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A HYBRID OF KANSEI ENGINEERING (KE) AND ANALYTICAL HIERARCHY PROCESS (AHP) TO DEVELOP CONCEPTUAL DESIGNS OF PORTABLE OIL SPILL SKIMMER

RPRAKASH RAMANATHAN, LOKMAN ABDULLAH*, MUHAMMAD HAFIDZ FAZLI MD FAUADI, MUHAMMAD SYAFIQ SYED MOHAMED AND KHAIRUN NAJMI KAMALUDIN

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia

Corresponding author: lokman@utem.edu.my

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ABSTRACT: Currently, there are huge demands on developing a design that fulfils the characteristics of performance, cost, safety, and aesthetics. However, the conceptual design stages in industrial products lack the involvement of user requirements as it is typically focused on the product's performance. Consequently, specific criteria such as the product's ease of use, safety, and robustness cannot be compared and measured when designing industrial products. Owing to this reason, this research proposes a new technique that integrates Kansei Engineering with Analytical Hierarchy Process (AHP) to address the issue. The research objective is to investigate an oil spill skimmer's user and technical requirements by incorporating the Kansei Engineering method. The approach to carry out this research is to incorporate the Kansei and the basic AHP methods. Kansei Engineering will suggest the required design elements that must be included to design and fabricate a portable oil spill skimmer. At the same time, the AHP method is used to select the best design based on the developed conceptual design. The effectiveness of the proposed method was verified by comparing it with other established methods, such as TOPSIS (Technique of Order Preference by Similarity to Ideal Solution). Moreover, sensitivity analysis was used to investigate the robustness of the AHP result. There are 5 conceptual designs in total, assessed in this research. The result showed that out of the 5 conceptual designs, design number 3 has the highest ranking (priority ranking = 0.2603). Thus, the most suitable conceptual design for the portable oil spill skimmer to be fabricated is design 3. The finding also shows that the result from AHP was valid and robust.

ABSTRAK: Pada masa kini, terdapat permintaan besar bagi membangunkan reka bentuk yang memenuhi ciri-ciri prestasi, kos, keselamatan dan estetika. Walau bagaimanapun, industri kurang melibatkan keperluan pengguna pada peringkat reka bentuk konsep produk industri, kerana ia biasanya tertumpu pada prestasi produk. Ini menyebabkan kriteria khusus seperti kemudahan menggunakan produk, keselamatan dan keteguhan produk tidak dapat dibandingkan dan diukur semasa mereka bentuk produk industri. Disebabkan faktor berkenaan, kajian ini mencadangkan teknik baharu yang mengintegrasikan Kejuruteraan Kansei bersama Proses Hierarki Analitik (AHP) bagi menangani isu tersebut. Objektif kajian adalah bagi menyiasat keperluan pengguna dan keperluan teknikal menyaring tumpahan minyak dengan menggabungkan kaedah Kejuruteraan Kansei. Pendekatan kajian ini adalah dengan menggabungkan Kansei dan kaedah asas AHP. Kejuruteraan Kansei mencadangkan elemen reka bentuk yang diperlukan yang mesti disertakan bagi mereka bentuk dan menyaring tumpahan minyak mudah alih. Pada masa sama, kaedah AHP digunakan bagi memilih reka bentuk terbaik berdasarkan reka bentuk konsep yang dibangunkan. Keberkesanan kaedah yang dicadangkan telah disahkan dengan membandingkannya dengan kaedah lain yang telah terbukti, seperti TOPSIS (Teknik Aturan Kehendak Berdasarkan Persamaan dengan Solusi Ideal). Selain itu, analisis sensitiviti digunakan bagi mengkaji keteguhan keputusan AHP. Terdapat 5 reka bentuk konseptual yang dinilai dalam kajian ini. Dapatan kajian menunjukkan bahawa reka bentuk nombor 3 mempunyai keputusan tertinggi (keutamaan kedudukan = 0.2603) daripada 5 reka bentuk konseptual ini. Oleh itu, reka bentuk konsep yang paling sesuai bagi saringan tumpahan minyak mudah alih yang akan dibina adalah reka bentuk 3. Dapatan kajian juga menunjukkan bahawa hasil daripada AHP adalah sah dan kukuh.

KEYWORDS: *Kansei Engineering; analytical hierarchy process (AHP); product development process; oil spill skimmer*

1. INTRODUCTION

Industrial equipment sales often face tough challenges in maintaining their sales volume and customer loyalty since many manufacturers compete with one another for customers. Therefore, manufacturers often spend their time and resources studying customers' purchasing behaviour and preferences, such as function, appearance, and usability. Of all these requirements, visual appeal plays a vital role in influencing customer purchasing decisions. Customer impressions are influenced by various elements, including the brand of the product, its purpose, look, and usefulness. However, the product look is the one that creates the most visual engagement to the client and product compared to other aspects [1]. The application of AHP has been utilised in the area of the machine tools industry and the textile industry

Consumer products, such as household appliances, are typically regarded as attractive and inexpensive, but industrial items, such as heavy machinery, should be of high quality but not necessarily attractive. Any industrial product's development usually focuses on technical standards, including objectives and well-defined metrics such as speed, power, and many others that could be compared and tested. While meeting technical criteria is essential, it is not always enough for a product to succeed [2]. Several elements are difficult to quantify yet influence machine design and selection. Users' impressions of different machine tools have received minimal attention in terms of strategies for selecting, analysing, and comparing machine tools. Thus, there is a need to incorporate both customer and technical requirements in the industrial product development process.

A study done by Marini investigated the use of AHP and Analytical Network Process (ANP) together with Quality Function Deployment (QFD) in concept design and material selection for making better decisions to improve product success [3]. However, the involvement of customer requirements is still lacking when developing a design concept [4]. Therefore, research was done to propose a method based on TOPSIS and fuzzy AHP, which could be used in concept design evaluation [5]. Renzi researched using AHP and ANP together with other multi-criteria decision methods for design evaluation in the automotive industry, trying to transfer knowledge on decision-making methods to the industrial context [6]. Moreover, Rosli investigated a systematic product design model that assists decision-makers or design engineers in improving current design through the idea generation method of Theory of Inventive Problem Solving (TRIZ) and utilising the analytical hierarchy process (AHP) to perform the selection of best-generated idea [7].

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A study was conducted to show that the proposed (House of Quality) HOQ and Fuzzy-AHP provided a novel alternative to existing methods to perform design concept evaluations in the early stages of product development, with the capability to accommodate uncertainties and vagueness using the optimum number of pairwise comparisons [8]. Furthermore, a research was conducted by Turan, proposing a rough number to be used by VIKOR and AHP methods to develop a systematic framework for the concept evaluation process [9]. Nevertheless, the proposed best design concept might be biased toward designers' expectations rather than the customers' expectations.

It is well known that previous researchers have investigated and reported on several modified AHP. To the best of the author's knowledge, however, the implementation of Kansei Engineering as a tool for optimisation paired with AHP in the development of industrial products such as oil spill skimmer is still inadequate and uncommon. Furthermore, although several researchers have researched the fabrication of oil spill skimmers, there is no proof that KE and AHP were utilised in the design and fabrication process [10]–[15]. Therefore, this study aims to employ Kansei Engineering to investigate the user and technical requirements to generate multiple conceptual designs for an oil spill skimmer, which will be analysed using Analytical Hierarchy Process (AHP) to choose the ideal oil spill skimmer conceptual design.

2. METHODOLOGY

2.1 Research Framework

The development and selection of the best conceptual design for a portable oil spill skimmer are split into two sections in this study. First, Kansei Engineering is employed to build an overall design aspect of the oil spill skimmer in phase one. This methodology has five layers: Kansei word selection, product sample collection, questionnaire distribution, reliability testing, data interpretation, and design idea creation. The AHP is then utilised in part 2 to determine the relative weight of each factor at each level to arrive at the overall product assessment system. This is done to determine which design idea produced by Kansei Engineering is the best. Finally, to evaluate the robustness of the AHP, the results are compared and analysed using TOPSIS and sensitivity analysis.

2.2 Kansei Engineering and Reliability Testing

Kansei Engineering (KE) uses seven primary stages to categorise the customer's needs and technical requirements. Kansei Engineering type 1 is employed in this study. This method transforms a single product concept into a more complex concept, which is then developed to numerous levels and interpreted in terms of the physical characteristics of the product design. Category categorisation is a breakdown strategy from a targeted concept of a new product to the corresponding subjective Kansei to the objective design requirements. Mazda's design of the Miata, the world's most successful sports automobile, is a well-known example of this category application [16]. A previous research can be referred to identify the step-by-step procedure of Kansei Engineering methodology [17].

Reliability testing aims to evaluate the reliability or internal consistency by utilising Cronbach's alpha to measure the strength of the consistency. Cronbach's alpha analysis determines whether the multiple-question Likert scale survey is reliable. Higher values of Cronbach's Alpha signify more reliability of the survey or questionnaire; it has a range of 0 to 1. The minimal number of questions and weak interconnection between objects result in a low alpha score in the reliability test. The alpha value achieved, for example, will be pretty low due to a lack of correlation between the variables and items, resulting in the questionnaire being rejected and requiring modification. On the other hand, the items may be redundant if the alpha is too high since the questions are the same but in a different format. The formula of Cronbach's Alpha and the rule of thumb is shown below in Eq. (1) [18].

$$a = \frac{N.\bar{c}}{\bar{v}+(N-1).\bar{c}} \quad (1)$$

where,

N= the number of items

$\bar{c}$ = average covariance between items-pairs

$\bar{v}$ = average variance

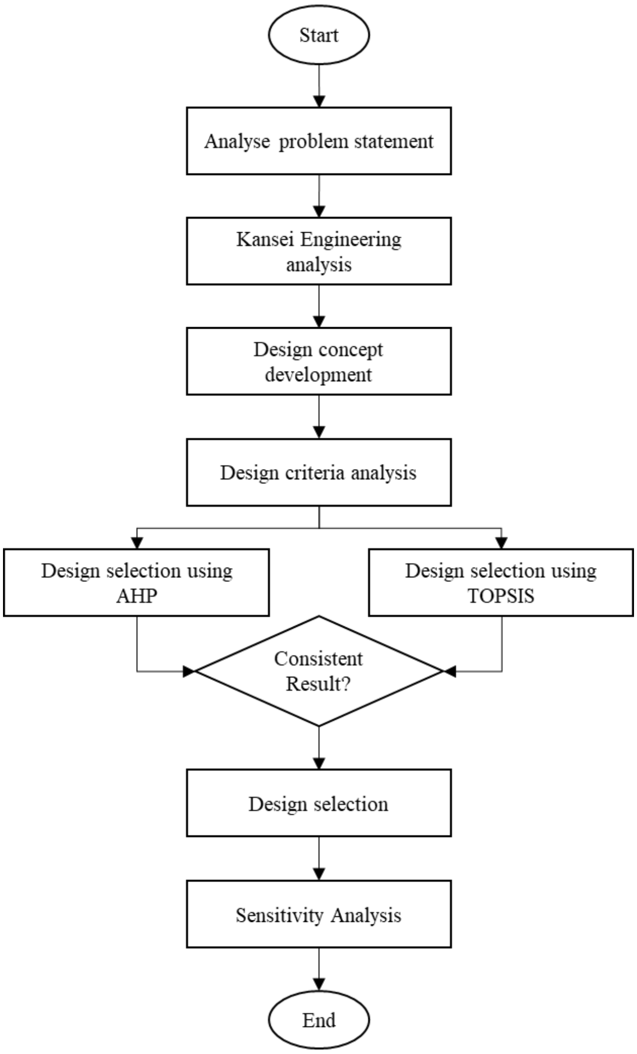

Fig. 1: Research framework.

2.3 Analytical Hierarchy Process (AHP)

In the next step, the research will focus on establishing the Analytical Hierarchy Process (AHP) in determining the most proper rank of the design options. Elements related to the goals, criteria, and relevant alternatives are synthesised from the Kansei Engineering method. Table 1 shows the linguistic variables and the pairwise matrix value.

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Table 1: Linguistic variables and values for pairwise matrix for basic AHP [19].

Linguistic variables	**AHP Scale**
Important	9
Very strongly important	7
Strongly important	5
Weakly important	3
Equally important	1
Intermediate	2,4,6,8

AHP technique is a process that consists of the following steps with the help of a few equations as narrated by [20]:

Step 1: First, decide what needs to be achieved, then narrow down the options. Selecting criteria, a quantifiable aspect that aids in illustrating and specifying options, necessitates practical judgment.

Step 2: Paired comparisons are needed in two segments as follows:

1. Between criteria
2. Between alternatives using each criterion.

The matrices of pairwise comparisons are on a fundamental scale from 1 to 9. The application of AHP is based on expert judgment. One of the major advantages of AHP is that the analysis does not always require statistically significant sample size as reported by [21]. Furthermore, it is obvious that conducting such huge numbers of real expert examinations requires too much effort, time, and financial resources. Thus, an evaluation from a single qualified expert is adequate [22]. As the input data in AHP analysis are based on an expert's perceived judgement, a single input from an expert is sufficient as a representative in the pairwise evaluation of AHP [23]. However, AHP may also be ineffective in research with a high sample size since "cold-called" experts are prone to give arbitrary responses, severely altering the consistency of the assessments [24]. Data is gathered through questionnaires and interviews. The comparison matrix determines which criteria and sub-criteria are more critical than others. Therefore, expert input is critical. An oil skimmer expert was selected as the respondent in this research. The respondent was chosen based on years of expertise and knowledge in the oil skimmer sector. The comparison matrix (n x n), where n is the number of criteria.

Step 3: Let Xij denote the order of preference of the ith factor compared to the jth factor. Then Eq. (2):

$$\text{Xij} = \frac{1}{X_{ij}} \tag{2}$$

Step 4: A normalised pairwise comparison matrix is obtained by adopting the following procedure:

1. Sum of every column.
2. Divide all the numbers in the matrix respectively by the obtained column sum.
3. Average the rows to obtain relative weights.

Step 5: Calculate Eigenvector, maximum Eigenvalue, and Consistency Index (CI). Refer to Eq. (3).

$$CI = \frac{\lambda_{\max - n}}{n-1} \tag{3}$$

Here, λmax is the Eigenvalue corresponding to the matrix of pairwise comparisons, and n is the number of criteria.

Consistency ratio (CR) is defined by referring to Eq. (4):

$$CR = \frac{CI}{RCI} \tag{4}$$

Where (RCI) is a random consistency index.

Generally, a CR value of less than 0.1 is acceptable; otherwise, the pairwise comparisons should be altered to eliminate incoherence. The TOPSIS and sensitivity analysis methods are used to validate the AHP results. First, the TOPSIS analysis is used to confirm the AHP ranking result. The AHP and TOPSIS parameters are the same, but the mathematical computations are different, allowing the TOPSIS ranking result to confirm the AHP ranking result. In terms of sensitivity analysis, the AHP result is examined to determine the result's robustness in relation to the weighted criteria. When modifications in criterion weightage are applied, a complete sensitivity analysis is done to detect the variance in the behaviour of the ranking alternatives.

2.4 Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS technique is a process that consists of the following steps with the help of equations [25]:

Step 1: Form the decision matrix. Refer to Eq. (5).

$$DM = \begin{matrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{matrix} \tag{5}$$

Step 2: The normalised decision matrix is done. Refer to Eq. (6)

$$NDM = r_{ij} = \frac{x_{ij}}{\sqrt(\Sigma_{i=1}^{m} x_{ij}^2)} \tag{6}$$

Step 3: The weighted normalised decision matrix refers to Eq. (7) (skipped as the weightage is obtained from AHP).

$$V = v_{ij} = w_j . r_{ij} \tag{7}$$

Step 4: The positive and negative ideal solutions for each criterion refer to Eq. (8) and Eq. (9), respectively

$$PIS = V_j^+ = MAX_i(V_{ij}) \tag{8}$$

$$NIS = V_j^- = MIN_i(V_{ij}) \tag{9}$$

Step 5: The geometry distance of each alternative from positive and negative ideal solution is calculated refer to Eq. (10) and Eq. (11), respectively.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \tag{10}$$

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \tag{11}$$

2.5 Sensitivity Analysis

Validation is a crucial method to be incorporated into any type of research to identify the credibility and validation of results. The application can be widely seen in the domain of renewable energy [26], controller design [27], CNC machining process [28], decision making [29] and others. Moreover, in engineering domains such as structural analysis and optimisation challenges, sensitivity analysis is used to analyse uncertainty. The goal of MCDM sensitivity analysis is to evaluate how changing the weights assigned to the criteria affects the ranking of the options. It also assures the robustness of the offered technique [29]. In addition, a sensitivity analysis is performed to confirm the final ranking recommendation. The sensitivity analysis results in several scenarios show that the best option could change depending on how the assessment criteria are weighted.

3. RESULTS AND DISCUSSION

3.1 Kansei Engineering

To conclude, the design aspects of the oil spill skimmer were identified using (PLS) analysis, which could be referred from [17]. The technique and analysis provide the coefficient plot values, illustrating whether or not that design aspect is essential for designing a portable oil spill skimmer. Certain design aspects have many high positive scores based on the table below. Therefore, certain design factors will be prioritised when developing the oil spill skimmer. On the other hand, several design aspects negatively associate with the Kansei terms. As a result, several design features will be neglected when developing the oil spill skimmer. These design components must be introduced into the design process and those that should be ignored while designing the portable oil spill skimmer (Table 2).

Table 2: List of positive and negative design elements

Positive design elements	Negative design elements
• Compact body appearance	• More than a pair of floating support
• Medium body size	• External oil tank location
• 41-100 kg weight	• Non-oleophilic skimmer material
• Medium-size oil tank	• Bulky body appearance
• A pair of floating support aid	• Round body shape
• Outrigger floating support shape	• Vacuum type skimmer
• Square/rectangular body shape	• Small body size
• Oleophilic skimmer material	• Cylindrical body shape
• Water extraction below 10%	
• Brush type skimmer	
• Internal oil tank storage	
• Less than 5 m/s speed	

3.1.1 Reliability Testing

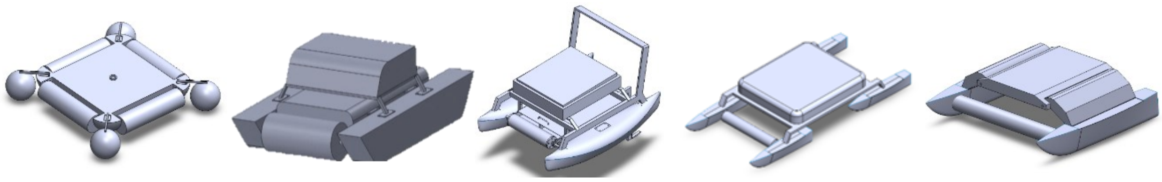
The acquired data is subjected to reliability testing using a questionnaire to assess whether the data is trustworthy. As a result, Cronbach's Alpha is used to assess the data's dependability. Cronbach's alpha is an internal consistency measurement that depicts the interaction of a group of items in collective data reliability, as represented by the coefficient figures. In contrast, homogeneity refers to one-dimensionality and falls under the Reliability Internal Consistency component, which measures the phenomenon that provides stable and consistent data collection. The questionnaire was conducted for 30 respondents in this research, calculated in Eq. 1. The Cronbach's Alpha calculated using the SPSS programme (Statistical Package for Social Science) is 0.912, indicating that the questionnaire set has a excellent Reliability Coefficient, as shown in Table 3 below. This result demonstrates that the questionnaires fit in, exhibiting the homogeneity of each question. However, originating from various parts demonstrates the dimensionality in measuring every response received, resulting in a more stable and complete analysis for this study.

Table 3: The Cronbach's Alpha Value and Reliability Coefficient [30].

Cronbach's Alpha Value	Reliability Coefficient
$\alpha > 0.9$	Excellent
$\alpha > 0.8$	Good
$\alpha > 0.7$	Acceptable
$\alpha > 0.6$	Questionable
$\alpha \geq 0.5$	Poor

3.1.2 Conceptual Design

The design concept of a portable oil spill skimmer is based on the results obtained from the Kansei Engineering analysis. Figure 2 shows the conceptual designs of the portable oil spill skimmer. Furthermore, the strengths and weaknesses of each design are elaborated in the AHP analysis, where it is compared using pairwise comparison with several sub-criteria.



(a) (b) (c) (d) (e)

Fig. 2: Developed conceptual design of portable oil spill skimmer:
(a) Design 1, (b) Design 2, (c) Design 3, (d) Design 4, (e) Design 5.

3.1.3 Specifications of Each Design

The specification of each design is shown in Table 4.

3.2 Analytical Hierarchy Process (AHP)

The pairwise comparison matrix is created using the hierarchy model from Fig. 3. The number in the pairwise matrix is decided by an expert such as oil and gas or OSRR engineers. This is done to improve the result accuracy of the AHP. The pairwise comparison in this research has three stages: design alternatives, sub-criteria and overall analysis of the criteria, sub-criteria, and design alternatives analysis. Finally, a matrix with regards to the plan will be determined. AHP is used to implement a hierarchy paradigm for structuring product principal decisions. Figure 3 depicts a four-level hierarchy decision mechanism.

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Table 4: The specification of each conceptual design

Specification	Design 1	Design 2	Design 3	Design 4	Design 5
Weight	5 – 40 kg	41 – 100 kg	5 – 40 kg	41 – 100 kg	41 – 100 kg
Speed	Less than 1 m/s	Less than 1 m/s	Less than 5 m/s	Less than 1 m/s	Less than 1 m/s
Oil Tank Capacity	Large	Large	Medium	Large	Medium
Oil Suction Capacity	Below 51 L/h	Below 51 L/h	Below 51 L/h	Below 51 L/h	Below 51 L/h
Self-Propelling Capacity	No	Yes	Yes	Yes	Yes
Size	Big	Big	Medium	Medium	Large
Oil Tank Location	External	Internal	Internal	External	Internal
Water extracted with oil	20%	20%	10%	10%	20%
Body shape	Square/Rectangular	Square/Rectangular	Square/Rectangular	Square/Rectangular	Square/Rectangular
Body appearance	Bulky	Bulky	Bulky	Compact	Compact
Portability	Carried by 2 person	Carried by more than 2 person	Carried by 2 person	Carried by more than 2 person	Carried by 2 person
Skimmer type	Brush	Brush	Roller	Roller	Brush
Material	Oleophilic	Oleophilic	Oleophilic	Oleophilic	Oleophilic
Floating support aid shape	Round	Cylindrical	Outrigger	Outrigger	Outrigger
Number of floating support aid	4	2	2	4	4
Support aid type	Polyvinyl chloride (PVC)	Polyvinyl chloride (PVC)	Fibreglass	PVC	Fibreglass

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The criteria are labelled as follows: Performance (P), Safety (S), Maintenance (M) and Portability (P). The sub-criteria are labelled as follows: Oil Suction (OS), Manoeuvrability (MA), Strong Body Frame (SBF), Stability (SA), Enclosed Components (EC), Easy to Repair (ER), Easy to Disassemble (ED), Easy to Relocate (ETR) and Lightweight (L). The stability of the design is evaluated according to the number of floating support (closely influenced by the shape of floating support) and floating support shapes (bow-ship shapes are recommended). Furthermore, the oil suction is evaluated according to the types of skimmer material.

This research does not consider the cost as main or sub-criteria since the criteria is not a concerning factor and also was inconsiderate in the previous research as well. The research in the oil and gas field that presents this scenario [31,32]. Moreover, the product will be focusing on specific customers as it is characterised as high variety, low volume production. The basic characteristics of high variety, low volume is the manufacturing of one or few numbers of products designed and produced as per the requirement of customers within pre decided time, with a drawback of high cost of production [33]. Thus, cost is not taken as one of the influencing factor as cost criteria will not affect the pairwise evaluation.

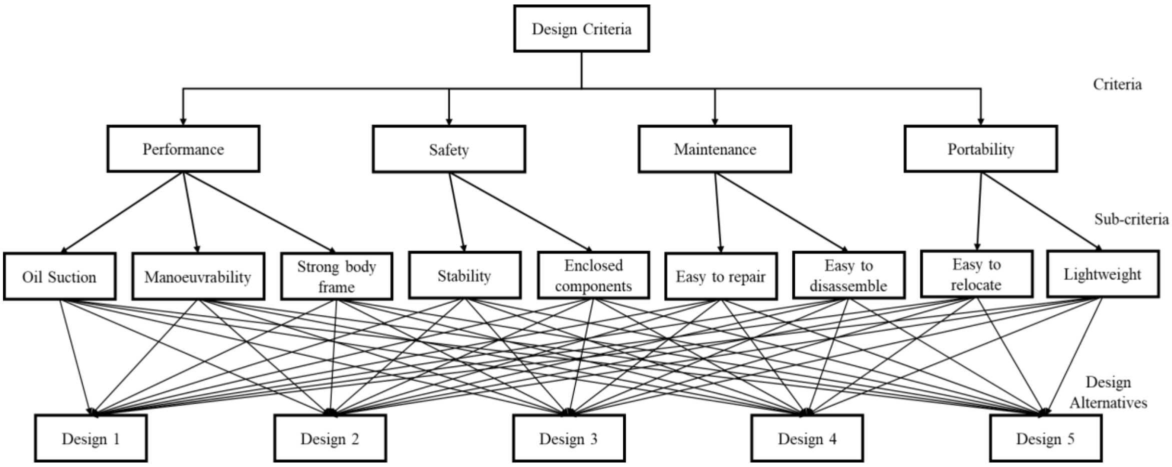

Fig. 3: A hierarchy model for the selection of design concept.

The following table is the pairwise comparison matrix of the design alternatives in each sub-criterion. The table below shows the step-by-step process of the pairwise comparison matrix for the oil suction sub-criteria. This process is done through all the nine sub-criteria. Note that the CR value needs to be less than 0.1. The expert decides the value inside the matrix. All the calculations were done following the steps explained in the methodology. Table 4 shows the pairwise comparison matrix of each design in the oil suction sub-criteria.

Table 5: Pairwise comparison matrix of each design in oil suction sub-criteria

Weight	D1	D2	D3	D4	D5
D1	1	4	3	4	4
D2	0.25	1	2	3	3
D3	0.33	0.5	1	0.5	0.5
D4	0.25	0.33	2	1	1
D5	0.25	0.33	2	1	1

Next, the synthesised matrix and consistency testing were done in Table 5. The same calculation applies to each of the sub-criteria. It is observed that the consistency ratio (CR) is below 0.1; thus, the pairwise comparison evaluation is accepted.

All the sub-criteria are analysed as shown in Tables 4 and 5. In the following analysis, the pairwise comparison of Oil Suction (OS), Manoeuvrability (MA), and Strong Body Frame (SBF) was made to calculate which sub-criteria in the performance criteria has higher weightage. Table 6 shows the pairwise comparison matrix of performance criteria. Table 7 shows the process of averaging the normalised columns. First, the eigenvector was calculated by multiplying to obtain the new vector. As the consistency ratio (CR) value is less than 0.1, thus the pairwise comparison evaluation is accepted.

Table 6: Synthesised matrix for the design alternatives

Wt	D1	D2	D3	D4	D5	SUM	PV	NV	NV/PV	CI	RI	CR
D1	0.4800	0.6480	0.3000	0.4210	0.4210	2.271	0.4542	2.5483	5.6111	0.08	1.12	0.07
D2	0.1200	0.1620	0.2000	0.3150	0.3150	1.1137	0.2227	1.2163	5.4605			
D3	0.1600	0.0810	0.1000	0.0520	0.0520	0.4463	0.0893	0.4689	5.2531			
D4	0.1200	0.0540	0.2000	0.1050	0.1050	0.5846	0.1169	0.6002	5.1332			
D5	0.1200	0.0540	0.2000	0.1050	0.1050	0.5846	0.1169	0.6002	5.1332			
								Total	26.59			
								λ max	5.3182			

Table 7: Pairwise comparison matrix of performance criteria

Wt	OS	MA	SBF
OS	1.0000	3.0000	5.0000
MA	0.3333	1.0000	2.0000
SBF	0.2000	0.5000	1.0000

Table 8: Synthesised matrix for the sub-criteria

Wt	OS	MA	SBF	PV	NV	NV/PV	CI	RI	CR
OS	0.6522	0.6667	0.6250	0.6479	1.9485	3.0071	0.00	0.58	0.0032
MA	0.2174	0.2222	0.2500	0.2299	0.6902	3.0026			
SBF	0.1304	0.1111	0.1250	0.1222	0.3667	3.0013			
					Total	9.01			
					λ max	5.3182			

Table 9: Overall priority vector for the alternatives

Alternatives	Overall PV			
D1	0.3098	0.0587	0.0588	0.1347
D2	0.1800	0.1359	0.1367	0.0531
D3	0.2055	0.2375	0.4580	0.3928
D4	0.1451	0.2840	0.2474	0.1691
D5	0.1596	0.2840	0.0991	0.2503

Table 9 reveals that design 3 (D3) has the most significant value (0.2603 or 26.03 per cent) among the various design concepts suitable for further development. Design 4 (D4) is the second highest, with a value of 0.2356 (23.6 per cent), while design 1 (D1) is the lowest, with a value of just 0.1323 per cent (13.23 per cent). As a result, D3 has been chosen as the preferred design idea, as it provides the most value among the five options.

Table 10: Oil spill skimmer design concept ranking

Alternatives	Priority Vector	Rank
D1	0.1323	5
D2	0.1440	4
D3	0.2603	1
D4	0.2356	2
D5	0.2278	3

3.3 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS multi-criteria decision matrix is utilised in this paper to compare the ranking result with AHP for verification purposes. The step-by-step calculations are explained earlier in the paper. The weights of the criteria were obtained from AHP. The weightage of the criteria and sub-criteria was calculated to identify the global weight of each sub-criteria. The calculation example of the criteria and sub-criteria are as follows. Table 11 shows the global weight of the priority vector obtained from AHP.

Table 11: Global weight of the priority vector obtained from AHP

Criteria	Priority Vector	Sub-criteria	Priority Vector	Global Weight
Performance	0.2776	(OS)	0.6479	0.1799
		(M)	0.2299	0.0638
		(SBF)	0.1222	0.0339
Safety	0.5635	(S)	0.7500	0.4226
		(EC)	0.2500	0.1409
Maintenance	0.1077	(ER)	0.6667	0.0718
		(ED)	0.3333	0.0359
Portability	0.0512	(ETR)	0.2500	0.0128
		(L)	0.7500	0.0384

Table 12 shows the pairwise comparison matrix of the TOPSIS analysis showing the Beneficial (B) and Non-Beneficial (NB) criteria. The value of the Positive Ideal Solution (PIS) is the highest, and the lowest value for the Negative Ideal Solution (NIS) is the beneficial (B) criteria. As for the non-beneficial (NB), it is contrariwise.

Table 12: Pairwise comparison matrix

	B	B	NB	B	NB	B	NB	NB	B
	OS	**M**	**SBF**	**S**	**EC**	**ETR**	**ETD**	**ER**	**L**
D1	5	2	3	3	2	2	2	4	4
D2	3	3	2	3	4	3	3	2	2
D3	4	5	4	4	4	5	5	4	4
D4	3	4	3	4	4	4	4	4	4
D5	3	4	5	4	4	2	2	4	4

The ranking is based on the Ci score, with a more excellent value of Ci indicating the best option among the five options (D1, D2, D3, D4, and D5). After calculating relative closeness (Ci), the value of Ci is used to rank the candidates. Because the D3 alternative has a better value than the other alternatives, it is rated first. D3 >D2 >D4 >D5 >D1 are the outcomes of all alternatives based on better scores, and their ordering preferences are shown in Table 13.

Table 13: The ranking of the best design concept for oil spill skimmer

Alternatives	Si+	Si-	Ci	Rank
D1	0.1199	0.3024	0.7160	5
D2	0.0946	0.2524	0.7274	2
D3	0.1146	0.3078	0.7287	1
D4	0.1206	0.3113	0.7208	3
D5	0.1232	0.3154	0.7192	4

Table 14 shows the ranking result from AHP and TOPSIS. The analysis between AHP and TOPSIS shows that design 3 is chosen as the best conceptual design for a portable oil spill skimmer. This result shows that the ranking from AHP is verified through the TOPSIS analysis.

Table 14: The comparison ranking of AHP and TOPSIS result

Alternatives	AHP Rank	TOPSIS Rank
D1	5	5
D2	4	2
D3	1	1
D4	2	3
D5	3	4

3.4 Sensitivity Analysis

The weighting of the primary criteria significantly impacts the final priority alternatives. As a result, even slight adjustments in the weighting of the criteria might have a significant impact on the final ranking. Furthermore, when extra criterion weights are applied, the ranking's stability must be reviewed because these weights are typically based on highly subjective viewpoints. Consequently, sensitivity analysis was used to test the AHP finding's robustness.

Super Decision software was used to conduct the sensitivity analysis. The performance graph depicts how the alternatives perform when the situation of all parameter's changes. D1 red, D2 blue, D3 black, D4 green, and D5 yellow are the colours of the design choices. In figure 1, the first ranking changes from design idea 3 to design concept 1 when the performance priority vector increases by 65 per cent. Figure 2 shows that when the priority is increased by 75%, design 4 gets the top position, followed by design 5 and design 1. In addition, when maintenance priority is increased by 70%, the ranking in design 2 to rank 3 and design 5 to rank 4 is shown in Fig. 3. Finally, there are ranking modifications for designs 2, 3, 4 and 5 for the portable criteria in Fig. 4, at 15%, although design 3 remains at the top of the ranking.

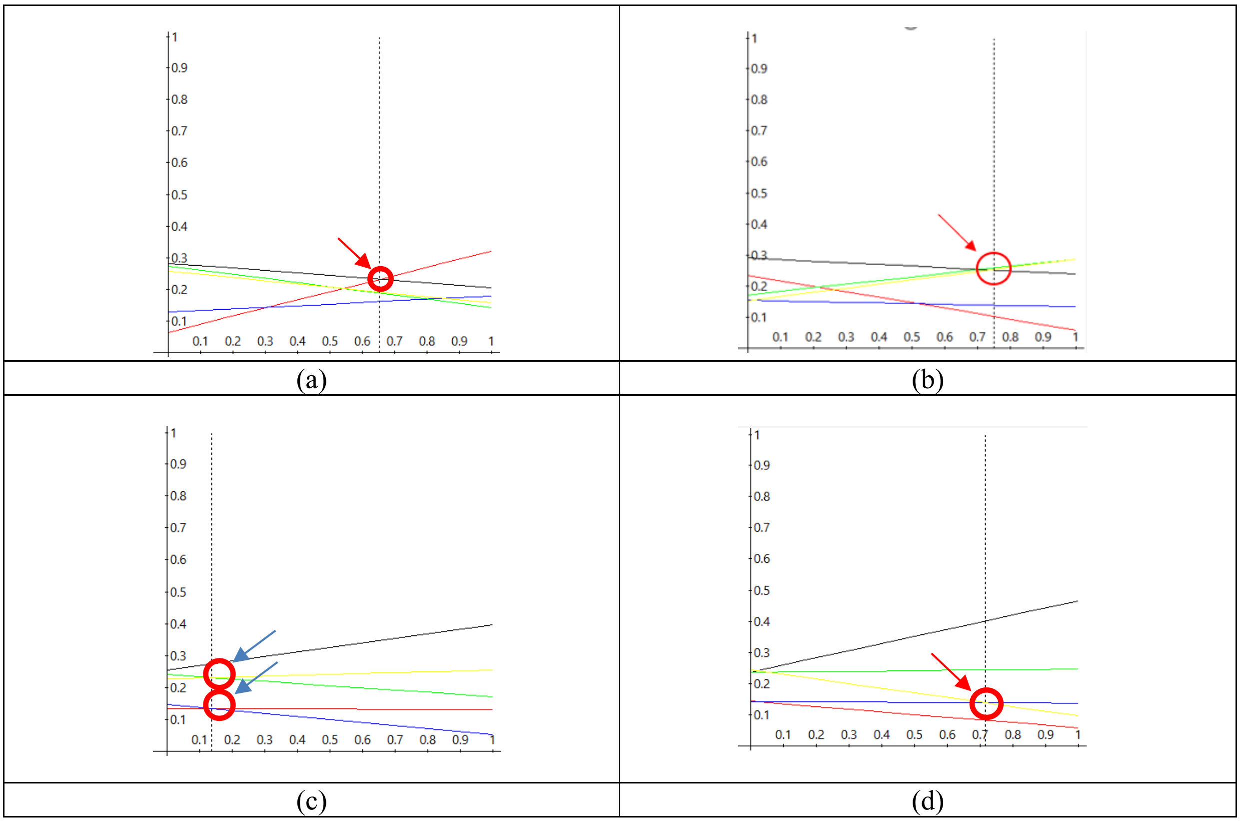

Fig. 4: The sensitivity analysis graph of the criteria; (a) performance, (b) safety, (c) maintenance, (d) portable.

4. CONCLUSION

Extensive studies on product development trends and customer demands, as well as the study on design techniques and methodologies, are required for product design. Designers should be able to see flaws in the design process, sum up the design experience regularly, and think about the meaning of the design from the perspectives of businesses, consumers, and social culture. The correct balance of perceptual inventiveness and rational assessment is required to develop exceptional design works. By combining Kansei Engineering and the Analytical Hierarchy Process, this study extracts the approach of analysing an oil spill skimmer's user demand and technical specification at the early design stage and proposes a technique for assessing and choosing the most appropriate design concepts during the conceptual design stage. TOPSIS and the sensitivity analysis approach were used to verify the AHP results. Design 3 was the best design concept for a portable oil spill skimmer because it has the highest value (26% or 0.26). AHP can help design engineers analyse and choose the optimal design concept based on the criteria and sub-criteria for a decision. Other forms of MCDM methods might be integrated with Kansei Engineering in the future as a recommendation since the findings would be valuable in determining whether other decision methods could be integrated to obtain more precise conclusions. In addition, the number of criteria and sub-criteria could be increased to produce more accurate result.

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