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The Development of a Vehicle Recovery Remanufacturing Tool: An Interior Parts Analysis Indicator

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Abstract: The rapid growth of the automotive industry has placed a significant demand on earth resources such as metal and minerals. This has led to a shortage of materials and an increase in material prices. One of the solutions to enhance resource management is to perform parts remanufacturing during product design to ease the part classification. However, this initiative is not yet widely explored, particularly in terms of guideline or tool development. For example, the recyclers have no idea on how to decide the suitability of an automotive part to be remanufactured. This study aims to develop a vehicle recovery analysis guideline to assist those in the automotive industry in developing vehicles with higher remanufacturing rates during the product development stage. In this study, there are three main criteria, and 11 sub-criteria were determined from the literatures that influences the vehicle part remanufacturing rate. These criteria are classified into three main categories namely: selection of material, method of joining, and mechanical design. Next, quantitative approach namely Analytic Hierarchy Process (AHP) methodology was applied to collect the pairwise comparison data from the automotive industry practitioners. The gathered data were analyzed using Expert Choice V11 software to determine the criteria priority weightage to influence the remanufacturing activities. From the analysis, the three most influencing criteria based on global weightage are type of joining (0.216), durability (0.131), type of material (0.103), whereas the criteria that least being considered are cost of material (0.018), cleanability (0.04), and design complexity (0.041). From the obtained priority weightage, these data were used to develop an assessment tool using Microsoft Excel software. The assessment tool was validated by experts to ensure its feasibility to be applied as a remanufacturing guideline. Positive feedbacks were obtained from the experts especially on the outputs of assessment tool which able to assist the practitioner in product design and ease the process of remanufacturing.

Keywords: Vehicle recovery, assessment tool, AHP, remanufacturing, sustainable manufacturing

1. Introduction

As industrialization continues, environmental pollution has become a major concern, with the growing amount of consumer waste having a significant impact on the environment. According to research, the amount of waste generated daily in Malaysia is currently 23,000 tons and is projected to reach 30,000 tons by 2020 [1]. The increasing population and development are also contributing to the gradual increase in waste generation. According to the report "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050" published by the World Bank Group in 2018, only about 13.5% of the world's waste is being recycled [2]. To address this issue, many countries such as Japan, Germany and Canada have implemented regulations requiring industries to take back used items from customers so that materials and parts can be recycled or reused [3]. Additionally, sustainable production patterns and consumption have been established as one of the United Nations' sustainable development objectives. One of the main goals in this area is to reduce the amount of waste generated by implementing the 3Rs of waste management: reduce, reuse, and recycle [4].

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The automotive industry plays a significant role in waste generation, specifically with the concept of End-of-Life Vehicles, which refers to vehicles that have become waste [5]. As the automotive industry accounts for around 5% of global industrial output, recycling end-of-life vehicles (ELVs) is not only an environmental concern, but also a financial concern for the industry [6]. ELVs are classified as hazardous waste and have the potential to pollute the environment if not properly managed. Due to these ecological concerns, the feasible management of End-of-Life Vehicles (ELVs) has become a global need.

As the automotive industry continues to advance globally, the amount of waste produced by the industry is also increasing gradually. Additionally, the use of raw materials is increasing as rapid growth in manufacturing industry such as automotive sector. Therefore, appropriate measures must be taken to control the materials used in vehicles from the initial stage. By implementing a proper supporting tool or analysis indicator to assist manufacturers in producing vehicles with a higher recovery rate, we can control the overexploitation of resources and reduce the cost of new vehicles. The aim of this study to is to determine the factors that influence vehicle recovery performance. At the end of the study, a vehicle recovery assessment tool was developed to assist designers in designing a car that has a higher part recovery rate.

2. Remanufacturing

The environmental damage that was caused by the disposal of end-of-life products is what that made ways for product recovery to be discovered. Product recovery reduces the amount of energy, unrefined components, and the impact it caused to the environment by the amount of waste produced. Furthermore, product recovery makes way for a highly beneficial and profitable business.

Remanufacturing is a practical method for extending the useful life of a product that has reached its end of life [7]. Despite the challenges faced in terms of ecology, society, and finances, there are also issues related to the core accessibility, timing, and quality of remanufacturing. As Mastsumoto et al. [8] explained, remanufacturing is a modern practice that can be summarized as a series of manufacturing phases that are applied to an end-of-life product to restore it to a new or improved state. During this phase, the core undergoes various remanufacturing sequences to ensure that the product meets the ideal item guidelines [9]. The summary of extracted factors to influence remanufacturing activities as shown in Figure 1 below.

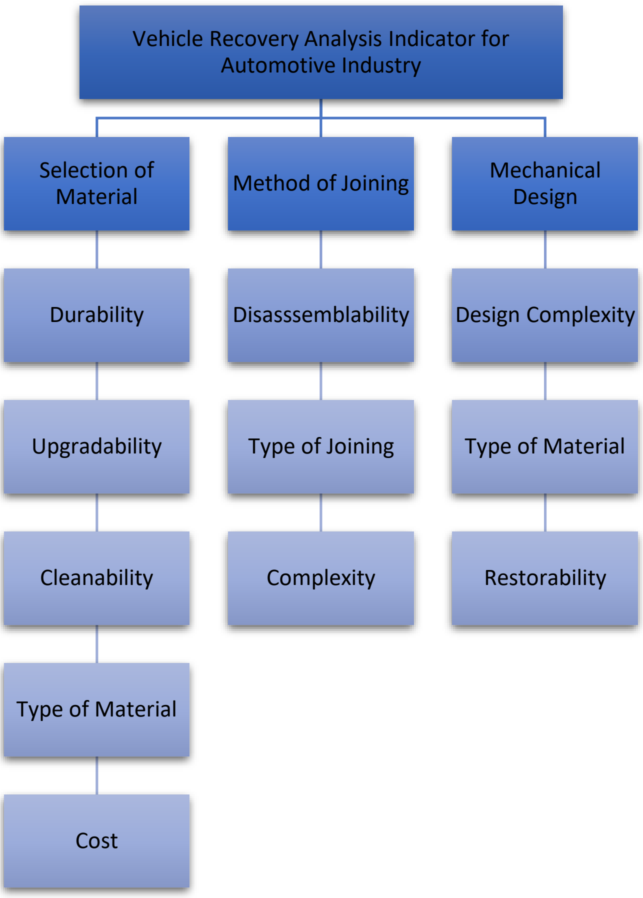

Fig. 1 - Extracted factors to influence vehicle recovery through remanufacturing activities

2.1 Factors to Influence Remanufacturing

The OEMs (Original Equipment Manufacturers) are the ones that have the capacity and facility to design a product for remanufacturing. They're the people that have command over the product design and remanufacturing phases. Moreover, not all products in the market are appropriate for remanufacturing. For remanufacturing to be considered, there are characteristics that a product ought to have, or more specifically, factors. There are written guidelines available for selecting products for remanufacturing, which can be obtained from numerous remanufacturing literatures [10][11]. These guidelines are the ones that help us to understand more about the factors that will influence the activities of remanufacturing such as part durability, long life technology, etc. In the next section, all these factors are categorised and discussed namely selection of material, method of joining (assembly), and mechanical design.

2.1.1 Selection of Material

According to Yang [11], choosing the right materials is a crucial aspect of automotive product development. As the design process for cars evolves, it becomes more responsive to environmental regulations. In 2002, the European Union established the End-of-Life Directive, which requires a certain percentage of end-of-life vehicles to be remanufactured to decrease waste [11].

The properties of the materials used in the remanufacturing of automobile items have a significant impact on the performance of the process, as well as economic incentives, the recoverability of components, and the amount and harmfulness of waste produced during remanufacturing [12]. Proper material selection can improve the efficiency of various remanufacturing processes, such as enhancing the ease of disassembling parts [13]. Given the crucial importance of material selection during vehicle remanufacturing, traditional material characteristics should be expanded to include different remanufacturing requirements. These requirements include technical feasibility, financial viability, and the environmental impact of the materials used in remanufacturing, to improve the potential for part remanufacturing [11].

2.1.2 Method of Joining

The method of joining is a design factor that impacts item fit, structure, and capability. Regularly, the method of joining includes using different techniques to join two or more items together. The usual techniques are crimping, welding, screws, bolts, etc. The method of joining is a major influence on deciding the credibility of a part to be considered for remanufacturing as how the items are combined can influence part disassembly [14]. Therefore, harm could happen to any single part during the disassembly process can compromise the entire product. For instance, a coordinated snap-fit design could be convenient, but a failed snap-fit can compromise the opportunity for the product to be reused.

2.1.3 Mechanical Design

One more factor that firmly affects the remanufacturing proficiency of a product is structure design. The disassembly process to isolate various components and recover the reusable parts in a non-damaging and cost-efficient manner is a difficult undertaking during product remanufacturing [15]. In the meantime, the productivity of different remanufacturing processes will be influenced by the design tolerance, number, position, and shape of parts [15]. For instance, remanufacturing can be challenging and costly if the part that must be replaced is supplanted deep inside an item.

3. Methodology

In this study, it starts with credible literature study to extract factors influencing the recovery rate of vehicle parts, followed by Analytical Hierarchy Process data collection, and lastly the analyzed data from the AHP are used to development a vehicle recovery assessment tool.

3.1 AHP Framework and Data Collection

In this phase, AHP methodology is used for data collection and analyse the priority weight of the factors identified in the literature review phase. The criteria in this study consist of three major categories of factors that influence car remanufacturing: selection of material, method of joining, and mechanical design used to manufacture parts. There are a total of 11 sub-criteria that fall under these categories. The complete factors in Figure 2 were used to form AHP framework for this study. From the obtained data, a pairwise comparison of the factors is performed. AHP uses pairwise comparisons of elements to match up each individual criterion and collects the results into a decision matrix. There are 4 stages of the analysis to conduct before obtaining the results:

1.Conduct the pairwise comparison matrix for each respondent.
2.Evaluate the consistency ratio of the pairwise judgment. (Information acknowledged for consistency ratio under 0.1 if not respondents need to redo the questionnaire for consistency ratio > 0.1)

3.Develop the geometric mean analysis.
4.The result of the priority of the criteria is shown.

The level of matrix consistency could be evaluated utilizing consistency index CI [14] as follows:

$$\lambda_{max} = \sum_{j=1}^{m} \frac{(S.v)_j}{m.v_j} \qquad (1)$$

Where,

$\lambda_{max} = Highest\ eigenvalue\ of\ the\ matrix$
$m = Number\ of\ independent\ rows\ of\ the\ matrix$
$S = Pairwise\ comparison\ matrix$
$v = Matrix\ eigenvector$

Later the consistency index can be determined as follows:

$$CI = \frac{\lambda_{max} - m}{m-1} \qquad (2)$$

If the matrix is perfectly consistent, the consistency index will be zero. However, as the number of pair-wise comparisons increases, the possibility of consistency error also increases. The consistency ratio (CR) can be calculated using another measure as follows [16]:

$$CR = \frac{CI}{RI} \qquad (3)$$

Where,

$$RI = Random\ Index$$

In this study, the selected respondents to answer AHP survey include engineers, managers, lecturers, and other executives who have the experience and knowledge in remanufacturing activities.

4. Results and Discussion

In this study, there are three key criteria to be evaluated namely, the selection of material, method of joining, and mechanical design. Hence, there are three pairs of pairwise comparisons, and 19 pairwise criteria subjected to all pairwise comparisons were evaluated. Furthermore, to obtain the local weightage, the data from the pairwise comparisons from the expert must be applied to the derivatives.

To analyse the data obtained in this study, the software Expert Choice V11 was used. Prior keying in all the data into the interface, the software compare and compute the weightage for each pairwise comparison matrix, and next calculate AHP pairwise factor weightage to obtain the priority ranking of the evaluated criteria. The stability of the pairwise comparisons are measure through the consistency ratio (recommended less than 0.1 or 10%). Therefore, from the identified the criteria's weightage, the criteria with highest value of priority score considered the top most important factor. For example, the results shows that method of joining has the highest weightage of 0.405, followed by the selection of material criteria with the weightage of 0.376. The mechanical design criteria obtain the least weightage of 0.219 in the main criteria category, as shown in Table 1.

Moving on to the sub criteria, among the sub criteria under method of joining, type of joining obtained highest weightage of 0.534. The importance of disasssemblability and complexity is almost equal, with 0.236 and 0.230 weightage, respectively. Following that, under the section of selection of material, the durability sub criteria obtained the highest weightage of 0.349. The cost, on the other hand obtained the lowest weightage of 0.049. The type of material sub criteria has a weightage of 0.262, followed by upgradability with 0.234 and cleanability with 0.107 weightage. The most essential sub criteria under mechanical design are type of material with 0.467 weightage. Next in line are the restorability sub criteria with a weightage of 0.345 and design complexity with a weightage of 0.188.

Thereafter, the process of obtaining the weightage using Expert Choice, consistency judgement of the data must be done to ensure that the weightage is at a reasonable level of consistency. Consistency levels should be less than 0.1.

In this study, the consistency ratio is less than 0.1, specifically 0.02. Therefore, the data is considered acceptable as it corresponds to a reasonable level of consistency. According to the data, the method of joining has a higher importance than the other criteria. This is because the method of joining has the greatest impact on vehicle parts recovery. The method of joining is a crucial factor to be considered before developing a part and is thus given higher importance.

The selection of material criteria was given the second-highest weightage in the vehicle part recovery rate calculation: the selection of material is significant because it influences the ability to remanufacture, which is related to the amount of energy consumed and the number of steps required in the manufacturing process. After obtained all the weightage for each criterion, the importance level of each criterion is ranked from the most important criteria to the least important criteria as shown in Table 1.

Table 1 - List of criteria and sub-criteria

Criteria	Local Weightage	Sub-Criteria	Sub-Criteria Weightage	Global Weightage	Rank
Selection of Material	0.376	Durability	0.349	0.131	2
		Upgradability	0.234	0.088	7
		Cleanability	0.107	0.040	10
		Type of Material	0.262	0.098	4
		Cost	0.049	0.018	11
Method of Joining	0.405	Disassemblability	0.236	0.096	5
		Type of Joining	0.534	0.216	1
		Complexity	0.23	0.093	6
Mechanical Design	0.219	Design Complexity	0.188	0.041	9
		Type of Material	0.467	0.103	3
		Restorability	0.345	0.076	8

4.1 Assessment Tool

From the AHP global priority weightages, these data are used to develop an assessment tool to evaluate the vehicle recovery of interior parts. The assessment tool was developed using Microsoft Excel, as shown in Figure 2.

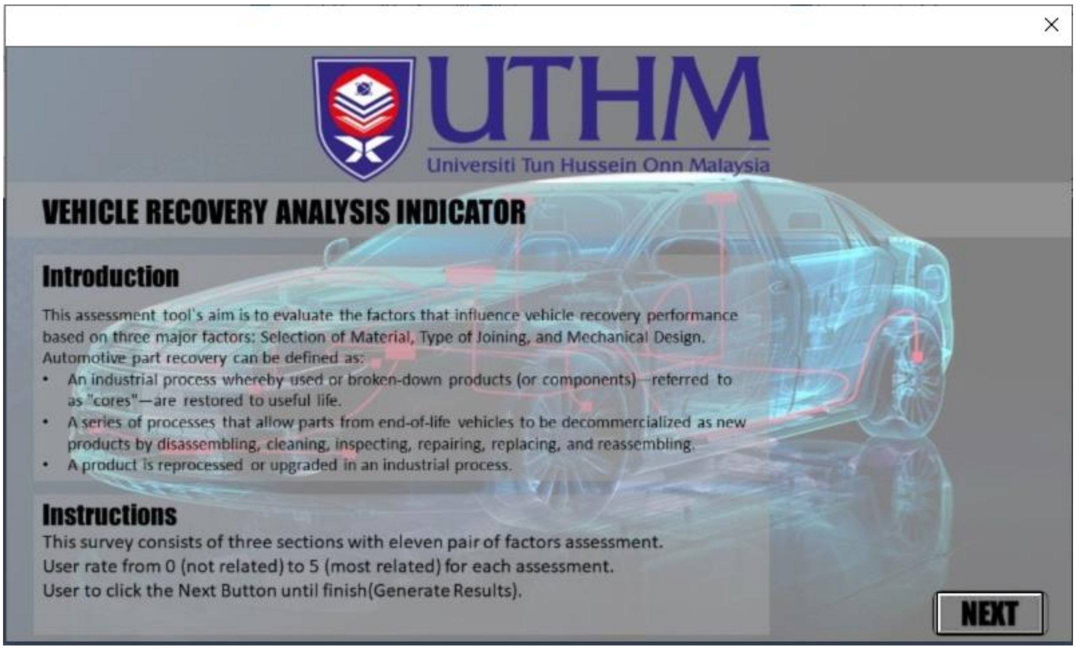

Fig. 2 - Assessment tool developed using Microsoft Excel

The assessment tool consists of 19 questions to be assessed, as illustrated in Figure 3. Each of the scales in the sub-criteria is allocated a specific weight based on the global weight. The user must rate each criterion on a scale of 0 to 5, with 0 representing the least important level and 5 representing the most important level. Before the user answers all the questions, the results interface will be generated using the data entered by the user, as shown in Figure 4.

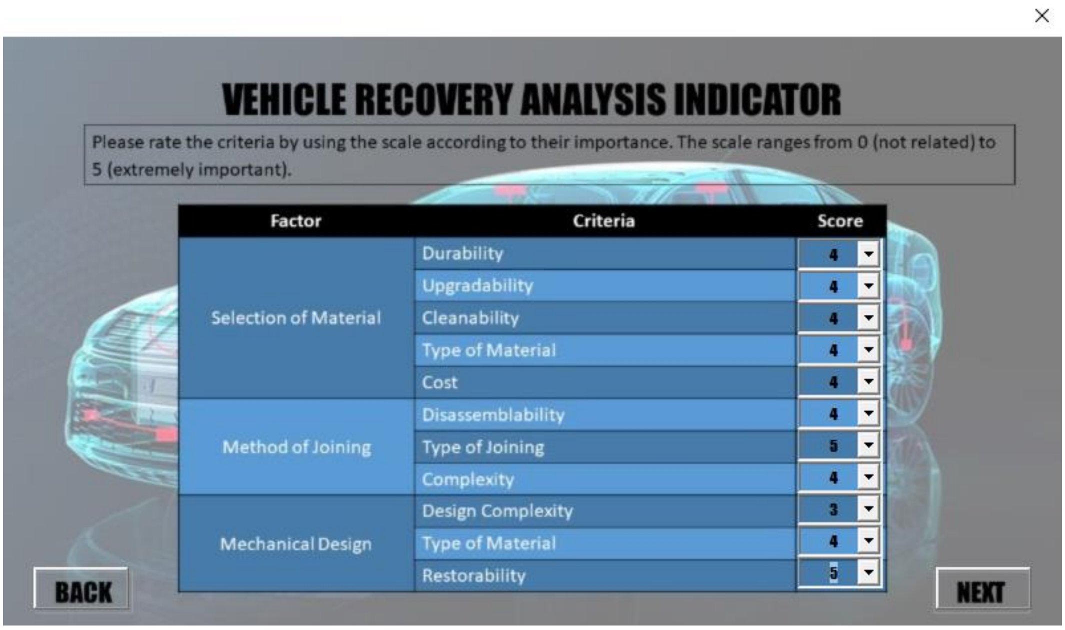

Fig. 3 - Example of assessment tool criteria

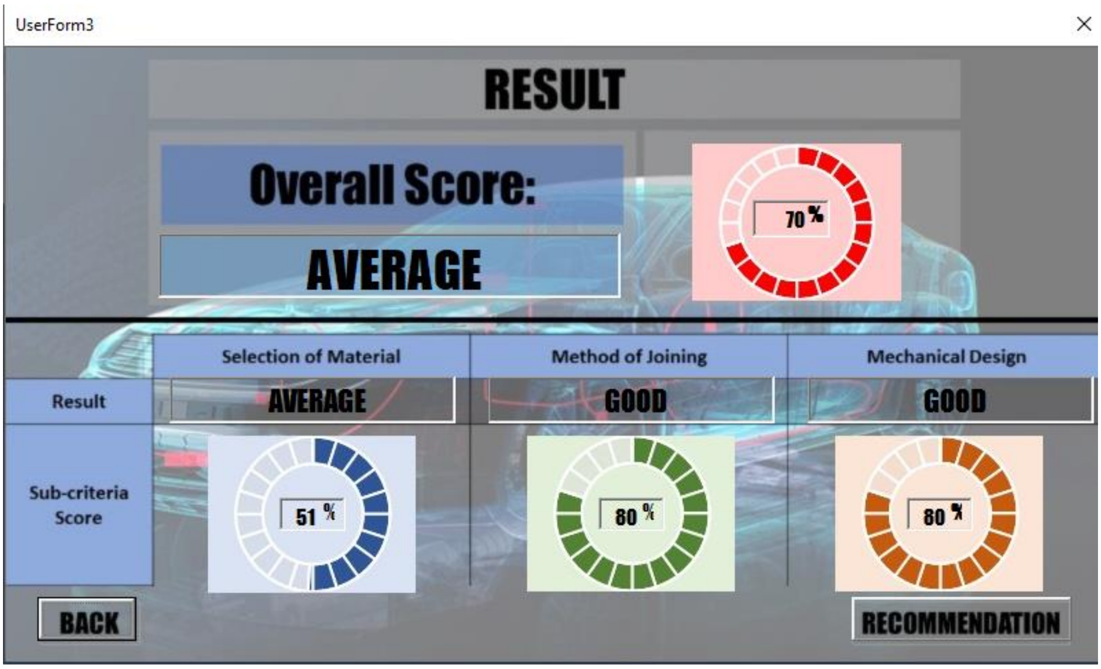

Fig. 4 - Example results generated by the assessment tool

Additionally, if the final score of the selection falls below 50%, the system will automatically generate recommendations for the user to improve the concerned criteria, as illustrated in Figure 5. The evaluation tool also helps in determining which criteria has the highest weightage, indicating that they will have a greater impact on the vehicle recovery rate compared to other criteria.

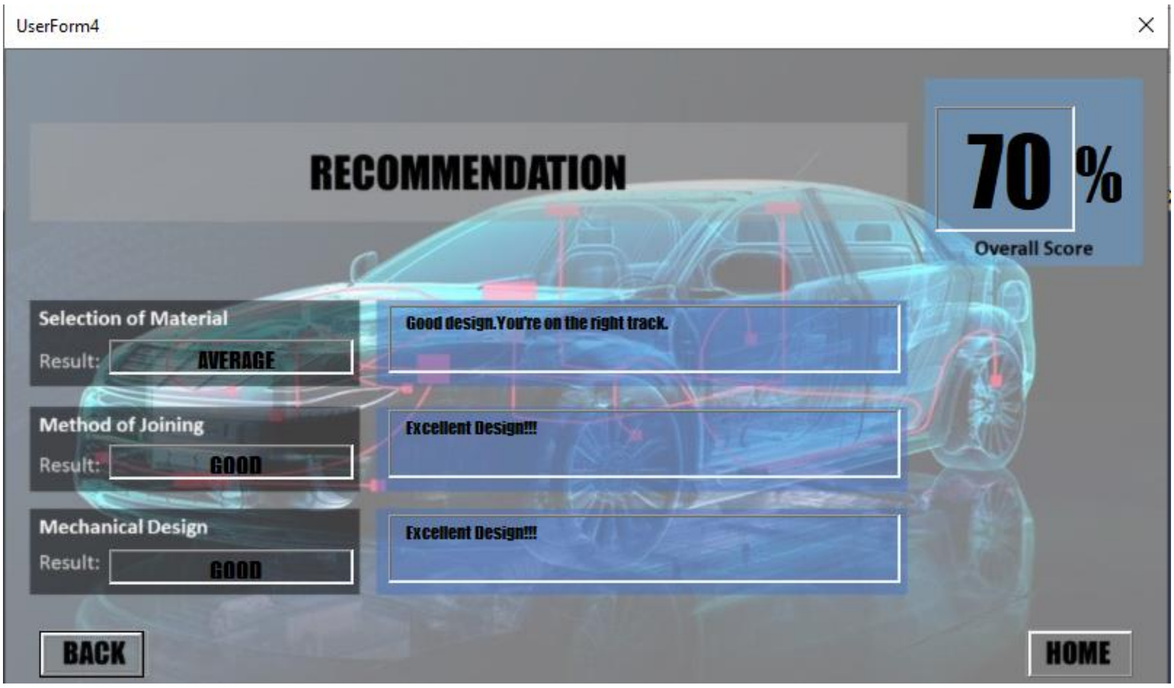

Fig. 5 - The assessment tool recommendations based on the generated scores

4.2 Discussion

The assessment tool is an effective tool in guiding the automotive industry in determining the recovery rate of interior parts during the development stage. When a designer begins developing a product, this assessment tool will act as a guide, identifying the components that have a high impact on car parts recovery. The assessment tool adopts an existing decision tool validation form to validate the tool feasibility [17]. There two university experts who have expertise in lean manufacturing, sustainable manufacturing, green manufacturing, sustainable product design, and industrial engineering. The validation aspects of the assessment tool included a user interface, graphical modelling, flexibility, result calculation, analysis model, remanufacturing term, information level, and the resulting interface.

4.2.1 Selection of Material

The durability sub criteria have the highest weightage of 0.349 under the selection of material criteria. Since the characteristics under durability, such as corrosion, wear, and fatigue resistance, play a huge role in a part's recovery rate, durability has been given more importance compared to other sub criteria. Next in line is the type of material with a weightage of 0.262, as the type of material used to make a part is crucial in deciding whether the part can be recovered. For example, parts made of plastic and rubber tend to be brittle over the years of usage compared to metal. The upgradability sub criteria come next with a weightage of 0.234. The upgradability sub criteria contribute in terms of determining the part's ease of receiving machining processes, additive processes, conditioning processes, and finally the reliability of the reconditioned part. The cleanability sub criteria has the second-lowest weightage of 0.107 because the ease of removing impurities and resistance to cleaning contributes less to parts recovery compared to other sub criteria. Lastly, the cost sub criteria have the lowest weightage of 0.049, because when it comes to parts recovery, material's cost doesn't really affect the process.

4.2.2 Method of Joining

From the results, the method of joining has the largest local weightage in the research vehicle part recovery rate. The type of joining has the greatest sub criteria weightage of 0.534 under the method of joining criteria. According to the findings of the study, expanding the type of joining criteria can efficiently minimize energy consumption and increase the recovery rate. The disasssemblability and complexity sub criteria have equal weightages of 0.236 and 0.23 respectively. The disasssemblability sub criteria includes the ability to perform disassembly without destruction (including fasteners/joints), disassembly without destruction (excluding fasteners/joints) and parts that will have higher ease of reassembly. For the complexity sub criteria, the number and types of fasteners/joints and accessibility to fasteners/joints contribute to the recovery rate of a part in a vehicle.

4.2.3 Mechanical Design

The mechanical design has a local weightage of 0.219, which is the least compared to the other two criteria. Under mechanical design, the type of material has obtained the highest weightage of 0.467. This is because the factor of whether the part is a mono-material or combined material is important when determining its recovery rate. Next is the restorability sub criteria with a weightage of 0.345, and design complexity with a weightage of 0.188. This is because restorability is more important as it focuses on accessibility to failure-prone parts. Meanwhile, design complexity focuses more on the number of parts and assembly orientation.

5. Conclusion

The study aims to develop an analysis indicator for the automotive industry, specifically for vehicle recovery of interior parts, during the product development stage. The assessment tool was developed using AHP data. The weighting of each criterion and sub-criterion was determined using the pairwise comparison analysis. Additionally, the consistency ratio of the collected data was determined to verify its authenticity.

Overall, the assessment tool could be used as an idicator to the industry practitioner in design phase to evaluate the value of product design in term of remanufacturing feasibility. It can be noticed that vehicle internal part remanufacturing are influnced mostly by method of joining,followed by material selection, and lastly is mechanical design. Future improvement for this research could be focussing on revisit and improve the AHP framework so that more criteria can be considered and evalauted.

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