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Enhancing Car Seat Cushion Production Performance Through Value Engineering: A Case Study

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ABSTRACT

This paper aimed to adopt the Value Engineering philosophy in enhancing the car seat cushion performance that emphasizes quality and productivity improvements. Value Engineering approaches are used to validate the design of car seat cushion to make the product more cost effective in terms of function and quality. Value Engineering methods are identified in the process of improving the design of car seat component cushion. The model of car seat component is developed using Autodesk® Inventor®. The design of the model is then analyzed using Boothroyd Dewhurst Design for Manufacture and Assembly (DFMA) software. Computer-aided engineering (CAE) ANSYS® software will be used in the analysis of displacement and stress. studies. The result shows that the force applied on the seat frame and seat cushion is set at 1177.2 N (120 kg). Maximum Von Mises Stresses for seat cushion and seat frame are 0.02337 MPa and 13.7 MPa. Maximum displacements for seat cushion and seat frame are 0.4026 mm and 0.006119 mm. FMEA was conducted on the model of car seat components to predict the possible failure and effect on the model. Hence, this paper provides valuable insight on potential car seat cushion improvement through Value Engineering approach.

1. INTRODUCTION

The progressive advancements in technology have precipitated an escalated demand for the value in automotive componentry. Value Engineering (VE), as an analytical methodology, has been employed within the automotive sector, exemplified by its application at Proton Holdings Berhad, to refine the design of automotive components. The increasing customer demand for higher quality products without compromising the aspects of functionality and price also causes automotive companies to have to take a systematic approach in the concept of VE and target costing in the product development process. VE and target costing are interdependent [1, 2] where VE allows for the identification of possible cost reductions and target costing must be achieved to ensure a long-term profit plan for a company.

In Malaysia, the automotive industry has experienced significant growth since the establishment of Proton in 1985 and Perodua in 1993 as part of the National Car Project. The initiation of the National Car Project has served as a catalyst for the manufacturing industries development in Malaysia. The domestic market saw vehicle sales reaching 799,731 units in 2023 (719,160 passenger cars and 80,571 commercial vehicles) with an increase of 10.97% (729,658 total sales) in 2022 [3]. Vehicle sales in Malaysia have shown signs of continued growth, driven by ongoing economic recovery in post pandemic, introduction of new models, and sustained consumer interest in both internal combustion engine vehicles and electric vehicles (EV). Besides, there is a growing interest in EVs in Malaysia, with the government and automotive manufacturers investing in EV infrastructure and launching new models to meet the increasing demand for sustainable and energy-efficient vehicles. Thus, it is imperative to incorporate user value in contemporary engineering design of automotive product development as the increasing competition in life causes customers to constantly demand new products that are better in terms of function and quality without affecting the price.

This research emphasized on the VE method in the product development process. VE represents a more comprehensive approach compared to traditional methods that prioritize cost reduction analysis. Based on the study [4], the concept of value associated with:

$$Value = \frac{Worth\ of\ a\ particular\ feature, component\ or\ assembly}{Cost} \qquad (1)$$

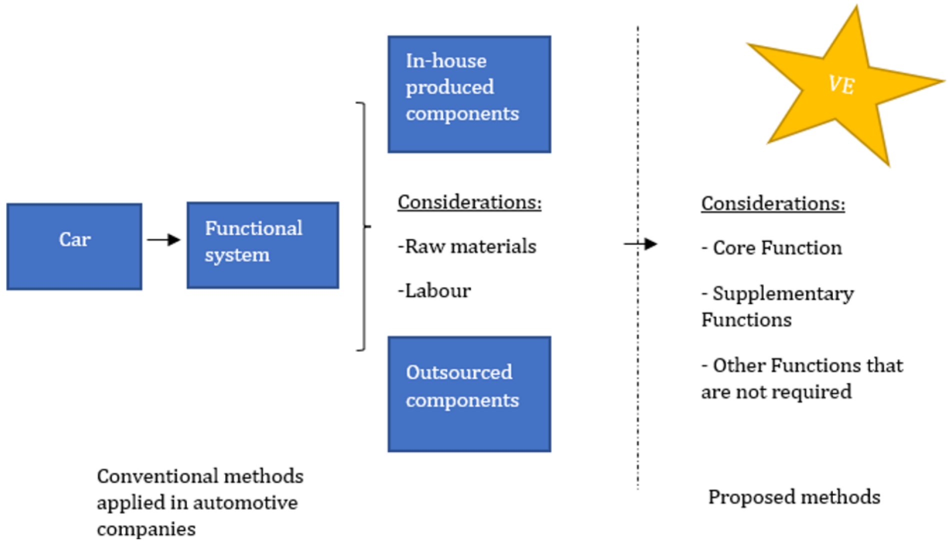

Figure 1. Scope of improvement for automotive companies

Worth is a measure of the willingness of a buyer to purchase a function paid for at a reasonable cost. Specific skills are required in determining the worth of a product. According to Kumar et al. [5], value enhancement can be achieved without compromising the quality, reliability, and maintainability. While previous research has applied Value Engineering to the design of automotive systems as a whole, this study provides a novel focus on car seat cushions—an under-researched component in terms of cost optimization and performance enhancement. This granular approach allows for more precise identification of inefficiencies and targeted improvements in material usage, production processes, and design optimization.

This study aimed at examining the car seat components for Proton's products such as the X50 and X70 models and proposing improvements in terms of the existing car seat components design. The primary objective of these improvements is to reduce development costs without compromising the quality and performance of the components. Hence, the appropriateness of the VE approach on enhancing car seat cushion performance will be demonstrated in Figure 1.

2. LITERATURE REVIEW

Value Engineering originated during World War II when General Electric (GE) faced material shortages and sought alternative ways to maintain production efficiency while reducing costs [5]. Developed by Lawrence D. Miles, VE emerged as a systematic approach to improve the value of products by analyzing their functions and exploring alternative ways to achieve those functions at a lower cost without compromising quality or performance. This approach revolves around identifying unnecessary costs that do not contribute to functionality and finding ways to optimize resources and design to enhance efficiency [4]. Initially applied to manufacturing, VE has since expanded to various industries, including construction, aerospace, and automotive companies such as Toyota and Volkswagen. Past studies focused to investigate the application of VE to individual automotive components, such as seating systems, dashboards, and suspension systems [1, 5]. Particular attention should be given to research focusing on seating systems, even if not specific to car seat cushions.

Reducing costs through VE can sometimes result in unintended compromises, such as the selection of lower-quality materials or reduced product features, potentially impacting long-term durability or safety performance [1]. Moreover, VE's focus on immediate cost savings may overshadow considerations of lifecycle costs and sustainability, which are increasingly important in the automotive industry. Another limitation is the challenge of integrating VE practices with existing production systems without causing disruptions or increased complexity in the manufacturing process [2]. These challenges highlight the need for a more integrated approach, where VE is applied with careful attention to maintaining product quality and ensuring that safety standards are not compromised in the pursuit of cost efficiency.

Car seat cushions are mass-produced in large volumes due to their presence in nearly every vehicle. This high production volume provides ample opportunities for cost savings through even small improvements [6]. In large-scale manufacturing, optimizing materials, reducing waste, or improving efficiency in just one component can have a significant financial impact. Car seat cushions are a key factor in vehicle comfort and ergonomics, directly influencing the driver and passengers' experience. Since car manufacturers must balance comfort with cost and performance, seat cushions are particularly well-suited for VE approach where it can help optimize the function (comfort) at the lowest cost without sacrificing quality. Seat cushions also play a role in passenger safety [3], especially in terms of posture and positioning during an accident. VE can ensure that cost-saving measures in production do not compromise the essential safety functions of seat cushions.

With the automotive industry moving towards sustainability, car seat cushions offer an area where manufacturers can adopt eco-friendly materials and processes. VE can play a vital role in achieving sustainability targets by balancing environmental concerns with cost and production efficiency [7]. As customer demands for better ergonomics and enhanced comfort features increase, VE can help manufacturers meet these expectations cost-effectively. Optimizing car seat cushions allows automakers to offer premium seating features in lower-cost models, potentially increasing market share [8, 9].

3. METHODOLOGY

In this research, the design process will adopt the Value Engineering approach. Subsequently, the model will be optimized using Design for Manufacturability and Assembly (DFMA). Based on the study [6], there are two sources for a design project, namely designing according to market demands or the development of new product ideas without market demand. 80 percent of new product development comes from market-driven forces. If there are no buyers for the produced product, then the product producer cannot recoup the costs involved in design and manufacturing processes. Therefore, understanding consumer needs is very important in the design process.

The design method with a VE approach is a method used to revalidate the design of existing products to make them more cost-effective. This method plays a crucial role in reducing the manufacturing costs of a product. The key to solution in Value Analysis is the evaluation of the design or system's function. VE prioritizes product functionality and the search for better solutions, which are decisions oriented towards functional cost.

3.1 Product development process

Based on the study [7], there are five dimensions that determine the performance value of a product development effort: product quality, product cost, product development time, and development capability as indicated in Figure 2. Product quality is closely related to the market and the buyer's willingness to pay commensurate with its function. Product cost includes the manufacturing cost for the product, capital expenditure costs, equipment, and tools. Product cost determines the profit for a company at a certain selling price. Development time refers to the period used in completing the development of a particular product. A short development time in the process of developing new products can speed up the time to market and ensure substantial sales. Development capability, on the other hand, refers to the company's ability to effectively develop future products economically in the future.

3.2 Design modelling using computer-aided software

In this study, three-dimensional (3D) modelling is adopted to provide a perfect geometry and a mathematical description of the geometric parts. It facilitates visualization and conceptualization of a component since the actual model of the product can be displayed from various views or angles. This three-dimensional modelling can be sectioned to reveal detailed insights or easily convert to traditional two-dimensional (2D) engineering drawings. This model possesses rich intrinsic information where it can be utilized for processes of analysis, design optimization, simulation, rapid prototyping, and manufacturing. Subsequently, the design process is followed by geometric modelling, material selection, and engineering analysis with the aid of computer software usage.

Among the geometric modelling software to be used in this study is Autodesk® Inventor. Based on the study [8], Autodesk® Inventor software provides a comprehensive set of design tools for the production, validation, and thorough documentation of digital prototypes. This is highly beneficial in assisting manufacturers to market their products at a faster rate by reducing the reliance on physical prototypes. Additionally, this software aids users in calculating mass properties, examining interference among interconnected components in assemblies, and other engineering calculations. The clear color representation of objects can help users better understand the model.

Autodesk® Inventor software also has the capability to produce animations of objects to assist users in understanding the movement of objects. This 3D CAD software used to create precise digital models of components and assemblies. It contributes by enabling the detailed modelling of car seat cushions, allowing to visualize different design iterations efficiently.

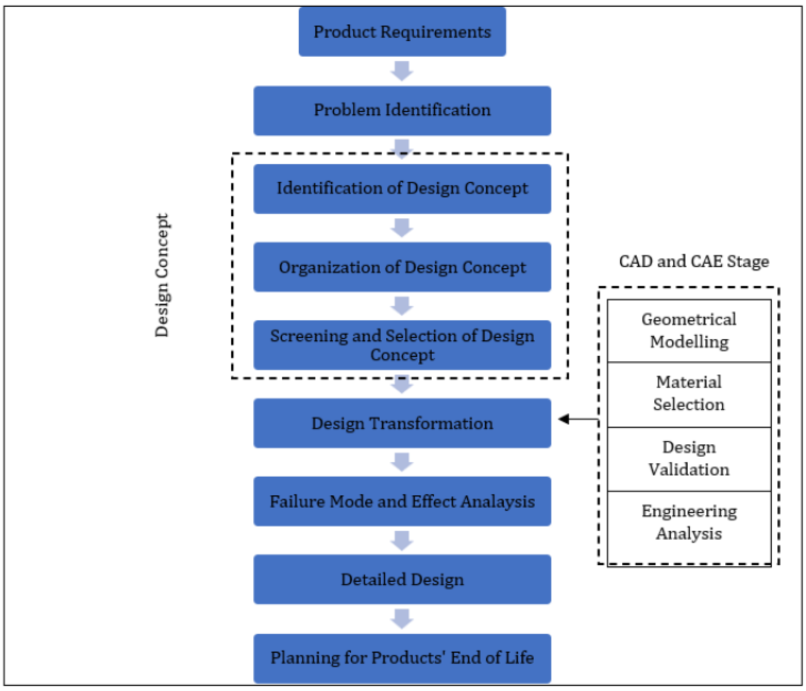

Figure 2. Design workflow chart

3.3 Material selection

The Cambridge Engineering Selector (CES) software will be used for the selection of suitable materials for components within car seats. Based on the study [9], the CES Selector assists in the rational selection of engineering materials- metals, ceramics, polymers, composite materials, woods, and manufacturing processes- forming, finishing, joining, and surface treatment. CES Selector provides information to product designers and manufacturers to avoid cost wastage and facilitate innovation while achieving eco-friendly concepts and adhering to existing regulations. Appendix A1 indicates the material selection matrix for car seat frame using the Pugh concept.

3.4 Design validation

The engineering analysis software that will be used in the design analysis would be Boothroyd Dewhurst Design for Manufacture and Assembly (DFMA)® software. Based on the study [10], DFMA® software enables users to analyze and understand the costs of production and assembly of products within the product development cycle. DFMA is a combination of two products: Design for Manufacture (DFM)® and Design for Assembly (DFA)®. The DFM software can estimate the production cost of products and provides a straightforward method for the analysis of alternative manufacturing processes and material selection, while the DFA software is used to reduce product complexity by integrating parts within the product to achieve significant cost savings.

The selection of optimal materials and manufacturing processes for each component in the design of a product can guarantee the potential for reducing the cost of product production. The use of DFM Software allows users to achieve a comprehensive understanding of the main costs associated with manufacturing a product. The cost model in DFM Software provides alternative assessments of processes and materials and generates cost information for the Bill of Materials (BOM). Automatic cost updates are provided when users specify tolerances, surface finishes, and details for other components. Choosing effective shape production processes and modifying component features for cost reduction can result in an optimum product.

In the early stages of design, control of part count is crucial for maintaining target costs. DFA Software enables products to be simplified through the application of minimum part count criteria. Minimum part count analysis can theoretically determine the minimum number of parts required in a product design to function as needed. By identifying and reducing unnecessary parts, users can decrease unnecessary manufacturing and assembly costs as well as related costs in warranty and service, order changes, and optimal use of factory space. In short, DFMA software directly supports the research objective of improving production performance by minimizing assembly time, reducing labor costs, and ensuring that design changes optimize manufacturing efficiency.

3.5 Engineering analysis

ANSYS® analysis software will be used as the engineering analysis of the design. It serves as a supporting tool for Autodesk® Inventor® software, used for pre- and post-processing in "Computer Aided Engineering" (CAE) simulations. However, this version of ANSYS® software cannot select a single node load because the software version has predefined load distributions. ANSYS® software is a finite element analysis tool that has the capability to analyze a wide range of problems across an extensive scope. ANSYS serves as an industry-standard tool for finite element analysis (FEA), which is essential for simulating how different materials and designs behave under stress, heat, or other operational conditions [11]. In the context of car seat cushion production, ANSYS enables virtual testing of the cushion's response to real-world conditions, such as pressure distribution, which is vital for ensuring comfort and safety standards. ANSYS also supports the reduction of costly physical prototyping by providing accurate predictions of design performance, aligning with Value Engineering's goal of minimizing unnecessary costs.

3.6 Failure mode and effect analysis

Failure Mode and Effects Analysis (FMEA) is utilized to identify potential issues that could arise in both new and existing designs [12]. This analysis identifies the failure modes of each component within a system and determines their impact on the system for every potential failure. The methodology of failure mode and effects analysis encompasses three aspects: predicting the types of failures that might occur, forecasting the impact of those failures on the system's functionality, and establishing measures that can be taken to prevent failures or mitigate their effects on function.

This analysis is a comprehensive process that starts with the collection of desired functions, identification of involved components, and listing all possible failure modes for each component. Three factors are emphasized in the development process of failure mode and effects analysis: the severity level of a failure, the probability of its occurrence, and the likelihood of detecting the failure either in the product design or manufacturing process before the product is released to the market. Risk Priority Number (RPN) is a key metric used in Failure Mode and Effects Analysis (FMEA) to evaluate and prioritize the risk associated with different failure modes. The RPN is calculated by multiplying three factors:

$$\text{RPN} = \text{Severity (S)} \times \text{Occurance (O)} \times \text{Detection (D)} \tag{2}$$

4. DESIGN CONCEPT

Automotive components lend themselves well to analysis, improvement, and optimization through the Value Engineering approach. In this study, the focus is on car seat components, specifically the seat cushion and seat frame. The automotive industry actively promotes research and development aimed at enhancing driver comfort, particularly in relation to seating and body posture. According to the findings in the study [13], understanding the biomechanics of a driver's posture is a critical element of ergonomic design. Properly designed car seat components can mitigate waist pain resulting from improper sitting positions.

Anthropometry, the study of human body dimensions, including measurements, shape, mass, center of gravity, body inertia, and physical capacity, plays a pivotal role in ergonomic design. When determining a product's shape and dimensions, the characteristics of the human body serve as the foundation for accurate sizing. This discipline, often referred to as human factors engineering, focuses on the interaction between humans and products. Consequently, one of the key objectives of this research is to develop an ergonomic design for car seat components.

4.1 Identification of the original design issue

Identifying the problem is a crucial step in the design process. Weaknesses in problem identification techniques can lead to delays in product development time to market. A black box model of the car seat component is shown in the following diagram to provide an understanding of the product in terms of output and input as well as its transfer characteristics without knowledge of the internal workings, which are considered "opaque" (black) in Figure 3.

Car seat components are physically disassembled to identify the crucial parts for redesign using the VE approach. The car seat components are divided into several main functions: seating (seat cushion and seat frame), backrest or back lining, headrest, and user safety components. The design of car seat components requires the integration of human measurement data with the car seat components per Figure 4. Ergonomic car seat component design can facilitate task performance, minimize fatigue and injury, and tailor the design to fit the body size, strength, and movement range of the user. The seat height should be pneumatically adjustable while seated [14]. The recommended range is between 406.4 mm (16 inches) to 520.7 mm (20.5 inches) from the floor. A seat with a width of 431.8 mm (17 inches) to 508 mm (20 inches) is considered adequate for most users. Additionally, the seat slope should have an inclination angle ranging from 0° to 10° as indicated in Figure 5. The seat cushion must be sufficiently padded to provide comfort to the user. If a seat cushion is too soft, the user's muscles are required to constantly adjust to maintain a stable posture, which can lead to strain and fatigue. Additionally, the fabric of the seat should allow for air circulation.

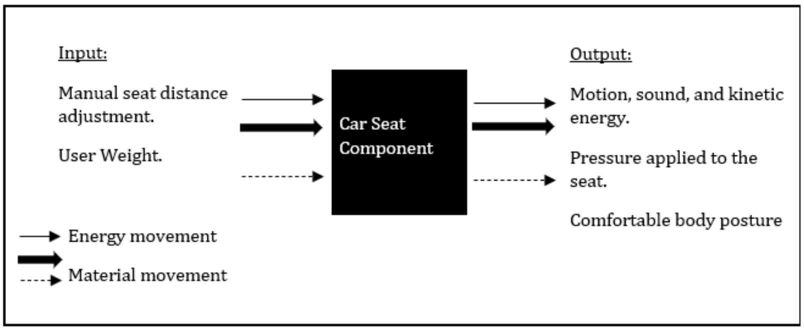

Figure 3. Black box model of car seat component

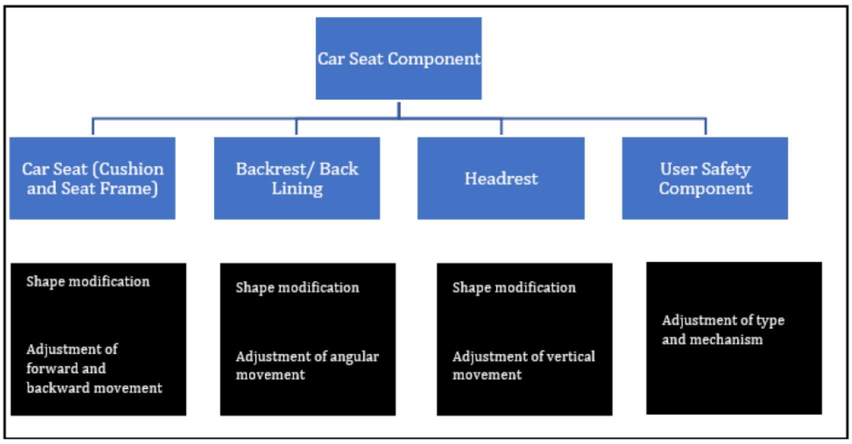

Figure 4. Disassembly of car seat components by function

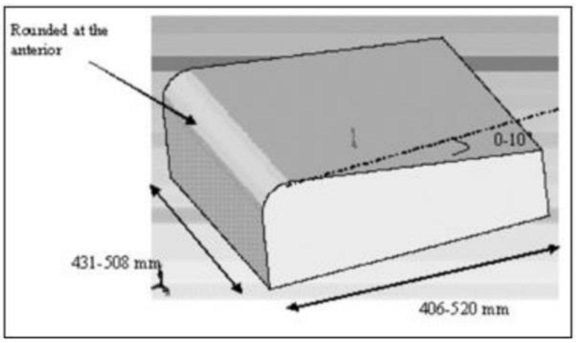

Figure 5. Car seat cushion dimensions based on ergonomic guidelines
Source: Wahab et al. [6]

5. DETAILED DESIGN AND ANALYSIS

The car seat components modelled using of Autodesk® Inventor software consist of four main components, namely seat cushions, seat frames, position adjusters (jacks) and side protectors. Figure 6 is the exploded view of components of the car seat.

With the use of the Boothroyd Dewhurst Design for Manufacture and Assembly (DFMA)® software, two types of analysis are studied, namely DFM Concurrent Costing and Design for Assembly. Result of DFM Concurrent Costing for each component are indicated in Table 1.

Result of Design for Assembly are indicated as per follow:

a) Number of parts in car seat component: 9;
b) Theoretical minimum number of parts: 4;
c) Design for assembly index: 19.2%;
d) Total assembly time per worker: 61.05s;
e) Total cost per product: RM 32.85.

Based on the Figure 7, the car seat component has a total assembly time of 64.5 seconds. 86.90% of the total product assembly time, which amounts to 56.05 seconds, is the time taken to assemble parts without sub-assembly. 7.75% of the total assembly time is allocated to standard operations such as welding time. The remaining 5.35% of the time is for sub-assembly tasks. There is a potential to eliminate 113.75 seconds of assembly time for certain parts.

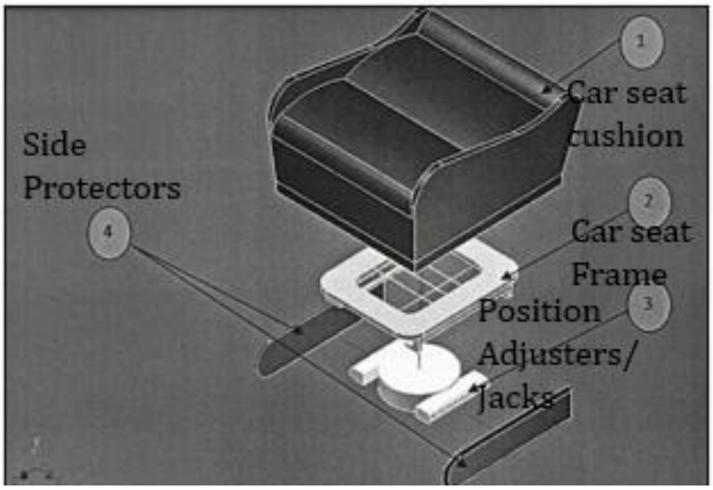

Figure 6. Exploded view of car seat components
Source: Autodesk® Inventor

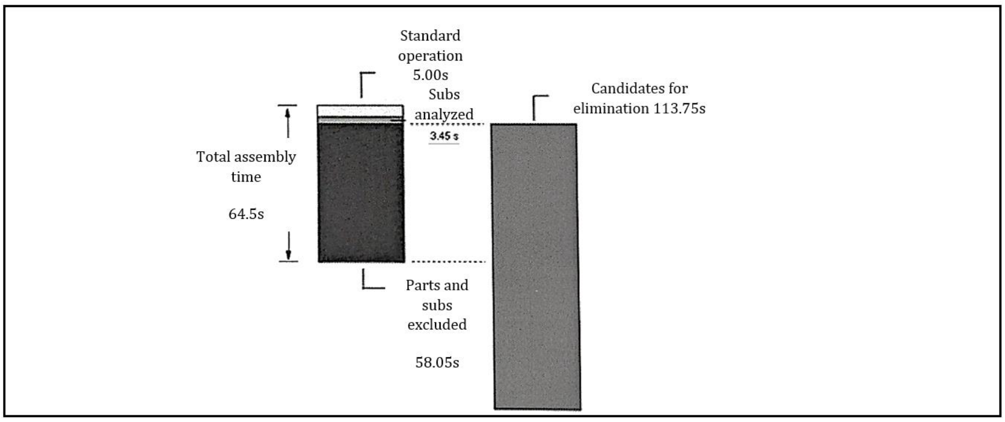

Figure 7. Chart for the assembly time per product
Source: DFMA®

Table 1. DFM concurrent costing analysis result of car seat frame and car seat cushion

Process	Material	Material Cost (RM)	Process Cost (RM)	Hardware Cost (RM)	Other Cost (RM)	Total Cost (RM)
Car seat frame						
Hot forging	Carbon Steel AISI 1025	13.52	5.95	0.36	0.37	20.20
Sand casting	Carbon Steel AISI 1025	11.89	7.06	0.35	0.41	19.71
Car seat cushion						
Thermoforming	Medium density flexible polymer foam	9.27	2.82	0.84	0.11	13.04
Injection moulding	Medium density flexible polymer foam	6.39	69.69	2.33	0.36	78.77

Source: DFMA®

The Boothroyd Dewhurst Design for Manufacture and Assembly (DFMA)® software can generate suggestions for redesigning for assembly to simplify the product structure and facilitate the product assembly process. Among the suggestions provided are proposals to integrate, eliminate, or modify fastening methods using screws. These suggestions are shown in the Table 2.

Suggestions were also made to reduce the number of parts in the assembly by combining or eliminating parts as shown in the Table 3. The consolidation of these parts could eliminate fastening components and unnecessary operations, which can reduce assembly time.

Table 2. Suggestions to integrate fastening methods into the redesign for assembly to simplify the product structure

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	#3 Slotted flat head screw	1	10.00	16.38
Sub assembly	#3 Slotted flat head screw	1	10.00	16.38
Total			20.00	32.76

Source: DFMA®

Table 3. Suggestions for part reduction in the redesign for assembly to simplify the product structure

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	Side cover	1	6.45	10.57

Source: DFMA®

Table 4. Suggestions to reduce operations in the redesign for assembly to simplify the product structure

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	Application of adhesive area	1	5.00	8.19

Table 5. Suggestions for incorporating assembly features (such as chamfers) in the redesign for assembly to simplify the product structure

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	Side cover	2	3.00	4.91
	#3 Slotted flat head screw	1	1.70	2.78
Sub assembly	Car seat frame	1	1.50	2.46
	Position Adjusters/ Jacks	1	1.50	2.46
	#3 Slotted flat head screw	1	1.70	2.78
Total			9.40	15.40

Source: DFMA®

In addition, separate operations that do not add value, such as welding, are advised to be reviewed. Suggestions for the removal of operations that do not add value to the product are shown in the Table 4.

The design of parts that require alignment during the assembly process will also be reviewed by introducing chamfers to allow the following parts to be aligned.

Redesign is also suggested for the following individual assembly to reduce handling issues that make the part difficult to manage with both hands as indicated in Table 5 and Table 6.

Suggestions for redesigning individual part assemblies to eliminate insertion difficulty issues are shown in the Table 7.

Table 6. Suggestions for incorporating assembly features (such as chamfers) in the redesign for assembly to simplify the product structure

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	Car seat cushion	1	1.85	3.03

Source: DFMA®

Table 7. Suggestions for redesigning individual assemblies within a product to address insertion difficulty issues

Main Assembly	Component Name	Qty	Total Time Saved (s)	Percentage Reduction (%)
Car seat component	Car seat cushion	1	1.50	2.48
	Side cover	2	3.00	4.91
Sub assembly	Car seat frame	1	1.50	2.46
	Position adjusters/ Jacks	1	1.50	2.46
Total			7.50	12.29

Source: DFMA®

5.1 Engineering analysis

Figure 8 is the results of the simulation study, indicating the effects of model shape changes on the magnitude of force, including displacement distribution, strain distribution, and the safety factor of the model. In the implementation of the simulation process, the magnitude of the force applied is 1177.2 N (120 kg) for the maximum weight of an adult. The materials used are medium density flexible polymer foam for the seat cushion and AISI 1025 carbon steel for the seat frame as indicated in Table 8.

Table 8. Simulation result for car seat cushion and car seat frame

Main Assembly	Car Seat Cushion	Car Seat Frame	Load Applied
Maximum stress (MPa)	0.02337	13.70	120kg (1177.2 N)
Maximum displacement (mm)	0.4026	0.006119	120kg (1177.2 N)

5.2 Failure mode and effect analysis

As a preventive measure against accidents, a Failure Mode and Effects Analysis (FMEA) is conducted to identify potential problems that could occur in the design of car seat components. Criteria of FMEA is indicated in Appendix A2. This analysis aims to predict the types of failures that might occur in components such as the seat cushion and seat frame, forecast their potential effects, and establish preventive measures for each stated failure.

Based on Table 9 several failure modes and effects were identified for car seat components such as the seat cushion, seat frame, position adjusters (Jack), and side cover. Some recommended actions were taken to reduce the causes of failure, including adding lubricant to the movement mechanism of the position adjuster and selecting softer materials for the seat cushion. By introducing these recommendations, functional failures in car seat components can be reduced. For example, the risk priority number for the seat frame, 288, can be reduced to 96 when the material used is replaced with a corrosion-resistant alloy material.

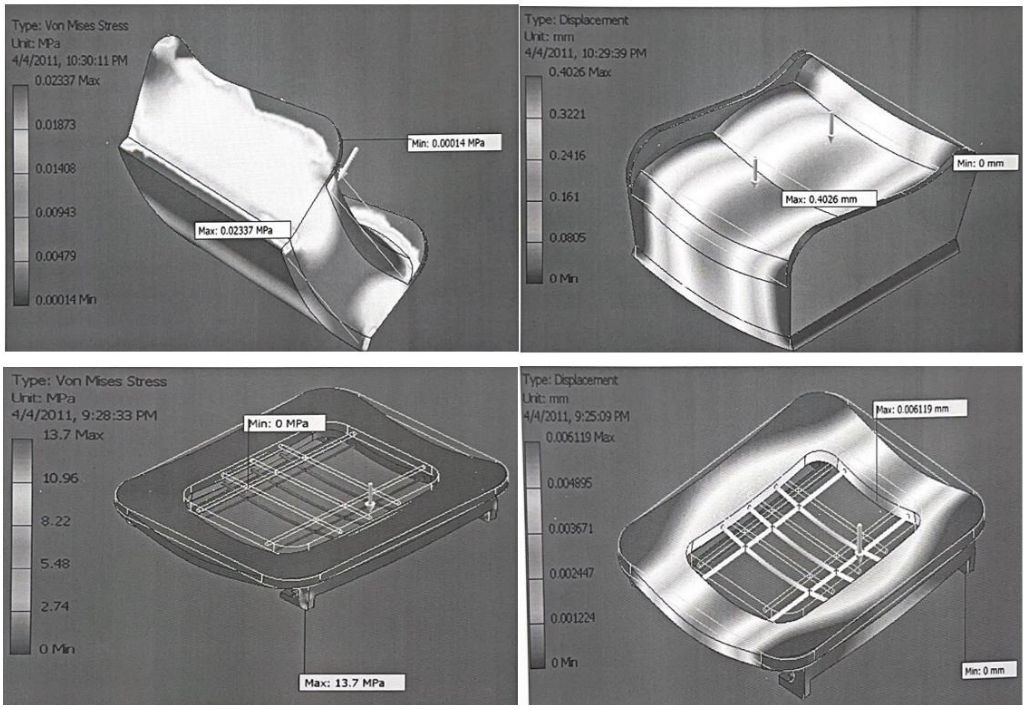

Figure 8. Simulation analyses for car seat cushion and car seat frame
Source: Autodesk® Inventor

Table 9. FMEA result for car seat cushion and car seat frame

System/ Function	Potential Mode of Failure	Potential Impact of Failure	SEV	Potential Cause of Failure	OCC	Detection Mode	DET	RPN	Suggested Action	SEV	OCC	DET	RPN
Car seat cushion	Cushion not ergonomic	Causing user fatigue	5	Cushioning material used is not padded	4	Discomfort when sitting on a seat cushion	8	160	Selection of a padded material to withstand compression forces	5	3	5	75
Car seat frame	Frame failure	Bent or broken seat frame, affect user safety	9	The material of the seat frame has a low safety factor	3	Bent seat frame	9	243	Reduce the shock force on the components of the car seat	8	1	9	72
	Corrosion occurs	The seat frame looks rusty	8	Component material	6	Color degradation	6	288	Reduce with corrosion-resistant alloy material	4	4	6	24
Position adjuster/ Jack	Position difficult to adjust	Causes user discomfort	7	Insufficient lubrication	3	The use of lubricant	4	84	Lubricant is added	4	2	3	24
Side cover	Detached from the seat frame	Position adjuster mechanism is disrupted	7	Damage during the assembly process	3	Side cover becomes detached	7	168	Different fastening methods	4	1	7	28

6. DISCUSSION

6.1 DFMA results and design improvements

DFMA analysis provided valuable insights into optimizing the car seat cushion and frame components. The results highlight several areas where design changes led to improved cost efficiency and production performance. The DFMA analysis identified opportunities to reduce the total number of parts in the seat component from 9 to 4. This reduction directly influenced the seat cushion design by simplifying the structure, eliminating unnecessary fasteners, and integrating multiple functions into single components. For example, the redesign of fastening methods, such as reducing the use of screws per Table 2, decreased assembly time by 20 seconds, contributing to an overall 32.76% reduction in assembly time. This streamlining also reduced labor costs and the likelihood of assembly errors, improving manufacturing efficiency.

DFMA results also provided insights into selecting cost-effective materials and processes. By comparing different manufacturing methods (e.g., thermoforming vs. injection molding for the seat cushion), the analysis recommended using thermoforming, which reduced material and process costs from RM 78.77 to RM 13.04. This substantial cost reduction did not compromise the structural integrity of the seat cushion. Instead, it optimized the material usage, allowing for better resource allocation and reducing waste.

The DFMA analysis suggested incorporating design features like chamfers and self-locating parts, which simplified the assembly process. By modifying the seat cushion design to include these features, the assembly time for parts was reduced significantly as indicated in Table 5, contributing to improved overall production performance. These design changes also ensured that the product met quality standards with fewer errors during the assembly process, ultimately improving the reliability and longevity of the final product. Table 10 indicates the comparison of VE design metrics.

6.2 Computer-Aided Engineering (CAE) results and design improvements

CAE analysis using ANSYS provided crucial data on how the car seat cushion and frame behaved under load, guiding specific design improvements that enhanced performance and safety. The CAE analysis showed that the seat cushion and frame experienced low stress and displacement under a load of 120 kg (1177.2 N). The maximum stress for the seat cushion was 0.02337 MPa, and for the frame, it was 13.7 MPa, both well within the material limits. This data allowed the design team to confidently reduce the thickness of the seat cushion material while maintaining structural integrity. The optimized thickness reduced material usage without affecting comfort or safety, contributing to cost savings and weight reduction.

The ANSYS results confirmed that the current material (medium-density polymer foam for the cushion and AISI 1025 carbon steel for the frame) provided adequate strength while maintaining flexibility. The low maximum displacement (0.4026 mm for the cushion and 0.006119 mm for the frame) indicated that the materials could handle loads without significant deformation. Based on these results, the material choice was validated as the optimal balance between cost, weight, and performance. However, the study also suggests that future iterations could explore lighter, more advanced materials that maintain similar stress tolerances while offering further cost or weight reductions.

The moderate displacement of the seat cushion (0.4026 mm) indicated that the cushion design effectively absorbed the load and distributed it across the surface, improving comfort and ergonomics for the user. Based on this data, the cushion's internal structure was adjusted to provide better support at key pressure points, ensuring consistent comfort for prolonged use. These design improvements were directly informed by the displacement data from the CAE analysis, which helped fine-tune the cushion's performance without sacrificing durability.

Table 10. Comparison of VE design metrics

Design Metrics	Pre-VE	Post-VE
Cost reduction	Initial design involved higher costs, with more expensive materials or unnecessary parts driving up production costs.	The car seat cushion manufactured using thermoforming now costs RM 13.04. The car seat frame costs RM 19.71 using sand casting showing competitive material and process cost optimizations.
Assembly and time reduction	The original assembly time for the car seat cushion and frame would have been longer due to the higher number of parts and more complex assembly operations.	The assembly time per product is now 64.5 seconds, with 86.90% of that time spent on part assembly. Table 3 suggested elimination of operations such as welding have further reduced assembly time by as much as 32.76%.
Stress and displacement improvements	Higher stress concentrations might have been observed in the seat cushion and frame due to less efficient material distribution.	The maximum Von Mises stress for the seat cushion is now 0.02337 MPa, and for the seat frame, it is 13.7 MPa. These values are significantly below the yield strength of the materials used, ensuring better durability and product longevity. The maximum displacements of 0.4026 mm for the seat cushion and 0.006119 mm for the seat frame indicate improved material performance.
Comfort and ergonomics	The initial design provided lower ergonomic benefits, with a less optimized load distribution leading to higher stress on the user's body during prolonged use.	The moderate displacement of 0.4026 mm for the seat cushion reflects improved load distribution, providing enhanced comfort without excessive deformation.

6.3 Specific design adjustments guided by DFMA and CAE analysis

Reduction in Material Thickness: The CAE results demonstrated that the stress on the seat cushion was well below the material's failure threshold. This allowed for a reduction in material thickness, contributing to weight reduction without affecting comfort or safety.

Fastener Reduction: DFMA analysis recommended reducing the use of fasteners, such as screws, in the assembly process. By integrating parts and designing self-locating features, the total number of fasteners was decreased, resulting in quicker assembly and lower production costs.

Optimization of Load Distribution: The CAE stress distribution analysis indicated areas of the cushion that experienced higher stress. By adjusting the cushion's geometry to redistribute load, the design improvements enhanced user comfort and extended the product's lifespan.

7. IMPLICATIONS

In this study, the design process for car seat components was conducted, with the seat cushion and seat frame selected as the components suitable for design improvements to meet the main objectives of this scientific study. Value Engineering techniques were applied to the car seat components to add value to the product and reduce production costs. Design considerations for manufacturing and assembly were analyzed for the produced car seat component models using Boothroyd Dewhurst DFMA® software. Moreover, redesigns of the seat cushion, seat frame, position adjuster, and side cover were proposed to facilitate the analysis of design considerations for manufacturing and assembly [15]. Engineering analysis or simulation was also conducted on the seat frame and seat cushion using ANSYS® analysis software, which supports Autodesk® Inventor® software. ANSYS® software was used to analyze displacement distribution and stress distribution when a load of 120 kg (1177.2 N) was applied to the model of the seat frame and seat cushion. FMEA was also performed on the seat cushion, seat frame, position adjuster, and side cover to predict potential failure types and effects and to generate preventive measures for identified failures [16].

The study practically implicates that the application of Value Engineering (VE) leads to significant cost reductions in car seat cushion production. By optimizing material selection and reducing the complexity of components, the study provides a clear path for automotive manufacturers to decrease production costs without compromising product quality [17]. This approach has implications for improving profit margins, especially in high-volume manufacturing, where even small cost savings per unit can lead to substantial financial benefits over time [18]. By simplifying the design and reducing assembly time through VE, the study highlights how manufacturers can streamline their production processes. The reduction in assembly time, as shown by the DFMA analysis, translates into lower labor costs, quicker production cycles, and greater manufacturing capacity. This efficiency not only benefits manufacturers by lowering production costs but also allows them to meet increasing market demands more effectively, contributing to overall competitiveness. The study evaluates stress and displacement provides evidence that VE can improve the structural integrity of car seat cushions and frames. With the optimized design maintaining both low stress and minimal displacement under load, the results ensure the product's durability and safety [19]. This has critical implications for maintaining high safety standards in the automotive industry, especially given the importance of car seat cushions in ensuring occupant comfort and crash safety. The study demonstrates how VE can lead to more comfortable seating solutions by optimizing load distribution and material flexibility. The enhanced comfort and ergonomics, as reflected in the moderate displacement of the cushion, have implications for consumer satisfaction. This is particularly important for car manufacturers targeting premium markets, where user experience and comfort are key differentiators. The findings suggest that automakers can offer more ergonomically sound and comfortable seating solutions at competitive prices, improving market appeal. Through material optimization, the study also has implications for sustainability. By reducing material usage and waste, the VE approach aligns with the growing trend of sustainable manufacturing in the automotive industry. The ability to use eco-friendly materials without sacrificing performance contributes to both corporate sustainability goals and regulatory compliance in environmental protection [20]. The methods and findings of this study could be applied to other automotive components beyond car seat cushions. The successful integration of VE and engineering analysis software (DFMA, ANSYS) sets a precedent for optimizing other parts of the vehicle that require cost efficiency, performance, and safety. This makes the study valuable for future research and practical applications across various automotive systems. By implementing VE and achieving cost reductions while maintaining high-quality standards, manufacturers can gain a competitive edge [21]. The study shows that manufacturers can produce premium-quality products at lower costs, allowing them to offer competitive pricing or reinvest savings into further innovation, helping them stay ahead in a rapidly evolving automotive market.

While the study effectively applies Value Engineering (VE) to reduce production costs and improve performance, it focuses primarily on immediate cost savings rather than lifecycle costs or sustainability. Future research could explore the long-term cost implications of material choices, considering factors such as product durability, recyclability, and end-of-life disposal costs. Additionally, integrating sustainable materials and processes in VE could offer insights into how environmental objectives can align with cost efficiency in car seat production. The current study focuses on static load analysis to measure stress and displacement under a 120 kg load. However, car seat cushions and frames are subjected to dynamic forces during use, such as vibrations, impacts, and variable occupant weights. Future studies could simulate dynamic loading conditions to assess how the VE-optimized designs perform under real-world driving conditions, further ensuring safety and durability. The study focuses on medium-density flexible polymer foam and AISI 1025 carbon steel as materials for the seat cushion and frame, respectively. Future research could explore the use of advanced materials, such as lightweight composites, memory foams, or recycled materials, which may further optimize performance, weight reduction, and sustainability [22]. Additionally, nanomaterials or smart materials that respond to external stimuli (e.g., temperature, pressure) could be examined to improve comfort and ergonomics [23]. While the study applies DFMA to optimize the manufacturing process, future research could investigate the impact of automation and Industry 4.0 technologies (e.g., robotics, artificial intelligence, and IoT) on the assembly and production of car seat cushions [24]. These technologies could further reduce labor costs, enhance precision, and improve overall production efficiency.

The study evaluates comfort and ergonomics primarily through simulation data (e.g., displacement) [25]. Future research could involve user-centered testing, where real occupants assess comfort, posture support, and fatigue over time [26, 27].

8. CONCLUSIONS

By collecting real-world user data, researchers could better align VE optimizations with consumer preferences, especially for premium vehicle markets that prioritize comfort. Although this study focuses on car seat cushions and frames, future research could expand the application of VE to other critical automotive components, such as dashboard systems, safety features, or suspension systems. Investigating how VE strategies impact these components' cost, performance, and safety would provide broader insights into its applicability across the automotive industry. The study notes that VE's focus on immediate cost savings can sometimes overshadow long-term durability and quality considerations. Future research could investigate hybrid approaches that balance short-term cost reductions with long-term product performance. This could include developing new methodologies or frameworks that incorporate both VE and Design for Reliability (DFR) principles to mitigate potential drawbacks in VE-focused designs.

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APPENDIX

APPENDIX A1. Material selection matrix for car seat frame using the Pugh concept

Characteristics	Rating	Carbon Steel AISI 1025 (Annealed)		Aluminium Alloy 6061-T4		Magnesium Alloy AM20 (Casted)		Standardized Product
		Score	Total	Score	Total	Score	Total	
Material Cost	0.25	3	0.75	2	0.50	1	0.25	D
Young's Modulus	0.05	2	0.10	3	0.15	2	0.10	A
Poisson Ratio	0.05	2	0.10	3	0.10	2	0.10	T
Hardness	0.30	5	1.50	5	1.50	5	1.50	U
Tensile Strength	0.15	2	0.30	2	0.30	3	0.45	M
Elongation	0.10	1	0.10	2	0.20	2	0.20	
Density	0.05	1	0.05	2	0.05	1	0.05	
Compressive strength	0.05	2	0.10	2	0.10	2	0.10	
Total Score			3.00		2.90		2.75	
Rank			1		2		3	

APPENDIX A2. FMEA criteria

The Severity (S) Level Description	Rate
The effect is not felt by the user	1
The impact is very minimal and not bothersome to the user	2
Minimal impact that is bothersome to the user but does not require advice	3
Minimal impact, user requires advice	4
Moderate impact, user needs immediate service	5
Major impact causing dissatisfaction among users	6
Significant impact that will cause the system to malfunction and result in complaints from users	7
Extreme impact causing the system to malfunction	8
Critical impact causing the entire system to shut down and posing a safety risk	9
Hazardous, failure may occur without warning and life is at risk	10

The Probability of Failure Occurrence (O) Description	Estimated Probability of Failure	Rate
Occurrence Rate is Extremely Remote: The probability of occurrence is nearly impossible, only under the most unusual circumstances.	$\leq 1\times10^{-6}$	1
Occurrence Rate is Remote, Highly Improbable: It's very unlikely that this failure will happen under normal conditions.	1×10^{-5}	2
Very Slim Chance of Occurrence: The possibility exists but is extremely low under typical conditions.	1×10^{-4}	3
Slim Chance of Occurrence: There is a small possibility of the failure occurring under normal operational conditions.	4×10^{-4}	4
Occasionally Occurs: The failure happens infrequently but is not unheard of.	2×10^{-3}	5
Occurs Moderately: The failure has a moderate probability of occurring during the product's lifecycle.	1×10^{-2}	6
Frequently Occurs: The failure is likely to happen regularly under normal operational conditions.	4×10^{-2}	7
High Rate of Occurrence: There is a high likelihood that the failure will occur.	0.2	8
Very High Rate of Occurrence: The failure is almost certain to occur during the product's operational life.	0.33	9
Exceedingly High Rate of Occurrence: The failure is expected to happen almost definitely, with an almost certain probability under standard conditions.	≥ 0.55	10

The Likelihood of Detecting (D) Failure Description	Rate
Almost certain to occur	1
Very high chance of failure detection	2
High chance of failure detection	3
Moderately high chance of failure detection	4
Moderate chance of failure detection	5
Low chance of failure detection	6
Slim chance of failure detection	7
Remote chance of failure detection	8
Very remote chance of failure detection	9
No chance of detection	10