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Development of A Material Efficiency Assessment Tool for Metal Stamping Product

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Abstract: Implementing material efficiency in manufacturing results directly in cost and energy savings in transformation, transportation, and disposal, along with reduced greenhouse gas emissions. The purpose of this study is to develop an assessment tool to evaluate material efficiency performance for metal stamping product from the aspect of machine factors, material factors and product factors. Analytic Hierarchy Process (AHP) approach was chosen for data collection and data analysis to obtain the importance weightage of criteria before being used to develop the assessment tool. The result show that in metal stamping process, product shape and material size give more influences, whereas by-product and machine capacity are giving least influence to material efficiency performance. The assessment tool was validated by experts to get the validation and feedback on the assessment tool developed for improvement. The development of the assessment tool perhaps could help the industry practitioners to determine their product design in term of material efficiency performance in metal stamping process.

Keywords: Material Efficiency, Analytic Hierarchy Process, Assessment Tool, Metal Stamping

1. Introduction

Global population and living standards have risen considerably in recent decades, resulting in greater product demand and, as a result, increasing manufacturing activities (Shahbazi, 2015). Material efficiency is a new thinking to address the environmental impact reduction and resource shortages, while meeting the demands of services and functions on materials. The generation of industrial waste is a critical cause for concern which has a negative impact on both sustainability and the environment (Macarthur, 2012). By applying material efficiency, it is able to reduce the generation of industrial solid waste, reduce the consumption of resources, reduce the energy demands and improving the recyclability, reusability of industrial by-product.

Implementing material efficiency in manufacturing results could directly benefits in term of cost and energy savings in production, transportation, material disposal, and reduced the greenhouse gas

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emissions. However, to obtain the material efficiency in a manufacturing industry, many criteria needed to be emphasized which are challenging especially for a specific process. Therefore, the objective is to develop an assessment tool to evaluate material efficiency performance for metal stamping product and to assist the practitioners to reduce solid waste along the metal stamping process.

2. Literature Review

2.1 Definition of material efficiency

Material efficiency means providing material services with less material production and processing (Allwood *et al.,* 2011). Other than that, material efficiency also means efficient use of energy, natural resources, and materials in order to create product and services with lesser resources and environmental impacts (Ruuska *et al.,* 2014). Furthermore, material efficiency aims to deliver the same services provided by materials today, but with less new materials production. Therefore, material efficiency can be defined by the ratio of material service delivered over new material produced (Allwood, 2013) or can be defined as the ratio between the performance output of a product, service or energy system and the input of materials required to provide such output (Cordella *et al.,* 2020). Table 1 below shows the summary of definition of material efficiency.

Table 1: Summary of definition of material efficiency

Definition of Material Efficiency	Author
• Providing material services with less material production and processing.	Allwood *et al.,* (2011)
• Efficient use of energy, natural resources, and materials to create product and services with lesser resources and environmental impacts.	Ruuska *et al.,* (2014)
• The ratio of material service delivered over new material produced.	Allwood (2013)
• The ratio between the performance output of a product, service or energy system and the input of materials required to provide such output.	Cordella *et al.,* (2020)

2.2 Material Efficiency Criteria in Metal Processing

2.2.1 Machine Factors

To produce a metal product, the raw material will go through machining process to be shaped and cut into desired design. There are many machining processes in manufacturing to produce a metal product. For example, stamping process, drilling process, milling process, turning process and laser cutting process. According to Allwood *et al*., (2011), a more efficient use of material resources in the manufacturing process including the minimization of the manufacturing waste. Metal forming's energy consumption reduction and energy efficiency enhancement have been significant challenges in recent years. The largest contributor to carbon emissions during equipment operation is energy consumption, and metal forming presses with significant energy losses have become a significant carbon dioxide emitter (Cao *et al*., 2012). According to Jonsson *et al*., (2020), many products are based of the tools in their production. The machine tooling can affect the production rate, material utilization, quality and also the rejection rate in a production. Other than that, the production rate is very crucial and important to a metal stamping industry. Therefore, it can be achieved by improving the machine capacity in the assembly line (Othman *et al*., 2019).

2.2.2 Material Factors

A raw material, also known as unprocessed material, is a basic material that is used to produce goods or finished products. To increase the material efficiency, the size of raw material should be almost exactly the same with end product. This is because when the size of raw material is extremely oversized, it will produce high amount of waste generated during the machining process. Lawson (2018) stated that, manufacturing waste can be reduced by controlling the materials being used in the manufacturing process. Reduction amount of excess raw materials in stock and quantity of hazardous materials bring down the amount of waste generated. A by-product is a secondary product derived from a production process or manufacturing process and it is not the primary product. It is important to know whether the waste can be reuse, recycle, or discarded. According to the Institute of Scrap Recycling Industries (ISRI), metal recycling can decrease the greenhouse emissions by 300 million to 500 million tons (Institute of Scrap Recycling Industries, 2016). In addition, using scrap metal generates 97% less mining waste and uses 40% less water. The residual value of products and materials can be recovered at the end of life through recycling and recovery processes. Recycling is advantageous since it reduces raw material use. Depending on whether the recycling operation's targets are components or materials, a distinction between non-destructive and destructive recycling can be formed. (Allwood *et al*., 2011).

2.2.3 Product Factors

Product parameters can affect the material efficiency performance in a manufacturing process. Poor awareness of the product parameters could lead to high amount of waste generation in the production process. For example, there are a variety of stamping techniques available to fulfil the shape, size, internal and exterior quality, and number of workpieces requirements. According to Badgujar *et al*., (2017), variety of shape, size, precision, production volume, and raw materials affect the processing methods which are used in stamping process. The researcher also stated that material used in stamping process must not only meet the technical requirement for product design, but also the functional requirements of the stamping process and subsequent processing requirements.

Table 2: Summary of material efficiency criteria

Criteria	Author(s)
• Energy consumption	Cao *et al*., (2012)
• Machine tooling	Jonsson *et al.*, (2020)
• Machine capacity	Othman *et al.*, (2019)
• By-product or waste reusability • Waste generated recyclability	Allwood *et al*. (2011)
• Shape and size of materials	Lawson (2018)
• Shape and size of product • Machining accuracy • Rate of production volume • The materials used	Badgujar *et al.*, (2017)

3. Methodology

In this research, the criteria to influence the material efficiency were extracted from the past studies, followed by data collection using AHP survey. Next, the priority weightage of criteria were analyzed and confirmed. Lastly, the results obtained from the AHP analysis were used to develop a material efficiency tool for stamping process. Figure 1 below shows the details flow of the study.

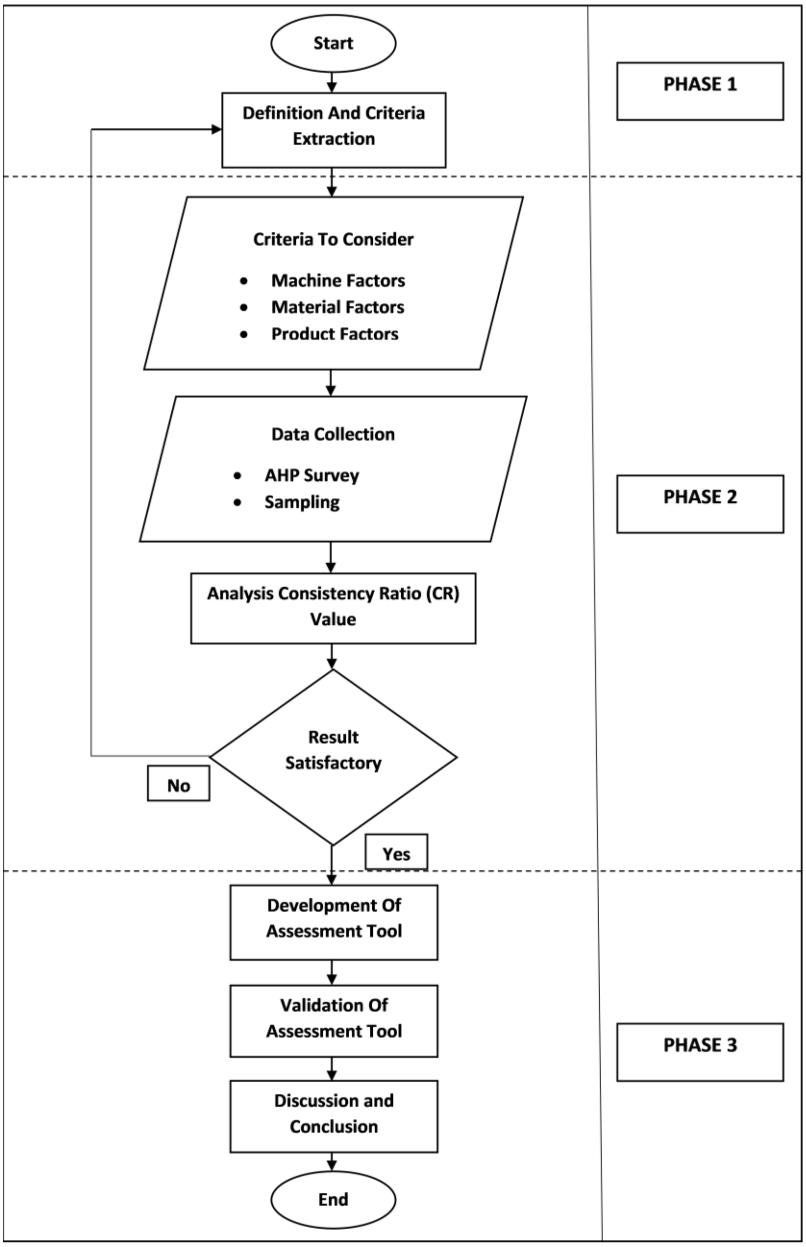

Figure 1: Research flow chart

3.1 AHP Framework

In this study, there are three main criteria that influence material efficiency. These criteria are Machine Factors, Material Factors and Product Factors. In total, there are nine sub-criteria within the three main criteria. Figure 2 shows the AHP hierarchical framework in this study.

Next, a list of pair wise comparison between each criterion was constructed before it was distributed to the expert for evaluation. Upon completion of data collection, the weights of criteria that influence material efficiency in metal stamping product was determined. The analysis of data was done using pairwise comparison matrix which holds the preference values based on the data obtained from the experts. After that, for consistency analysis, the consistency ratio was calculated. The purpose for doing this is to make sure that the original preference ratings were consistent. In practice, a consistency ratio of 0.1 or below is considered acceptable but any higher value at any level indicate that the judgements warrant reexamination.

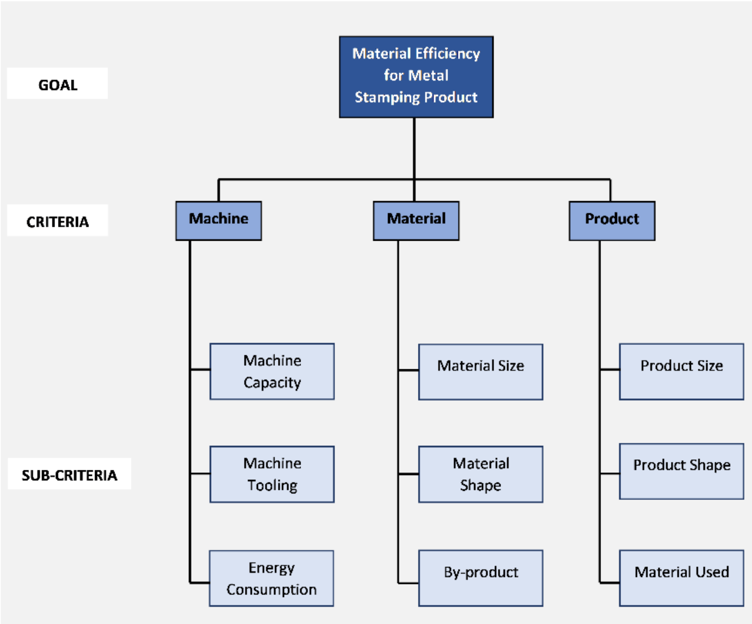

Figure 2: AHP hierarchical framework

3.2 Development of Assessment Tool

Based on the AHP analysis, a material efficiency assessment tool was developed using Microsoft Excel to evaluate material efficiency performance of a product. The assessment tool consists of nine questions that need to be answered by users with provided six points of score (0-5). Upon completion of the score in each criteria, user will be redirected to the result section with the material performance index of each factor and the overall index. The performances will be categorized into several categories based on the score obtained such as excellent (80-100%), good (70-79%), average (50-69%) and poor (<50%). In addition, the tool will recommend the improvement steps according to the obtained index. The example of tool interface is shown in Figure 3.

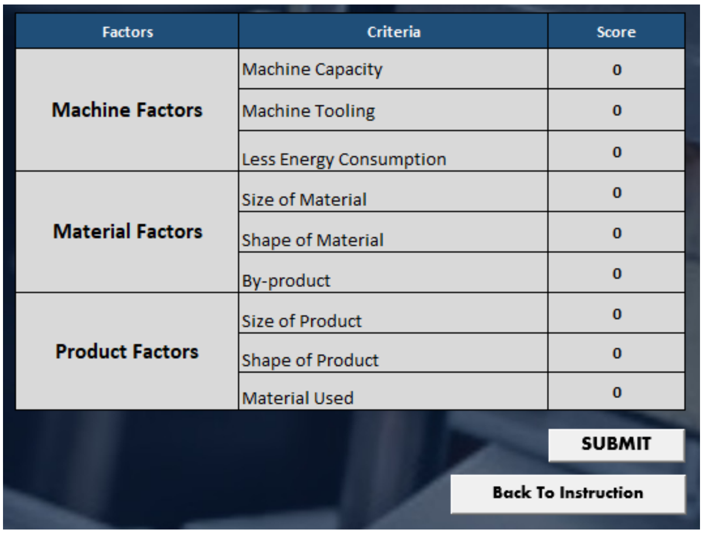

Figure 3: Developed tool interface

3.3 Validation of Tool

Tool validation is important to ensure its feasibility and validity to the user. In this study, the tool underwent validation process by both academic and industry experts. The validation criteria was adopted from past studies (Bockstaller, 2003), and it was converted to online form to ease the experts during validation process. The aspects of tool validation are user interface, quality result estimation, presentation of result, knowledge-based system, flexibility of tool, usefulness level and informative level. In addition, experts are requested to comment or give feedback on the assessment tool for future improvement. Figure 4 below show the checklist that needed to be filled online.

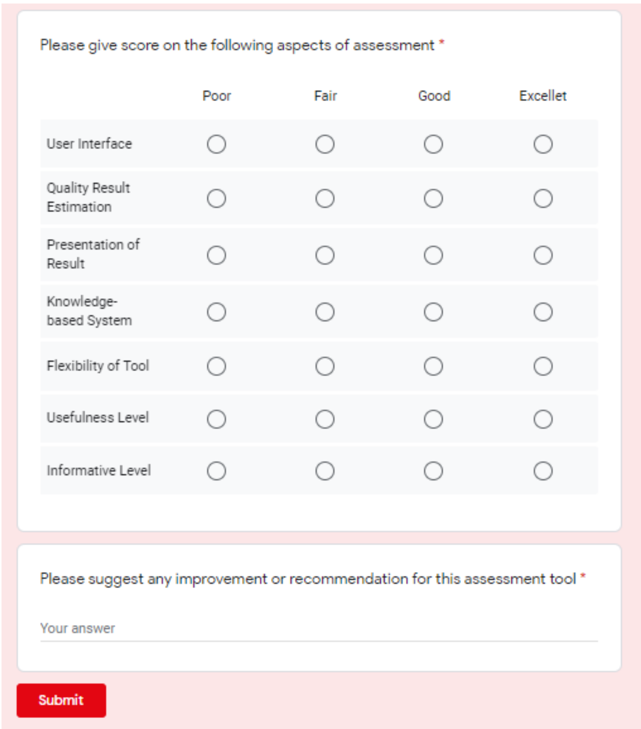

Figure 4: Checklist Validation

4. Result and Discussion

4.1 AHP result

AHP analysis was conducted to the collected data, particularly to evaluate the priority weight for each criterion that influence material efficiency in metal stamping product. In total, there are three main criteria, and nine sub-criteria were gone through the pairwise comparison under its own category. For example, main criteria consists of machine factors, the sub-criteria are machine capacity, machine tooling and energy consumption. For material factors, the sub-criteria are material size, material shape and by-product. For product factors, the sub-criteria are product size, product shape and material used.

Table 3 show the AHP analysis result that was conducted using Expert Choice software based on the eight set of data obtained from pairwise comparison survey. The result displays the priority factors that influence material efficiency for metal stamping product. Based on the result from the analysis, it shows that product factors had the highest weightage of 0.631, followed by material factors with 0.272 weightage, and lastly is machine factors with weightage 0.098.

In term of product factors, product shape was identified as the most important criteria that influence material efficiency with weight of 0.622 followed by product size which weighted 0.294 and material used that weighted 0.084. Next, in term of material factors, material size was found as the most significant criteria weighted 0.708 and after that is the material shape which weighted 0.212 followed by by-product with weight 0.080. Lastly, the criteria that influence material efficiency the most in term of machine factors is energy consumption which weighted 0.620. Second important after energy consumption is machine tooling with weight 0.292 followed by machine capacity that weighted 0.088.

Table 3: Summary of AHP result

Criteria	Weight of criteria	Sub-criteria	Weight of sub-criteria	Global weight of sub-criteria	Rank
Machine Factors	0.098	Machine Capacity	0.088	0.009	9
		Machine Tooling	0.292	0.029	7
		Energy Consumption	0.620	0.061	4
Material Factors	0.272	Material Size	0.708	0.193	2
		Material Shape	0.212	0.058	5
		By-product	0.080	0.022	8
Product Factors	0.631	Product Size	0.294	0.186	3
		Product Shape	0.622	0.392	1
		Material Used	0.084	0.053	6

4.2 Material Efficiency Assessment Tool

Based on the AHP analysis, a material efficiency assessment tool was developed to evaluate material efficiency performance for metal stamping product. Figure 5 below shows the homepage of the assessment tool that have been developed using Microsoft Excel.

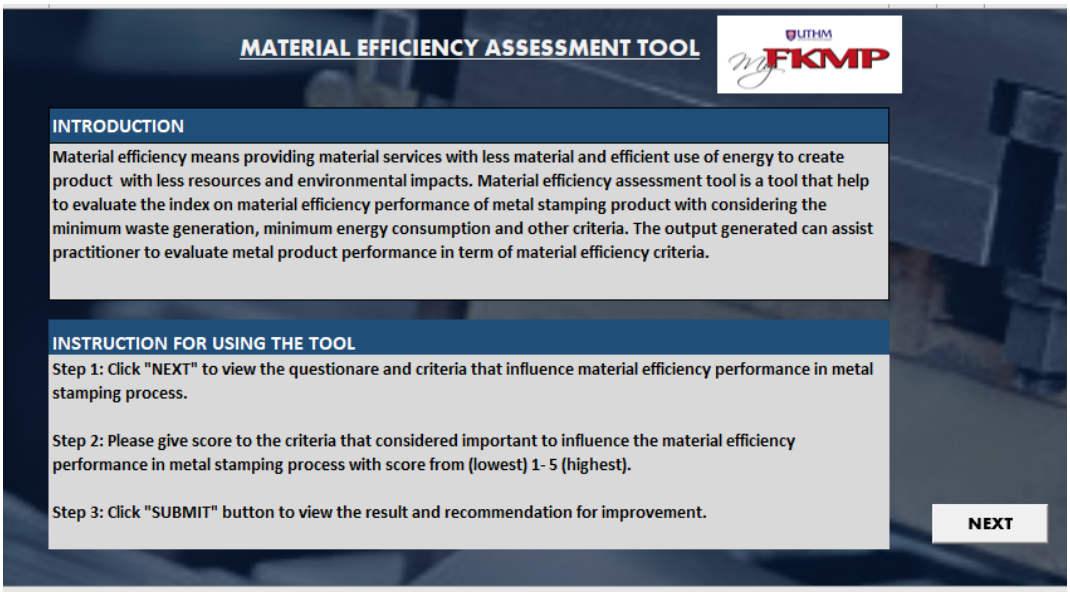

Figure 5: Home page of assessment tool

Figure 6 below shows the list of question asked in the assessment tool to evaluate the material efficiency performance. The assessment tool consists of nine questions to be answered by users with score from zero (0) which is not related until five (5) which is extremely related. Next, the result section will displays the index of each factor and the overall material efficiency index for metal stamping product. In the result section, it will shows the overall material efficiency performance and each criterion that categorized into several categories based on the score obtained. Figure 7 shows an example of result obtained using the assessment tool after with sample score inputs. In addition, the assessment tool will provide suggestion and recommendation in terms of the criteria to improve the material efficiency performance based on the result (refer example in Figure 8).

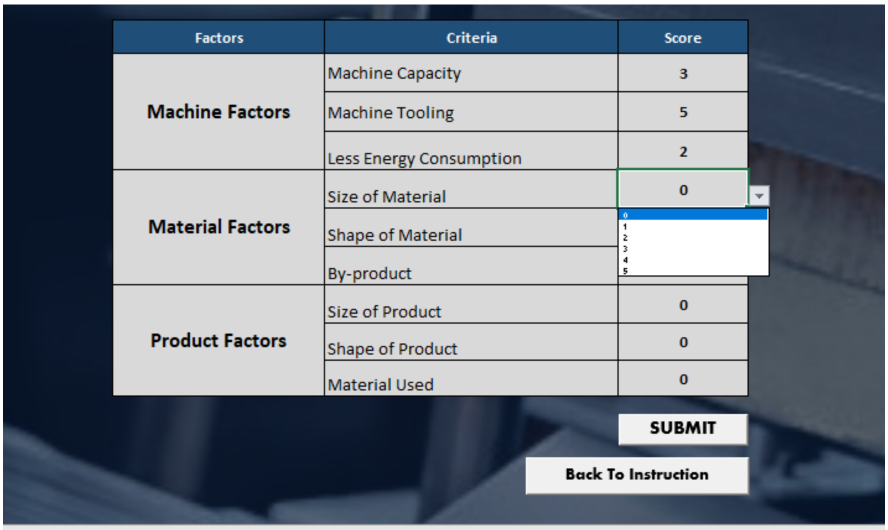

Figure 6: List of question in the assessment tool

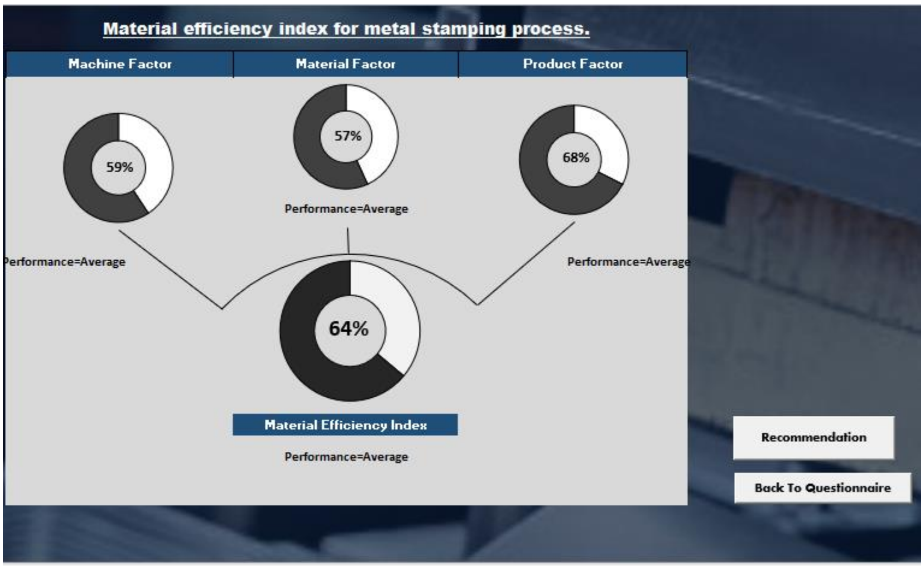

Figure 7: Example of result generated

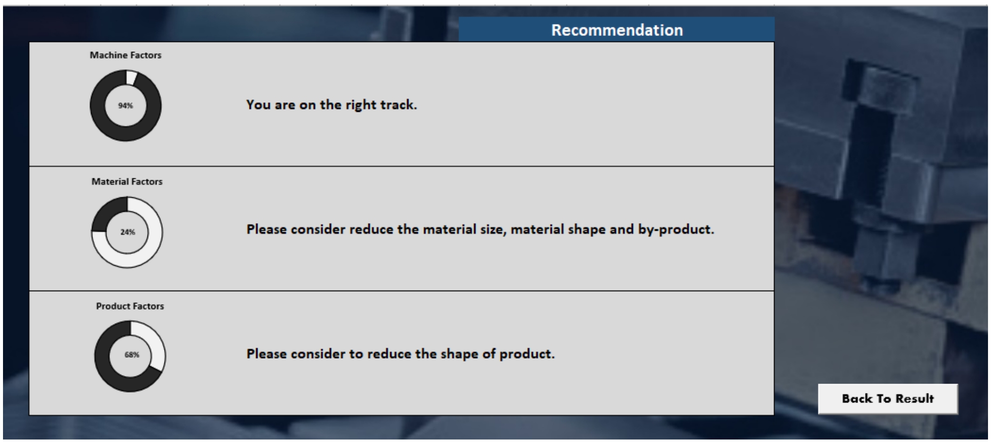

Figure 8: Example of recommendation generated

4.3 Discussion

4.3.1 Machine Factors

From the analysis, it shows that machine factor has gained the lowest weightage compared to other two main criteria with a weight of 0.098. Under machine factor, energy consumptions is given the highest weight 0.620 of the weight of sub-criteria. This is corresponds to what was reported that manufacturing activities are is contributed to the 30% of global carbon dioxide emissions and energy consumption (Allwood *et al*., 2011). Other than that, machine tooling also plays an important role to influence material efficiency with weight of 0.292, second highest after energy consumption. Many products are based on the tools in the production. Component characteristics, production rate, material utilization, post processing, quality, and rejection rates are all affected by machine tooling (Jonsson *et al*., 2020). While machine capacity recorded as the lowest weightage (0.088) because in common practice all product design must suit to the available machine.

4.3.2 Material Factors

In this study, material factor obtained second highest weightage which is 0.272. In material factor, material size is more important than by-product with a weight of sub-criteria of 0.708 and 0.080, respectively. This is because manufacturing waste can be reduced by controlling the materials being used in the manufacturing process (Lawson, 2018). One of the keys to reducing waste is improving the usage of the material. This could be done by reuse the by-products for other small parts, or batching parts together that have similar straight edges. Other than that, material shape obtains second highest of weightage for material factor which is 0.212. Semi-finished product or material is produced, as near as possible to their definite shape and contour. So, cutting operations are confined to the finishing steps.

4.3.3 Product Factors

From the result, it shows that product factor has the highest weightage obtained in the AHP analysis with weight of 0.631. In other word, product factor is the most important criteria that influence material efficiency. This may be due to product parameters can influence material efficiency performance in metal stamping products, and without consider product parameters can result in a large amount of waste in the manufacturing process. In product factor, product shape has the highest weightage of sub-criteria that influence material efficiency. Even the global weight of product shape is the highest compared to other sub-criteria of other main criteria. The variety of shape, size, precision, production volume, and raw materials affect the processing methods in stamping process (Badgujar *et al*., 2017). Other than that, product size has the second highest weightage which 0.294 followed by material used with 0.084 weightage

4.4 Assessment Tool Validation

. Table below 4 show the validation results obtained from four experts through online approach-google form. Based on the validation results below, it can be seen that most of the aspect scoring good and fair performance. The quality result estimation, knowledge-based system and informative level of the assessment tool are the aspect that needed to be improved the most because these aspects were rated fair by all the experts. From the feedback of the expert, the expert suggested that more questions could be added to get more information on material efficiency. Other than that, the expert commented that more criteria should be included to increase the accuracy of the result. Lastly, the expert suggested that more information should be added in the recommendation section so that the material efficiency performance could be increased. Author has make appropriate changes to the assessment tool, while for parts that required major changes are proposed as future recommendations.

Table 4: Result of validation

Aspect	Expert 1	Expert 2	Expert 3
User Interface	Good	Good	Good
Quality Result Estimation	Fair	Fair	Fair
Presentation of Result	Fair	Good	Fair
Knowledge-based System	Fair	Fair	Fair
Flexibility of Tool	Good	Good	Good
Usefulness Level	Good	Good	Good
Informative Level	Fair	Fair	Fair

5. Conclusion

In conclusion, the main objective of this study is to extract the criteria to influence material efficiency in metal stamping process. Next, the findings are used to developing a material efficiency assessment tool for metal stamping product. There are three main criteria that influence material efficiency namely machine factors, material factors and product factors. For each main criteria, there are three sub criteria were extracted. The tool was developed using Microsoft Excel because to evaluate the the material efficiency performance for stamping product and process. The developed material efficiency assessment tool was validated by experts to ensure the feasibility and usability of the tool. Perhaps, with the presence of the material efficiency assessment tool, it can assists the practitioner to obtain material efficiency performance and reduce waste in metal stamping production or other related industries.

Acknowledgement

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