneficial in sectors such as automotive manufacturing, where affordability and practicality are essential for process optimization [4].

Another key principle in Lean manufacturing is Poka-Yoke, or mistake-proofing, which aims to eliminate human errors in production systems by designing error-proof mechanisms. These systems automatically prevent potential mistakes, ensuring that production processes remain smooth and defect-free. In the automotive industry, Poka-Yoke is commonly applied to prevent errors such as incorrect component placement, assembly mistakes, and missing parts, thus ensuring higher quality and reducing defects [5]. Recent advancements indicate that the implementation of Poka-Yoke can significantly boost both the operational efficiency and quality in manufacturing environments [6].

This paper examines the Nut Dispenser Mechanism in the automotive sector, which integrates the principles of both Karakuri Kaizen and Poka-Yoke. The mechanism is designed to automate the process of dispensing small parts, such as nuts, during assembly. The incorporation of Poka-Yoke ensures the correct number of nuts are dispensed each time, thereby preventing errors and minimizing the chances of defects in the final assembly.

The objective of this research is to assess the effectiveness of the Nut Dispenser Mechanism in improving production efficiency, reducing waste, and enhancing overall product quality within automotive manufacturing. By lowering errors and promoting continuous improvement, this study assesses how the combination of Karakuri Kaizen and Poka-Yoke can help create manufacturing processes that are more dependable and efficient.

2. LITERATURE REVIEW

The automotive manufacturing sector is continuously seeking ways to improve operational efficiency, reduce waste, and enhance product quality. Lean manufacturing, a framework derived from the Toyota Production System (TPS), is a widely adopted approach designed to achieve

these goals. At its core, Lean focuses on eliminating waste, optimizing processes, and ensuring continuous improvements (Kaizen) through the empowerment of workers [1]. Numerous studies have shown that the application of Lean principles significantly enhances efficiency and reduces operational costs while improving the final product's quality in the automotive industry [2].

2.1 Lean Manufacturing in Automotive Production

The key tenets of Lean manufacturing—waste elimination, process optimization, and continuous improvement—have been critical in boosting the effectiveness of automotive production lines. By focusing on improving value creation and reducing inefficiencies, automotive manufacturers have achieved notable advancements. For instance, Panwar and Jain (2017) has successfully applied Lean practices to cut down production cycle times and improve quality simultaneously [2]. Panwar and Jain (2017) found that the integration of Lean practices with robust management strategies led to marked improvements in both operational efficiency and financial outcomes in the automotive industry [2].

Moreover, tools like Value Stream Mapping (VSM) have become indispensable in identifying and eliminating inefficiencies in automotive production lines. As the automotive industry faces ever-increasing pressure to optimize costs and maintain quality, Lean methodologies, including VSM, have been tailored to meet the unique challenges of mass production [9].

2.2 Karakuri Kaizen: A Low-Cost Innovation for Process Improvement

A standout concept within Lean manufacturing is Karakuri Kaizen, which uses simple mechanical systems to enhance production efficiency without relying on costly automation. This method has gained significant attention due to its affordability and effectiveness, making it accessible even to smaller manufacturers alongside large corporations in the automotive industry [3].

Karakuri Kaizen has proven effective in reducing operational inefficiencies, improving productivity, and enhancing worker safety. Pogowonto & Amrina (2020) reported that the introduction of Karakuri devices in an automotive production line led to faster part handling, reduced downtime, and smoother process flows [7]. Employee involvement is also encouraged and a continuous improvement culture is fostered by the simplicity of Karakuri systems. These devices are particularly beneficial in environments like automotive manufacturing, where small inefficiencies can compound, affecting overall production timelines and costs [6].

2.3 Poka-Yoke: Mistake-Proofing for Error-Free Manufacturing

Another vital Lean tool is Poka-Yoke, which aims to prevent human errors by designing processes that automatically detect and correct mistakes before they result in defects. This technique is especially important in automotive manufacturing, where precision is crucial and errors can have significant consequences. Poka-Yoke systems help eliminate issues such as incorrect part placement, assembly mistakes, and missing components, ensuring higher quality and fewer defects [5].

Research by Liker and Meier (2019) emphasized that even simple Poka-Yoke devices could effectively reduce defects and enhance speed in automotive assembly lines [8]. Shingo (2018) highlighted that Poka-Yoke not only improves product quality but also boosts workers' confidence by providing safeguards against common errors during production [6]. In high-volume environments, the ability to detect and prevent errors automatically is a critical advantage, reducing the risk of defects and the need for rework.

2.4 Nut Dispenser Mechanism: An Example of Integrating Karakuri Kaizen and Poka-Yoke

The Nut Dispenser Mechanism serves as a prime example of how the integration of Karakuri Kaizen and Poka-Yoke can significantly enhance automotive production. This simple mechanical device automates the dispensing of nuts and small components, ensuring that the correct number of parts are dispensed without error. The incorporation of Poka-Yoke ensures that the dispensing process is both error-proof and efficient, preventing issues such as the dispensing of incorrect quantities.

The use of a Nut Dispenser Mechanism in automotive assembly lines can save time by automating the part-handling process while minimizing errors such as missing or over-dispensed parts. This mechanism exemplifies how combining Karakuri Kaizen's low-cost mechanical solutions with Poka-Yoke's mistake-proofing can streamline operations, reduce waste, and enhance overall product quality.

2.5 Conclusion

The literature highlights the significant role of Lean manufacturing, Karakuri Kaizen, and Poka-Yoke in driving operational improvements and ensuring high-quality output in automotive manufacturing. By using these approaches, businesses can increase overall productivity, decrease faults, and streamline their manufacturing processes. The Nut Dispenser Mechanism represents an effective application of both Karakuri Kaizen and Poka-Yoke principles, demonstrating their potential to improve manufacturing efficiency. Future research could further explore the

refinement and broader application of these techniques to maximize their effectiveness in diverse manufacturing contexts.

3. METHODOLOGY

This study utilizes an experimental research approach to design, implement, and evaluate the Nut Dispenser Mechanism, which incorporates Karakuri Kaizen and Poka-Yoke principles to enhance the nut dispensing process in an automotive assembly line. The objective is to automate the nut dispensing system, improving both accuracy and efficiency while reducing human error and operational costs.

3.1 Research Design

The study employs a quantitative methodology to assess the Nut Dispenser Mechanism's performance under actual assembly line conditions. The system is tested in a controlled automotive assembly environment, comparing its operational efficiency and error rates to those of manual nut dispensing methods.

In addition to quantitative analysis, qualitative assessments are conducted based on operator feedback and direct observation, focusing on ease of use, ergonomics, and the system's overall reliability.

3.2 Problem Identification and Objectives

- Problem: Prior to the system's implementation, operators manually selected nuts from a bowl or hopper, a process that was prone to errors, such as:

- Incorrect nut counts, with the possibility of either too few or too many nuts being selected.

- Loose nuts left inside vehicles, posing significant safety and quality risks.

- Increased cycle times due to the repetitive and time-consuming nature of the manual process.

- Objective: The goal of this research is to automate the nut dispensing process by introducing a system that consistently dispenses exactly two nuts per cycle, reducing human errors and improving operational efficiency. A key focus was also to address the issue of loose nuts left inside vehicles, a common defect prior to implementation.

3.3 Design and Development of the Nut Dispenser Mechanism

The Nut Dispenser Mechanism was designed using the principles of Karakuri Kaizen, which focuses on low-cost, simple mechanical systems powered by gravity, magnets, and basic mechanical motions. This design choice aligns with lean manufacturing principles, ensuring that the system is both cost-effective and energy-efficient.

Poka-Yoke (error-proofing) techniques were integrated into the design, incorporating mechanical guides and a visual feedback system to ensure the accuracy of the dispensing process and prevent errors from occurring.

3.4 System Components and Functionality

- Bowl-Type Container: The mechanism begins with a bowl-type container, which holds the nuts to be dispensed. The material handling operator manually loads the container with the necessary quantity of nuts, which are then conveyed through the dispensing system.

- Magnetic Wheel with Flanges: A magnetic wheel with flanges is attached to the container. When the operator presses the lever, the wheel rotates, generating a magnetic field that lifts the nuts and moves them from one side of the container to the other.

- Magnetic Lifting and Transfer: The magnetic wheel's rotation creates a magnetic lifting effect that transfers the nuts from the container and moves them along a predefined path. This transfer process removes the requirement for manual intervention, enhancing both the speed and accuracy of nut movement.

- Striking the Secondary Container: After transferring, the nuts strike a secondary container wall, which helps to control and direct their movement, ensuring that they are properly positioned for the next stage.

- Slope and Nut Alignment: The system includes a slope that allows only a single layer of nuts to pass through at a time. The slope ensures that the nuts are aligned vertically, which allows for optimal positioning during dispensing.

- Guide Channels: The nuts travel through precision guide channels that ensure correct alignment and accurate positioning as they move toward the dispensing zone, preventing misalignment and ensuring smooth operation.

- Final Dispensing Mechanism: The dispensing mechanism is triggered by pressing a small platform, which releases exactly two nuts per cycle. This guarantees the correct number of nuts is dispensed, reducing the potential for errors associated with manual counting.

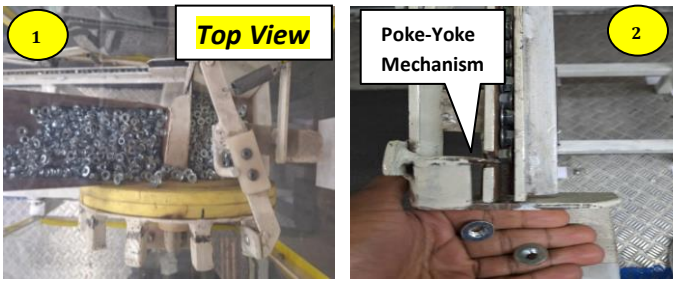

Fig -1, 2: Nut Dispenser Mechanism

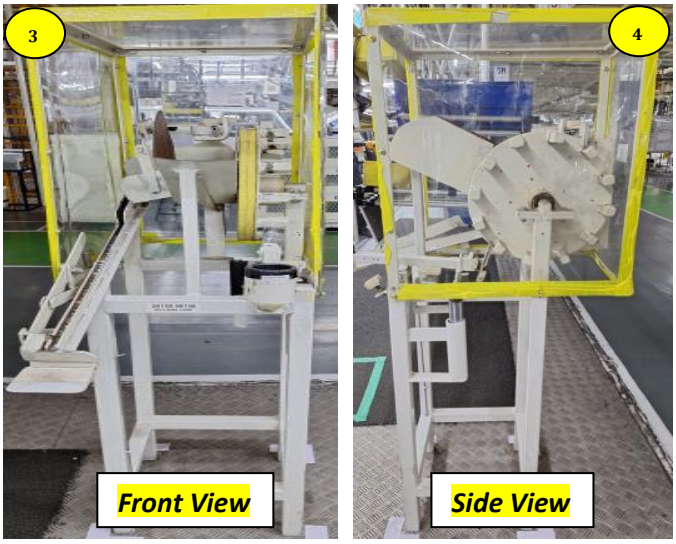

Fig -3, 4: Nut Dispenser Mechanism

3.5 Error-Proofing Features

The Nut Dispenser Mechanism integrates a visual feedback system, which provides real-time visual indicators to alert the operator if there are any issues, such as misalignment or a blockage in the dispensing process. This feedback system allows the operator to take immediate corrective action, ensuring the system operates smoothly and minimizing the likelihood of dispensing errors.

3.6 Implementation and Testing

The Nut Dispenser Mechanism was installed in a pilot section of the automotive assembly line for real-world testing. The system was evaluated under production conditions to assess its reliability and overall performance.

- Data Collection: Various performance metrics were collected, including:

- Time Efficiency: A comparison between the time required for manual dispensing and that of the automated system.

- Accuracy Metrics: The frequency of dispensing errors—such as under- or over-dispensing—measured before and after the system was introduced.

- Impact on Line Performance: The effect of the automated nut dispensing system on overall assembly line throughput.

- Loose Defect Trend: Prior to implementation, the system experienced an average of four loose nut defects per month. After the implementation of the Nut Dispenser Mechanism, this defect rate was reduced to zero, indicating a significant improvement in the accuracy and reliability of the nut dispensing process.

- Observational Analysis: Operator feedback was gathered to evaluate the usability and ergonomics of the system, as well as any issues encountered during the implementation phase.

3.7 Evaluation Metrics

The Nut Dispenser Mechanism's performance was evaluated based on the following key metrics:

- Error Reduction: A reduction in dispensing errors, including under- or over-dispensing.

- Time Efficiency: Faster dispensing, resulting in increased throughput and reduced cycle time.

- Cost-Effectiveness: A cost-benefit analysis of the low-cost mechanical design compared to more expensive automated systems.

- Loose Defect Reduction: The elimination of the loose nut defect trend, which was previously a major issue in the assembly process.

- Operator Feedback: Qualitative feedback from operators on the system's ease of use and impact on ergonomics and safety.

3.8 Limitations

- System Adjustments: Minor adjustments were required to fine-tune the gravity-fed dispensing system to accommodate variations in the assembly line's speed and operation.

- Training Requirements: Initial training was necessary for operators to familiarize them with the new system, which may have temporarily reduced productivity during the learning phase.

4. RESULTS

The implementation of the Nut Dispenser Mechanism led to significant improvements in time efficiency, dispensing accuracy, and defect reduction in the assembly process.

1. Time Efficiency

- Before Implementation: The manual nut picking process required approximately 3 seconds per cycle, including the time taken for the operator to select, count, and prepare the nuts.

- After Implementation: With the Nut Dispenser Mechanism in place, the time per cycle was reduced to 1.5 seconds, resulting in a 50% decrease in cycle time, which enhanced the overall speed of the assembly line.

2. Accuracy of Nut Dispensing

- Before Implementation: Operators manually dispensed a variable number of nuts, often resulting in either too few or too many nuts, which created inconsistencies and delays in the assembly.

- After Implementation: The Nut Dispenser now ensures that exactly 2 nuts are dispensed every cycle, completely eliminating errors and ensuring consistent, accurate dispensing for each assembly process.

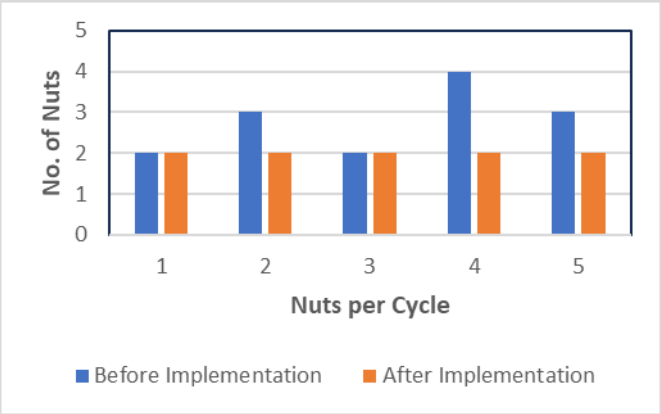

Chart -1: Nuts Pick-up Accuracy Trend

3. Loose Nut Defects

- Before Implementation: The manual process led to loose nuts being left inside vehicles, which posed safety concerns and affected product quality. This occurred approximately 4 times per month.

- After Implementation: The Nut Dispenser Mechanism effectively eliminated this issue, bringing the number of loose nut defects to zero, thereby improving both safety and product quality.

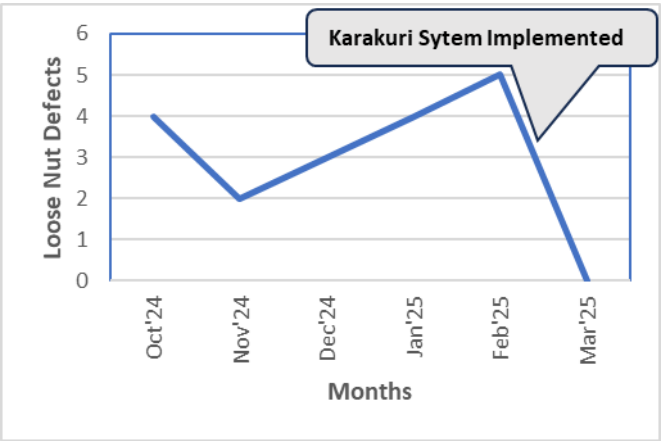

Chart -2: Loose Defects Trend

4.1 Impact on Overall Performance

The introduction of the Nut Dispenser Mechanism not only reduced cycle time but also increased overall assembly line throughput. By speeding up the nut dispensing process and reducing defects, the system contributed to smoother and more efficient production flow.

4.2 Summary of Results

Metric	Before Implementation	After Implementation
Time per Cycle	3 seconds	1.5 seconds
Accuracy of Nut Dispensing	More or less than 2 nuts	Exactly 2 nuts
Loose Nut Defects per Month	4 defects	0 defects

These improvements demonstrate the Nut Dispenser Mechanism's ability to enhance time efficiency, ensure precise dispensing, and eliminate defects, resulting in better performance and higher quality in the assembly line.

5. DISCUSSION

The implementation of the Nut Dispenser Mechanism in the automotive assembly line has resulted in notable improvements in time efficiency, dispensing accuracy, and defect reduction. These outcomes emphasize the effectiveness of integrating lean manufacturing principles, particularly waste reduction and process optimization. The following discusses the interpretation of these results, compares them with existing literature, and outlines the implications for the automotive sector.

5.1 Interpretation of Results

The reduction in cycle time from 3 seconds to 1.5 seconds represents a 50% decrease in time per cycle. This improvement highlights the Nut Dispenser Mechanism's ability to streamline operations, reduce unnecessary waiting times, and increase productivity on the assembly line. This aligns well with lean manufacturing principles, which emphasize minimizing cycle time to enhance throughput and efficiency (10).

In terms of accuracy, the Nut Dispenser Mechanism effectively ensured the dispensing of exactly 2 nuts per cycle. The earlier manual process often resulted in dispensing either too few or too many nuts, causing delays and inconsistencies in the assembly process. The mechanism's error-proofing capabilities, such as guides and mechanical features, helped to eliminate this variability, ensuring a

consistent outcome for each cycle. This precision exemplifies the role of Poka-Yoke systems in improving quality and reducing human error in manufacturing (6).

The Nut Dispenser also significantly impacted defect reduction, particularly regarding loose nut defects. Before implementation, 4 loose nut defects were reported monthly, a safety and quality concern. After the mechanism was introduced, these defects were reduced to zero. This result underscores the importance of error-proofing in preventing safety hazards and maintaining product quality, two essential aspects of lean manufacturing (11).

5.2 Comparison with Literature

These findings are consistent with previous research on Poka-Yoke and Karakuri Kaizen in manufacturing environments. Poka-Yoke techniques have been well-documented for preventing errors and improving process reliability (6). The Nut Dispenser Mechanism, by guaranteeing exact nut dispensing and eliminating defects, aligns with these established benefits.

Moreover, the mechanism's design, relying on simple mechanical solutions without external energy sources, follows the Karakuri Kaizen approach, which emphasizes low-cost, sustainable innovations (3). This approach has been proven to drive efficiency and foster innovation within lean systems (12), and the Nut Dispenser Mechanism serves as a practical example of these principles in action.

5.3 Implications of Findings

The findings from this study suggest several benefits for the automotive assembly line. Reducing cycle time and ensuring accurate dispensing of parts enhances the overall flow of production, which is a core principle of lean manufacturing (10). The elimination of loose nut defects is particularly significant, as it directly improves safety and product quality, which are critical concerns in the automotive industry.

These results also offer broader implications for cost reduction. With improved cycle times, reduced errors, and less manual intervention required, labor costs can be reduced, while throughput increases. The reduction in defects also means fewer recalls or warranty claims, leading to cost savings for manufacturers in the long term.

5.4 Limitations

While the results are promising, there are some limitations. First, the study was conducted on a single assembly line, and its applicability to other types of manufacturing processes or industries is still uncertain. Future studies should consider testing the Nut Dispenser Mechanism in other contexts to determine its scalability and adaptability. Moreover, the study did not compare the Nut Dispenser Mechanism with other potential error-proofing systems, such as automated dispensing machines or other Poka-Yoke solutions. Such comparisons would help assess the relative effectiveness of the mechanism.

Another limitation is that the study only focused on one aspect of the assembly process—nut dispensing. Other areas of the assembly process, such as fastener placement or component inspection, could also benefit from similar improvements, and future research could examine the broader application of such systems.

5.5 Suggestions for Future Research

Future research could focus on expanding the Nut Dispenser Mechanism's application to larger, high-volume manufacturing environments. As production scales up, additional challenges may arise, and the system may need modifications to handle greater complexity or varying part sizes.

Another promising direction for future research involves integrating smart technology into the Nut Dispenser Mechanism. Sensors or automated feedback systems could be incorporated to monitor dispensing accuracy in real-time, providing operators with immediate feedback and further enhancing process control.

Additionally, researchers could explore the potential application of similar mechanisms in industries beyond automotive manufacturing. Industries such as electronics or consumer goods assembly, which require precise and repetitive part handling, could benefit from the principles of Poka-Yoke and Karakuri Kaizen.

6. CONCLUSION

This research has demonstrated the significant advantages of integrating the Nut Dispenser Mechanism into the automotive assembly line, leveraging lean manufacturing principles such as Poka-Yoke and Karakuri Kaizen. The findings reveal a remarkable 50% reduction in cycle time, from 3 seconds to 1.5 seconds, which enhances overall production efficiency and throughput. Additionally, the mechanism's precise dispensing of exactly 2 nuts per cycle has minimized human error, improving the accuracy of the process. More importantly, the Nut Dispenser has completely eradicated loose nut defects, reducing them from 4 per month to zero, thus improving both product quality and safety.

These improvements in cycle time, dispensing accuracy, and defect reduction demonstrate the powerful impact of lean manufacturing techniques on modern assembly lines. The study shows that even simple and cost-effective mechanical solutions, like the Nut Dispenser Mechanism, can lead to significant improvements in productivity and quality in the automotive sector.

The outcomes of this study carry important implications for manufacturers aiming to reduce waste, enhance safety, and optimize assembly line operations. By reducing manual intervention and preventing defects, the Nut Dispenser Mechanism helps achieve cost reductions, greater efficiency, and improved safety standards.

However, this study has some limitations. The Nut Dispenser Mechanism was evaluated on a single assembly line, and its applicability to other manufacturing environments needs further exploration. Additionally, comparing this mechanism with alternative lean tools or automated systems could offer more insight into its effectiveness.

For future research, further studies could focus on adapting the Nut Dispenser Mechanism for large-scale production settings, incorporating smart technologies for real-time monitoring and feedback, and testing the mechanism in industries beyond automotive manufacturing, such as electronics or consumer goods. Enhancing the mechanism with automation could also improve its efficiency and extend its use across various sectors.

In summary, the Nut Dispenser Mechanism is a practical and cost-efficient solution for ensuring error-free assembly, fully aligned with the core values of lean manufacturing. Its successful implementation addresses critical manufacturing challenges and sets the foundation for future innovations in the industry.

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