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Optimizing New Product Development in Automotive Manufacturing: The Role of DFMA in Multi-Purpose Vehicle Production

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Abstract

This study examines the application of Design for Manufacturing and Assembly (DFMA) principles to enhance the production process of Multi-Purpose Vehicles (MPVs). The research aims to improve assembly efficiency and reduce manufacturing costs by evaluating and modifying the existing MPV design. By eliminating unnecessary components, such as Bolt Type 1, PU Box, Rear Cabin, and Bolt Type 2, and incorporating fit-in technologies like snap-fit mechanisms, the design is simplified to streamline the assembly process and reduce complexity. DFMA software analysis, along with design modifications, shows a substantial reduction in assembly time and cost, while improving product reliability. The findings demonstrate how DFMA can enhance the manufacturability of MPVs, providing an effective strategy for manufacturers to stay competitive in the automotive sector. The study also underscores the importance of iterative design evaluation and re-evaluation in achieving optimal product quality and operational efficiency. This research offers practical insights into applying DFMA in automotive product development and sets the foundation for further studies on its impact in other industries.

Keywords: *Design For Manufacturing And Assembly, Multi-Purpose Vehicle, Design Optimization, Assembly Efficiency, Manufacturing Costs*

1. Introduction

The global industrial landscape is evolving at an unprecedented pace, with companies relentlessly competing to lead in technological innovation and market strategies. Particularly within the automotive manufacturing sector, car production has experienced a substantial transformation over the past few decades. Factors such as increasing disposable incomes, rapid economic growth, and evolving lifestyle preferences have contributed to a higher demand for private vehicles. This dynamic shift has driven automotive manufacturers to consistently innovate to meet the escalating demands and expectations of consumers [1]. Consequently, product development has become a pivotal stage in ensuring customer satisfaction, operational efficiency, and competitive advantage. This process spans several phases, including market need identification, conceptual design, design refinement, and prototyping/testing [2]. During the testing and refinement phase, design evaluation plays a crucial role in simplifying the assembly process, reducing costs and assembly time, and enhancing product quality.

One of the most widely adopted approaches for design optimization is Design for Manufacturing and Assembly (DFMA). DFMA combines manufacturing and assembly considerations to reduce unnecessary components and streamline the product structure, thus making the production process more cost-effective and efficient [3, 4]. Numerous studies have highlighted the potential of DFMA in reducing costs, improving manufacturability, and enhancing product quality [5, 6]. However, much of the existing DFMA research has primarily focused on individual components or generic industrial applications. There is a notable lack of research on applying DFMA to the complete vehicle system assembly, especially in the case of Multi-Purpose Vehicles (MPVs). MPVs are strategically important in the automotive industry due to their high versatility, customizable seating configurations, and dual appeal for personal and commercial use. In emerging markets like Indonesia, MPVs dominate the vehicle sales segment, making design efficiency and cost-effectiveness essential for maintaining competitiveness [7]. Despite the market relevance, studies applying DFMA to optimize the modular design and assembly process of MPVs, especially those incorporating rapid prototyping for validation, remain scarce.

This research aims to fill this gap by conducting a design-based case study that focuses on optimizing the assembly process and reducing costs in MPV manufacturing through the application of DFMA principles, supported by rapid prototyping tools. The scientific contribution of this study lies in demonstrating how the integrated use of DFMA analysis and iterative design techniques can result in measurable improvements in part reduction, assembly time, and overall cost efficiency, providing a practical methodology for enhancing competitiveness in automotive manufacturing.

2. Research Methods

2.1. Types of Research

This study adopts a mixed-methods approach that integrates both qualitative and quantitative research methodologies. The qualitative approach is utilized for exploratory research conducted in natural settings, where the data collection is based on observational facts obtained from real-world applications. Meanwhile, the quantitative approach incorporates numerical data analysis to evaluate the impact of design changes on manufacturing costs and assembly time, thereby providing measurable insights [8]. This methodology combines inductive reasoning, starting from observations to formulating hypotheses or theories based on the research findings [9].

2.2. Research Methods

The methodology for this research is illustrated through the following process flowchart:

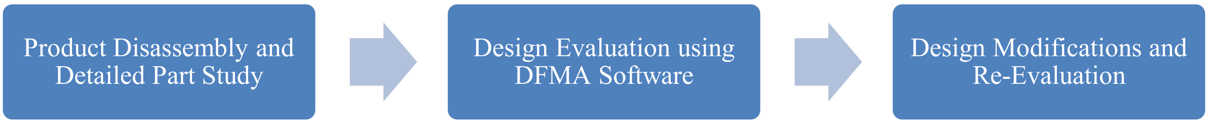

Figure 1. Research Flowchart

2.2.1. Stage 1 : Product Disassembly and Detailed Part Study

In the initial stage, the disassembly of the MPV is performed to thoroughly examine all individual components and assess their sizes, tolerances, and interrelationships. The objective is to clearly understand the constituent parts required for assembling the MPV, which include Chassis, Axle Shaft, Holder, Tires, Nuts, Cabin 1, Rear Cabin Type-2, PU Box, Bolt Type-1, and Bolt Type-2. The detailed part study helps identify potential issues in manufacturing and assembly that need to be addressed in the design phase [8].

2.2.2. Stage 2 : Design Evaluation using DFMA Software

In the second stage, Design for Manufacturing and Assembly (DFMA) software is employed to assess the assembly process and part designs. DFMA software assists in identifying potential challenges in the assembly process, including the identification of complex or costly components. The software also provides insights into optimizing design elements to simplify manufacturing and reduce assembly time [9]. The software allows the researcher to:

- Evaluate whether the current design allows for easy and cost-effective assembly.
- Identify components that could be simplified or eliminated to reduce manufacturing time.
- Propose design modifications to improve manufacturability.

The software generates recommendations that guide the researcher to redefine the design by reducing part count and simplifying assembly steps, which can then be verified through further design iterations [10].

2.2.3. Stage 3 : Design Modifications and Re-Evaluation

Following the DFMA software evaluation, the next step involves modifying the components that require improvements based on the feedback and recommendations provided by the software. These modifications aim to:

- Reduce the number of parts by combining multiple components into a single part.
- Replace traditional fasteners with alternative solutions (e.g., snap-fits, molded hinges, press fits) that reduce assembly time and complexity [11].

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After these modifications are proposed, the revised design will undergo re-evaluation using the DFMA software. This will allow the researcher to compare the new design against the original design and determine whether the changes have optimized the production process, assembly time, and cost efficiency.

3. Results and Discussions

3.1. *Product Disassembly and Detailed Part Study*

BOM Tree (Bill of Materials Tree) aims to present a hierarchical structure of the MPV by showing the relationship between the components that make up the car featuring the main components at the top level and more specific component details at a lower level.

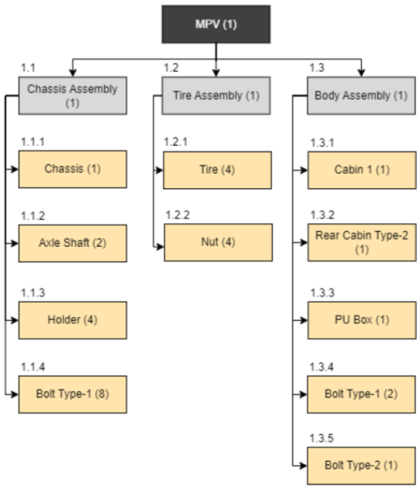

Figure 2. BOM Tree MPV Existing

The Flow Chart for Assembly Process in Existing Design can represent a graphic showing the steps involved in the MPV product assembly process. This flowchart helps to visualize the sequence of actions that operators must perform to properly assemble the product.

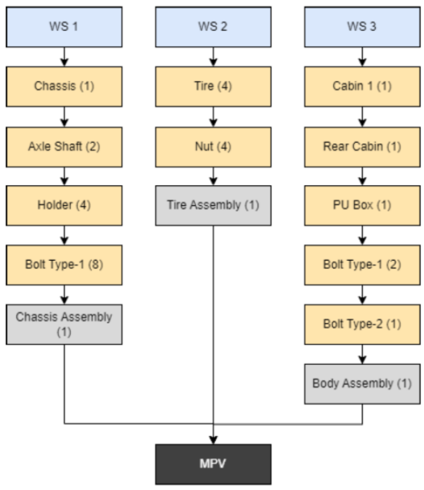

Figure 3. Flow Chart for Assembly Process for Existing Conditions

The following is an existing design of the MPV car that has been made through Solidworks, starting with the manufacture of each part that makes up the car. The parts that make up the MPV car product in its existing condition consist of Chassis, Axle Shaft, Holder, Tire, Nut, Cabin 1, Rear Cabin Type-2, Pu Box, Bolt Type-1 and Bolt Type-2.

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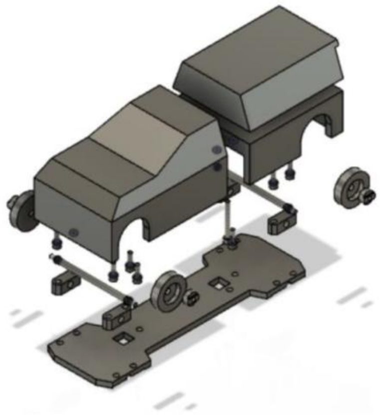

Figure 4. MPV Design in Existing Conditions

3.2.*Design Evaluation using DFMA Software*

Optimization of the MPV design is carried out by analyzing the results ofapplying the design and manufacturing concepts obtained through DFMA software. DFMA concept that helps in representing the analysis are DFM and DFA.

1. DesignforManufacturing(DFM) whichfocusesonproductdesign that considers convenience and efficiency in the manufacturing process. The principle of DFM includes several elements:
   - Design simplification by reducing product complexity by reducing the number of components and using standard components that are easy to obtain.
   - Selection of the right material and suitable for the manufacturing process and canproduceproductsat low costs.
   - Ease of manufacturing processing, namely cutting, molding,orotherprocesses.
   - Minimizesproduct dimension variations to reduce the need for special equipment or complex adjustments.
   - Simplify complex or expensive manufacturing processes.
2. Design for Assembly (DFA) whichfocusesonproductdesign by considering ease and efficiency in the assembly process. The DFA principle includes several elements:
   - Simplify assembly by reducing the number of assembly steps and the use of special tools.
   - Component compatibility to ensurethatcomponentscanbe easily fitted together without difficulty.
   - Simple and effective use of locking, connecting or connecting systems.
   - Easy access for component assembly, maintenance and replacement.
   - Avoidance of assembly conflicts: Avoiding designs that may lead to assembly conflicts, such as having components that interfere with each other or difficulty accessing certain parts.

DFA Index also known as assembly efficiency, is determined by dividing the actual assembly time by the theoretical minimum assembly time.

$$\textbf{DFAIndex}(E_{ma})=N_{min}.t_a/t_{ma} \quad (1)$$

Where,

N_{min}=Theoreticalminimumnumber of parts.
t_a = The basic or average assembly time for onepartequalto56.3 sec.
t_{ma} = Estimated time to complete the assembly of theactualproduct.

By taking into consideration the above method, the number of parts have been reduced which are included in the table of results and the DFA index was calculated using the formula. Assembling time and number of parts is shown in the table below.

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Table 1.Details of Parts and Assembly Time for Existing Design

No	Part	Number	Insertion Code	Assembly Time (s)	Theoretical Part Count
1	Chasis	1	0	3,45	1
2	Axle Shaft	2	4	7,46	2
3	Holder	4	4	16,4	4
4	Bolt Type 1	10	16	47,6	**0**
5	Tire	4	8	16,4	4
6	Nut	4	20	32	4
7	Cabin 1	1	0	3,45	1
8	PU Box	1	15	7,45	**0**
9	Rear Cabin	1	25	9,65	**0**
10	Bolt Type 2	1	04	6,2	**0**
		29		**150,06**	**16**

DFAIndex$_{Existing}$=16*56.3/150,06=6.00%

A DFA Index of 6.00% indicates that the existing product design is somewhat efficient but can still be improved. One key improvement is eliminating parts like Bolt Type 1, PU Box, Rear Cabin, and Bolt Type 2, which can be replaced using fit-in technology, such as snap-fit mechanisms. This approach reduces the number of components, simplifies assembly, and lowers costs. The use of snap-fit designs can significantly reduce assembly time and manufacturing costs while improving product reliability by eliminating errors associated with traditional fasteners[14, 15]. Additionally, DFMA principles emphasize reducing part counts and simplifying assembly processes, leading to lower production costs and faster assembly times. By adopting these methods, the design can achieve better manufacturability and assembly efficiency

3.3.*Design Modifications and Re-Evaluation*

After the initial design evaluation with DFMA software, the next important step is implementing the necessary design modifications based on the results. The goal of this phase is to improve the manufacturability and assembly efficiency by removing unnecessary components and optimizing the overall design. Components that do not significantly contribute to the product's function or complicate the assembly process are identified for removal or simplification. This includes eliminating theoretical parts with a part count of zero (0), such as Bolt Type 1, PU Box, Rear Cabin, and Bolt Type 2. By following DFMA principles, which focus on reducing part numbers, simplifying assembly, and improving product quality, these modifications aim to streamline the design and make it more efficient.

This redesign process not only reduces complexity but also enhances manufacturing and assembly efficiency. The re-evaluation ensures that the design changes lead to clear improvements in assembly time, production costs, and overall product reliability. This iterative cycle of design modification and re-assessment is crucial to achieving a more efficient and cost-effective final product.

Table 2.Details of Parts and Assembly Time for Improvement Design

No	Part	Number	Insertion Code	Assembly Time (s)	Theoretical Part Count
1	Chasis	1	0	5,12	1
2	Axle Shaft	2	4	10,80	2
3	Holder	4	25	23,07	4
4	Tire	4	0	23,07	4
5	Nut	4	0	38,67	4
6	Body	1	15	9,12	1
		16		**109,85**	**16**

DFAIndex$_{Improvement}$=16*56.3/109,85=8.20%

A DFA Index of 8.20% reflects a significant improvement in assembly efficiency. By reducing the assembly time from 150.06 seconds to 109.85 seconds, the enhanced design proves to be more efficient. This means that even though the number of components remains the same, the assembly now takes less time, indicating that the product design has become simpler and easier to assemble.

4. Conclusion

This research highlights the significant role of Design for Manufacturing and Assembly (DFMA) in optimizing the production process of Multi-Purpose Vehicles (MPVs). By integrating DFMA principles, this study has demonstrated how design modifications can reduce part complexity, improve manufacturability, and streamline

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the assembly process. Through the elimination of unnecessary components, such as Bolt Type 1, PU Box, Rear Cabin, and Bolt Type 2, and the application of fit-in technologies like snap-fit mechanisms, the design has been optimized for efficiency. The results indicate that the re-evaluated design, with fewer parts and simplified assembly, leads to measurable improvements in assembly time, reduced manufacturing costs, and enhanced product reliability. This study contributes to the growing body of knowledge on DFMA applications in the automotive industry, particularly for MPVs, offering a practical methodology for manufacturers aiming to stay competitive in a fast-paced market. Furthermore, the findings underscore the value of DFMA as a tool for not only improving operational efficiency but also for achieving higher levels of customer satisfaction by delivering quality products at lower costs and in shorter production cycles. Future research may explore the broader application of DFMA principles across various industries to further validate its benefits in product development and manufacturing processes.

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