Application of Product Sustainability Evaluation Tool (ProSET) on Car Seat Design Configurations

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Abstract— In current global sustainability trends, so far, measuring on sustainability impacts of a product lifecycle is necessary as a preparation towards more sustainable products in the future. However, most of the proposed tools in literature have not been used effectively as a tool in decision-making on the scale that is needed. This paper reports on the application of Product Sustainability Evaluation Tool (ProSET) that was developed to assess the sustainability level of a product at the design stage. In this study, ProSET was used to evaluate car seat design configurations that taking into consideration various factors required for ensuring sustainability. The ProSET uses weighted decision matrix as the platform and computes the sustainability index, known as Weighted Sustainability Score (WSS) using neural network model. Four alternatives design configurations of car seat were assessed accordingly. Based on the case study presented, it was evident that the application of ProSET at the design stage, facilitates the design engineers to make a quick decision on the future part configurations. In conclusion, the main goal of the ProSET to provide decision-making of measuring sustainability at an early stage in the product development through the application on a car seat has been successfully reported and other engineered products is suggested to be applied for continuous improvement of research.

Index Term— Product development, sustainable product design, sustainability

I. INTRODUCTION

Recently, achieving sustainability goals in discrete products is a major concern of research that is adopted in the working environment of design engineers all over the world. Since integrating sustainability considerations in designing and manufacturing new products has become a priority for researchers and industries [1], the need to develop new models to quantify all the sustainability aspects, has become a major issue [2]. Sustainable product design is a viable solution for ensuring sustainable products can be produced taking into account the various sustainability requirements at the earlier stage prior to manufacturing. To examine the sustainability of a product along its entire life cycle makes the goal of producing a sustainable product a rather complex and difficult process [3]. This is due to the fact that in order to assess a newly designed product, the sustainability aspects need to be considered and final decision has to be made where the selected designed product is verified for better sustainability performance than the other competitors. Therefore, a systematic approach is important for indicating the sustainability of a newly designed product with regard to the consideration of environmental, economic, and societal aspects [4] through its life cycle so that the selection of the final designed product for the manufacture phase is much more meaningful and valuable [5].

Comprehensive sustainability evaluation of designed products is required in situations where the level of sustainability of the design alternatives can be estimated, and the design alternative with the most sustainability is the winner. However, Lindow et al. [3] claimed that it is very difficult to estimate in terms of certain technical parameters and characteristics of the products or systems that are directly associated with specific sustainability criteria. In addition, implementing the concept of sustainability into the process of design is no easy task since there are no standard requirements for sustainable product design. According to Jawahir et al. [6] there are a number of quantitative methods to assess the environmental aspect of sustainability such as Life Cycle Assessment (LCA) method where the environmental impacts
of a product system is evaluated, but there is no universally accepted method to quantify all the aspects of product sustainability.

Variety of different approaches towards the development of sustainability assessment tools. Many of the assessment or evaluation tools are developed by previous study on sustainability product design. However, relatively few of these developed methods and tools are applied by manufacturing companies [7]. This is due to evaluation tools that targeting on level needed for application within manufacturing [4,8]. In addition, the tools may considered too theoretical and general [8,9] or too technical and complicated for used of manufacturing companies [10]. Furthermore, several results obtained by developed assessment tools in term of ‘index’, ‘percentage’ or ‘rate’ does not provide manufacturing companies with practical information for their usage [7]. This may create barrier for manufacturing companies for completing product design assessment. However, the result for this type of assessment is clear and easy for interpretation.

Several popular methodologies for assessing the sustainability are focusing on external reporting do not suitable for manufacturing practices. These methodology introduced several set of indicators for assessing sustainability such Framework for United Nation (CSD), Global Report Initiative (GRI), Lowell Centre for Sustainable Production (LWSP) and Wuppertal Sustainable Framework [11]. CSD was developed for monitoring the various sustainability indicators for assessing performance of governmental progress. GRI was introduced by The Institution of Chemical Engineers (IChemE) that set up a set of sustainability indicators for measuring the sustainability operation focus on process industry. GRI are commonly criticized in the literature because of their too general nature [9]. LWSP was developed to improve sustainability by eliminate waste, benign emission and redesign commerce. All the introduced methodologies had their strength and weaknesses. However, indicators developed is more suitable for governmental reporting and do not suitable for product design assessment.

On the other hand, some tools aiming an environmental assessment in their sustainable manufacturing analysis for claiming ‘greener product’ compared to others. During 1990s, most of the companies increasingly adopted environmental management system to promote and demonstrate sound environmental practices [12]. Manufacturing industries found themselves scrambling for improving to the public that their product were greener that their competitors. Here, LCA studies was conducted at their sustainable analysis. However, it is just an environmental consideration without concerning another important pillars of sustainability that is economy aspect and social aspect.

Several methodologies applying intelligence system such as fuzzy logic and artificial neural network. Previous researchers worked in the development of sustainability assessment based on implication of fuzzy methods for handling human-subjective opinion [12]. Fuzzy Inference System based model was intended for assessing the sustainability in manufacturing industries [9,13,14]. The final result are based on subjective of experts’ opinion. Thus reliability of the result is low, and the result are not able to point out problems and potential solutions [7]. However, these type of assessments helps on determination of set of indicators for varies case study.

A decision support system (DSS) is developed to be comprehensive, yet simple enough for being applied by any user even without a technical background [15]. Sliogeriene et al. [16] developed a DSS for sustainability evaluation of power generation technologies. Shin et al. [17] developed a DSS to improve sustainability performance of manufacturing process. Do et al. [15] programmed a DSS to select food drying technologies. Vinodh et al. [18] implemented a DSS linked fuzzy logic-based sustainability evaluation to measure the sustainability level of a manufacturing organization. Pediaditi et al. [19] presented a web-based DSS named Protected Area Sustainability Evaluation and Monitoring (PASEM) to monitor and evaluate the sustainability of Mediterranean protected areas. Rosen et al. [20] developed SCORE (Sustainable Choice of Remediation) to provide a transparent assessment of the sustainability of possible remediation alternatives relative to a reference alternative. Hassan et al. [21] developed a decision tool using analytic hierarchy process (AHP) for sustainability performance evaluation in configuring product design. In a summary, it was found that although many researchers have developed the DSS on sustainability evaluation but the DSS that developed for making decisions in the product development process is very scarce.

Configuration design is one of the three main phases in preliminary design after conceptual design and before the parametric design, and it is an essential part of the entire product development activity. This phase can be integrated with the concept of sustainability and deserves further investigation. Hassan et al. [22] summarized that inclusion of a sustainability performance evaluation among the criteria in the configuration design phase, the generation of several possible design alternatives of a product, the evaluation of the generated design alternatives with regard to sustainability criteria, and the selection of the most sustainable design among the generated design alternatives is suggested as a critical point of concern in the sustainability assessment strategy. It includes the evaluation of a group of newly designed parts with regard to the sustainability criteria, the selection of the designed part based on sustainability performance, and the combination of the selected designed part into a complete product while satisfying sustainability requirements and constraints. In this case, design engineers or decision makers will play an important role in achieving the design goal of the products based on their knowledge. However, they basically do not have sufficient knowledge to evaluate the sustainability of a product and only have limited knowledge on feasible configurations with regard to the sustainability measurement of multiple criteria [3]. This is due to fact that the processes of evaluation and selection of the feasible product configurations requires an
appropriate design tool that enable to support the above processes with an accurate data of analysis. Furthermore, the product contains several possible alternative configurations with limited information which make the evaluation and selection processes more complex. Most of assessment tools have been integrated during the conceptual design phase which is overlooks the other phases in the preliminary design stage. In order to achieve comprehensive design process, most of the tools provide an assessment at the end of their methodologies.

Recently, there exist numerous tools that may be useful in sustainability assessment but the decisions that have been made based on the selection of the appropriate tools depends on the goal and scope of the problem, the limitations of the analysis, and the circle of influence of the stakeholders [23]. Hence, the analysis of sustainability in the product development stage should be pertinent with the available data so that quick decision can be made. The integration of appropriate tools with the sustainability elements in the selected stage of the product development process is much more importance and useful. Therefore, a new methodology has been proposed in the previous work by Hassan et al. [24,25]. However, further improvement has been made to the previous work since manual calculation of sustainability score consumes more time and requires knowledgeable person in charge to completely make a decision. Due to those limitations, a DSS named Product Sustainability Evaluation Tool (ProSET) was developed [24]. The system calculates a Weighted Sustainability Score (WSS) of alternative part configurations by quantifying 26 sustainability metrics throughout the total product’s life-cycle using neural network model and weighted decision matrix as the platform. In this paper, the developed ProSET is applied to a real world situation through a case study on car seat design configurations.

The paper is presented as follows. Product Sustainability Evaluation Tool (ProSET) can be found in Section 2 where the methodology is highlighted in this section, and the case study application of ProSET on the car seat design configurations is described in Section 3. Discussion of this study is in Section 4, and followed by conclusion in Section 5.

II. PRODUCT SUSTAINABILITY EVALUATION TOOL (PROSET)

Based on previous work by Hassan et al. [24,25], a methodology to evaluate sustainability in configuration design using weighted decision matrix and artificial neural network has been successfully presented. The methodology involved the following steps:

Step 1: Identify a product to be configured
Step 2: Decompose product: Standard/special-purpose part
Step 3: Generate alternate part configurations
Step 4: Sustainability analysis
Step 5: Arrange the selected part configuration into a complete product

A. Implementation of ProSET

The most important stages in this study are the evaluation and selection processes of several alternative part configurations in the sustainability analysis. Thus, ProSET is developed accordingly and plays an important role in both processes in order to come out with the best solution. The system calculates a Weighted Sustainability Score (WSS) of alternative part configurations by quantifying 26 sustainability metrics throughout the total product’s life-cycle using neural network model and weighted decision matrix as the platform. Fig. 1 shows the application of ProSET in the configuration design activities from product decomposition, generating alternative part configurations, and evaluating the generated alternative parts to select the most sustainable part configuration based on WSS.

B. ProSET methodology

Basically, the methodology of ProSET involves two sections: Section A for determining the weight factors for sustainability performance based on analytic hierarchy process (AHP), and Section B for evaluating alternative part configurations using weighted decision matrix and neural network approach. The detail steps in both sections are explained as follow:
Section A: ProSET Front Page

The entry of the ProSET displays the Main Menu page and provides the user with five key options; Introduction, Methodology, Sustainability consideration, Help and Evaluation, as illustrated in Fig. 2. Basically, an introduction plays an important role in introducing a product or system for a first-time user. In this page, the Introduction menu links to the Introduction page of ProSET. This page provides a lot of information about the developed system including product descriptions, product features and capabilities, approaches used in the system, and applications. The Methodology menu links with the Methodology page for ProSET, which can assist the user to understand in more detail a step-by-step approach to conduct the ProSET. The link that concerns about sustainability consideration has been placed under the Sustainability Consideration menu to provide information directly to the user for better understanding the sustainability factors that have been considered in the ProSET. Help menu is to provide guidelines to a user when using the ProSET. It presents a detailed explanation of how to run the system and understand how the ProSET works, which aims to help any level of user. This page provides a step-by-step process from the analysis of sustainability performance, and the sustainability performance evaluation on the alternate part configurations to the selection of the most sustainable part configuration based on the generated WSS on each of them. Start Evaluation menu will link to the page of sustainability evaluation once the user has ready to begin the activity.

Section B: Analysis of sustainability performance

In the next page (Fig. 3), user needs to fill in the weights for the TBL aspect based on their opinions. Once the weights for the TBL aspect are confirmed, the weight factors for the sustainability criteria are automatically generated. Afterwards, the weight factors will be visualized by plotting charts that represent the environmental, economic and societal performances. The required steps in this section as follows:

Step 1: Set the weights for the three major aspects of sustainability (environmental, economic, and societal). The desired weights are set in order to determine the attributes of intended product design.
Step 2: Set the weight factors for sustainability metrics. The assigned metrics are grouped under the different sustainability aspects.

**Section C: Sustainability performance evaluation of alternative part configuration**

After the sustainability performance is confirmed, the next page begins with the sustainability evaluation process as shown in Fig. 4. This system uses a weighted decision matrix as the platform. The alternate part configurations need to be clarified in terms of forms/shapes, material types and production methods. After entering the magnitude of the alternate part configurations with regards to the sustainability metrics, a score is given based on comparison of the magnitude for alternate part configurations. When all required data are entered, this system calculates the WSS by quantifying 26 sustainability metrics throughout the total product’s life-cycle using neural network model. To generate the WSS, the user needs to click the Calculate button on the right side of the page. Furthermore, Plot graph button shows a visual representation of the evaluation so that better understanding and modification of the evaluated alternate part configurations can be achieved for further improvement. The required steps in this section as follows:

**Evaluation step:** 1) Identify a product to be evaluated; 2) Decompose the product into several parts and identify a part to be evaluated; 3) Generate several alternative designs for the function of the part with different form/shape, material, or manufacturing method; 4) Collect all required information of the generated alternative part configurations for each sustainability metric; 5) Evaluate the alternative part configurations by scoring the degree to which each alternative configuration meets the sustainability metric; and finally 6) Calculate the WSS for each alternative part configuration to indicate the level of sustainability of each other.

**Selection step:** 1) Selection of the alternative part configuration is based on the generated WSS; 2) The WSS uses a scale from 0 (the least sustainable) to 1 (the most sustainable) for easily decision-making; and 3) Plot graph to illustrate the visual representation of sustainability performance of the evaluated part configurations.
III. CASE STUDY

The application of ProSET in a car seat design for ensuring sustainability has been illustrated in this section. A case study was conducted on the car seat that belongs to one of the car manufacturers in Malaysia. A car seat is one of the important elements among the automotive components that plays a major role in ensuring passengers comfortability and safety during a long driving trip. The organization was planning to propose a new design car seat and was investigating the future car seat configurations by benchmarking the existing car seat in the market. The authors were responsible to take the opportunity for the implementation of sustainability concepts on the proposed car seat design.

For conducting the sustainability evaluation, it is suggested to evaluate an individual component of a whole product where the whole product is decomposed into components. This is necessary since the whole product consists of a variety of components where it is complicated when the evaluation is conducted on the whole product [26]. Due to this important process, this study uses morphological analysis method. The process of morphological analysis starts with the decomposition of a product into several design elements. Each design element will be redesigned using new concepts and the generation of several possible design alternatives. Morphological analysis performs the arrangement of the design elements in logical order by structuring the design alternative of each design element into a complete product. Accordingly, a new product assembly will be produced systematically. In this case study, the car seat consists of three basic elements: a Headrest support, Backseat part and Base part, as shown in Fig. 5. Due to space limitations, only the cushion foam configuration of the Backseat part is presented in this paper.

Table I illustrates the generated alternative configurations for cushion foam of Backseat part that were organized in a morphological table. From the morphological analysis, four generated alternative forms and two types of material along with the manufacturing method resulting in a total number of eight alternative part configurations as shown in Table II. Based on the generated different configurations, the materials and production methods also will be included in the process of sustainability evaluation.
**TABLE I**
Generated alternative configurations for cushion foam of Backseat part.

<table>
<thead>
<tr>
<th>Function as cushion foam for Backseat part</th>
<th>Forms/shapes</th>
<th>Types of material and manufacturing method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>Form 1</td>
<td>Polyfoam (polyurethane) and injection moulding</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>Form 2</td>
<td>Nimbus (polyurethane-rubber blend) and injection moulding</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>Form 3</td>
<td></td>
</tr>
<tr>
<td>Alternative 4</td>
<td>Form 4</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II**
Generated alternative configurations for cushion foam of Backseat part.

<table>
<thead>
<tr>
<th>No</th>
<th>Configuration process</th>
<th>Alternative part configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Form 1 + Polyfoam (polyurethane) + injection moulding</td>
<td>BackseatFoam11</td>
</tr>
<tr>
<td>2</td>
<td>Form 1 + Nimbus (polyurethane-rubber blend) + injection moulding</td>
<td>BackseatFoam12</td>
</tr>
<tr>
<td>3</td>
<td>Form 2 + Polyfoam (polyurethane) + injection moulding</td>
<td>BackseatFoam21</td>
</tr>
<tr>
<td>4</td>
<td>Form 2 + Nimbus (polyurethane-rubber blend) + injection moulding</td>
<td>BackseatFoam22</td>
</tr>
<tr>
<td>5</td>
<td>Form 3 + Polyfoam (polyurethane) + injection moulding</td>
<td>BackseatFoam31</td>
</tr>
<tr>
<td>6</td>
<td>Form 3 + Nimbus (polyurethane-rubber blend) + injection moulding</td>
<td>BackseatFoam32</td>
</tr>
<tr>
<td>7</td>
<td>Form 4 + Polyfoam (polyurethane) + injection moulding</td>
<td>BackseatFoam41</td>
</tr>
<tr>
<td>8</td>
<td>Form 4 + Nimbus (polyurethane-rubber blend) + injection moulding</td>
<td>BackseatFoam42</td>
</tr>
</tbody>
</table>
Once the required information of the generated alternative part configurations for cushion foam of Backseat part were available, ProSET was implemented in the next step. The sustainability performance of ProSET was set to be balanced among the environmental, economic, and societal aspect and all weight factors of each sustainability metric were automatically calculated, as depicted in Fig. 6. Basically, for a sustainable product, the weights should be balanced by entering “1” into the three blank boxes which result in “0.333” for each relative weights of sustainability aspects. However, the weights can be adjusted according to the desire of the designers. These values have an influence on the sustainability performance in the next process.

When the sustainability performance was set, the generated alternative part configurations for cushion foam of the Backseat part were filled in the Evaluation page of ProSET in terms of the form, material and production method as illustrated in Fig. 7. Afterward, process of evaluating sustainability based on weighted decision matrix was performed. Fig. 8 shows the completed sustainability evaluation on generated alternative part configurations for cushion foam of Backseat part. In this paper, only partial sustainability evaluation by ProSET is presented. From the evaluation of four alternatives, ProSET has selected BackseatFoam21 as the most sustainable design due to higher WSS (0.3128) than the other configurations where BackseatFoam11 (WSS=0.0761); BackseatFoam12 (WSS=0.0676); and BackseatFoam22 (WSS=0.2399).
IV. DISCUSSION

From the above case study presented, it was evident that the application of ProSET at the design stage, facilitates the design engineers to make a quick decision on the future part configurations. ProSET also requires only limited information that normally difficult to evaluate/assess sustainability using commercial software when the product has not been manufactured yet. During the design stage, modifying the product design configuration until it meets the sustainability requirement is the major advantages. Different forms will affect the use of material, whereby a good configuration needs to use less material. The quantity of used material is the key element for achieving a good level of sustainability, but the function and appearance of the product should not be ignored for social attractiveness.

V. CONCLUSIONS

As the demand for the importance of sustainability issues in the field of product development are increasing in industries and society, sustainability evaluation is becoming very important and necessary for design engineers in making final decisions of the future product design. For this reason, a Decision Support System (DSS) named Product Sustainability Evaluation Tool (ProSET) was developed based on the previous work by Hassan et al. [25], for evaluating sustainability performance of alternative part configurations. The purpose of the previous work was to evaluate sustainability level of designed part configurations taking into consideration various factors needed for enabling sustainability. In this paper, the application of ProSET on car seat design configurations has been presented. The ProSET methodology uses weighted decision matrix as the platform and calculates the sustainability score of each alternate part configuration called Weighted Sustainability Score (WSS) by quantifying 26 sustainability metrics throughout the total product’s life-cycle using neural network model. Based on the generated WSS, improvement can be made on the designed part configuration to be more sustainable in the future. The ProSET provides a new and comprehensive basis for evaluating sustainability performance in the product development process. It is expected that in the future work, the ProSET methodology could be extended to be applied in any stage of product development process. Also, refinement could be done in the ProSET system for enhancing its effectiveness.

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AUTHOR CONTRIBUTION

Mohd Fahrul Hassan and Muhamad Zameri Mat Saman developed the methodology and designed the 3D CAD Model. Mohd Fahrul Hassan and Salwa Mahmood performed the experimental research, analysis and wrote the paper. Syarfa Zahirah Sapuan advised about the expert system and GUI development. Safian Sharif checked and revised the whole structure of the paper. All authors commented on the manuscript and approved the final manuscript.
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