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# USE OF ANALYTICAL HIERARCHY PROCESS (AHP) FOR SELECTING THE BEST DESIGN CONCEPT

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**Abstract.** Selecting the right design concept at conceptual design stage in product development process is a crucial decision. Inaccurate decision can cause the product to be redesigned or remanufactured. One of the useful tools that can be employed in determining the most appropriate design concept is Analytical Hierarchy Process (AHP). AHP has been employed in almost all applications related to decision-making problems. In this paper, the results of a case study illustrates that AHP concept can assist designers to effectively evaluate various conceptual design alternatives at the conceptual design stage. This paper presents the methodology of selecting design concepts using analytical hierarchy process.

*Keywords:* Analytical hierarchy process; conceptual design; product development process; pairwise comparison; wheelchair development

**Abstrak.** Pemilihan konsep reka bentuk yang sesuai di peringkat reka bentuk gagasan dalam proses pembangunan produk adalah merupakan keputusan yang genting. Keputusan yang tidak tepat boleh menyebabkan sesuatu produk itu perlu direka bentuk semula atau dikilang semula. Salah satu daripada keadah yang boleh digunakan dalam menentukan konsep reka bentuk yang paling sesuai adalah process hierarki beranalitis (AHP). AHP telah digunakan dalam hampir kesemua aplikasi yang berkaitan dengan membuat sesuatu keputusan. Dalam kertas kerja ini, hasil daripada kajian kes menunjukkan bahawa konsep AHP boleh membantu pereka bentuk untuk membuat penilaian secara berkesan daripada pelbagai konsep reka bentuk di peringkat reka bentuk gagasan. Kertas kerja ini memaparkan kaedah pemilihan konsep reka bentuk dengan menggunakan proses hierarki beranalitis.

*Kata kunci:* Process hierarki beranalitis; reka bentuk gagasan; proses pembangunan produk; perbandingan pasangan; pembangunan kerusi roda

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## 1.0 INTRODUCTION

Selecting the right design concepts at the conceptual design stage in product development process is a crucial decision. According to Xu *et al.* [1], implementing appropriate evaluation and decision tool should be considered at the conceptual design stage that involves many complex decision-making tasks. One of the useful tools that can be employed at the conceptual design stage is Analytical Hierarchy Process (AHP). The AHP, developed at the Wharton School of Business by Saaty [2], is a powerful and flexible weighted scoring decision making process to help people set priorities and make the best decision. AHP has been widely used to solve multi-criteria decision making in both academic research and in industrial practice. AHP has been implemented in almost all applications related to decision-making and is currently predominantly used in the theme of selection and evaluation especially in the area of engineering, personal and social categories [3]. Generally, implementing AHP is based on experience and knowledge of the experts or users to determine the factors affecting the decision process [4, 5]. According to Hajeeh and Al-Othman [6], AHP is an intuitive method for formulating and analyzing decisions whereas Cheng and Li [7] cited that AHP approach is a subjective methodology. AHP is not only used as a stand-alone tool but also can be integrated with other techniques. AHP can be combined with other techniques such as quality function deployment (QFD), data envelopment analysis (DEA), and its integration can be employed to a wide variety of fields especially in logistic and manufacturing areas [4].

There are a number of activities in product development process related to decision-making such as product design selection, materials selection, ergonomic evaluation and manufacturing process selection. Various methods have been developed to assist designers to make the right decision at the conceptual design stage in the literature. The simple decision method is the Pugh concept selection method [8]. This method involves qualitative comparison of each alternative to a reference or datum alternative, criterion by criterion. It is useful in conceptual design because it requires the least amount of detailed information. However, no measure is given of the importance of each of the criteria and it does not allow for coupled decisions. Therefore, there is a danger that the final concept can be imprecise [9]. In order to support the efficiency in selecting the optimum design concepts at the conceptual design stage, an appropriate evaluation and decision tools need to be considered.

Since, AHP application is related to evaluating and selecting different alternatives or options, it can also be implemented in product development process especially in selecting the most appropriate design concept at the conceptual design stage. At this stage, designers have to consider a number of factors in order to determine and select the optimum decision options. It is because the inappropriate decision can lead to possible product to be redesigned or remanufactured. The advantages of using AHP include achieving higher quality product and shorter product development process. AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team thus reducing bias in decision-making. AHP allows organizations to minimize common pitfalls of decision-making process, such as lack of focus, planning, participation or ownership, which ultimately are costly distractions that can prevent teams from making the right choice [10]. Some applications of AHP in product development process are to select the best conceptual design for the music toy design during product development process [11], select the best material for a key [5]. AHP was also employed in ergonomic evaluation [12].

This paper discusses AHP implementation in the area of product development process. Thus, employing AHP can make the job of product development process shorter, reduce cost and produce higher product quality. Despite some works have been carried out in terms of AHP implementation in product development process, there is still a very limited information or study on the conceptual design in product development process. Thus, the paper illustrates the use of AHP in evaluating and determining the most suitable design concepts in wheelchair development at the conceptual design stage.

## 2.0 ANALYTICAL HIERARCHY PROCESS PRINCIPLES

Generally, AHP consists of three main principles, including hierarchy framework, priority analysis and consistency verification [2, 13-14]. Formulating the decision problem in the form of the hierarchy framework is the first step of AHP, with the top level representing overall objectives or goal, the middle levels representing criteria and sub-criteria, and the decision alternatives at the lowest level. Once a hierarchy framework is constructed, users are requested to set up a pairwise comparison matrix at each hierarchy and compare each other by using a scale pairwise comparison as shown in Table 1. Finally, in the synthesis of priority stage, each comparison matrix is then solved by an eigenvector method to determine the criteria importance and alternative performance [14]. These principles can be elaborated by structuring them in a more encompassing nine steps process as shown in Figure 1.

**Table 1** Scale for pair-wise comparisons [6]

| Relative intensity | Definition | Explanation |
|---|---|---|
| 1 | Equal value | Two requirements are of equal value |
| 3 | Slightly more value | Experience slightly favours one requirement over another |
| 5 | Essential or strong value | Experience strongly favours one requirement over another |
| 7 | Very strong value | A requirement is strongly favoured and its dominance is demonstrated in practice |
| 9 | Extreme value | The evidence favouring one over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between two adjacent judgements | When compromise is needed |
| Reciprocals | Reciprocals for inverse comparison | |

## 3.0 AHP AT THE CONCEPTUAL DESIGN STAGE-CASE STUDY

Generally, there are six stages in product development process [8]. One of them is conceptual design. It consists of three processes namely concept generation, concept evaluation and concept development. Nevertheless, the concept evaluation or selection is discussed in this paper. In order to choose the most suitable design concepts in wheelchair development, the following AHP steps as mentioned in Figure 1 should be considered:

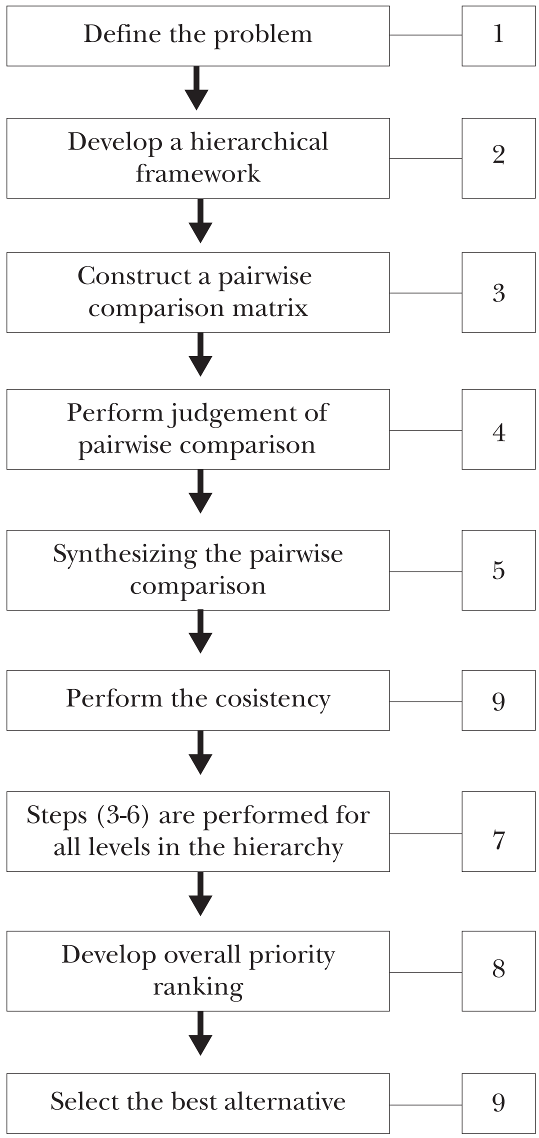


**Figure 1** The steps of the analytical hierarchy process (AHP)

### 3.1 Step 1: Define the Problem

A case study for this research is about wheelchair transfer problems [15]. After implementing several steps in product development process, there are seven wheelchair design concepts of wheelchairs produced as shown in Figure 2. Thus, it is necessary to choose the most suitable design concept by using AHP.

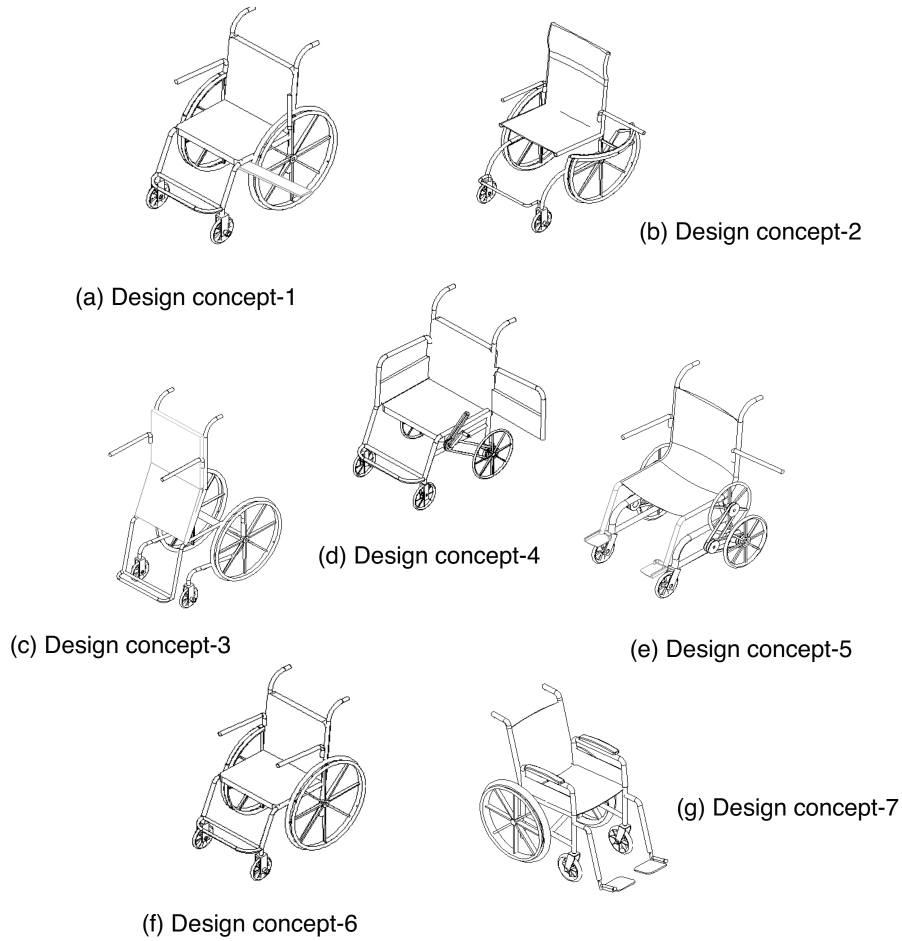


**Figure 2** Decision options

### 3.2 Step 2: Develop a Hierarchy Model

In this section, a hierarchy model for structuring design concept decisions using AHP is introduced. A four level hierarchy decision process displayed in Figure 3 is described below:

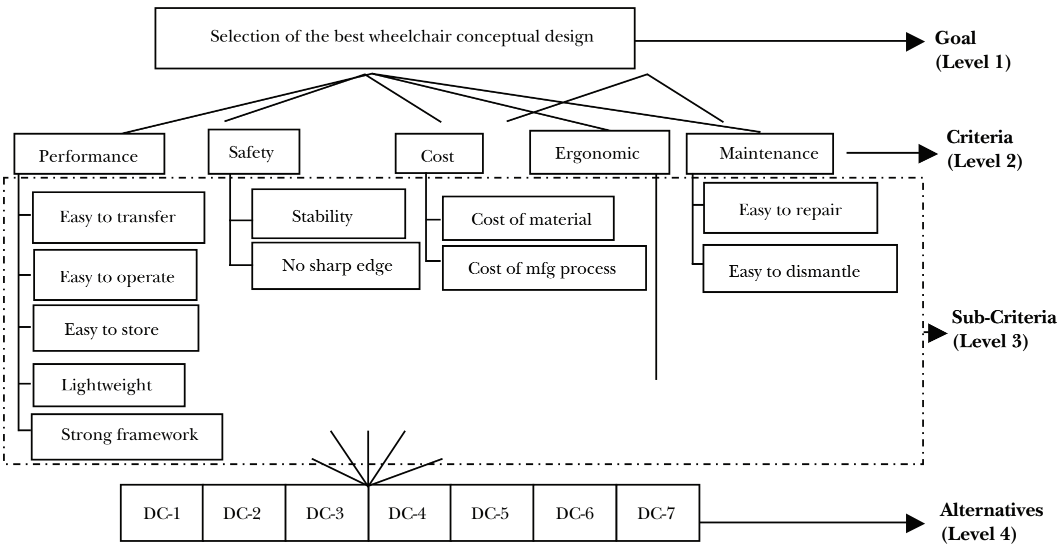


**Figure 3** A hierarchy model for the selection of design concept

### *3.2.1 Level I:*

Initially, the objective or the overall goal of the decision is presented at the top level of the hierarchy. Specifically, the overall goal of this application is to 'select the most suitable wheelchair conceptual design'.

### *3.2.2 Level II:*

The second level represents the main criteria affecting the development of wheelchair design. The main criteria can be classified into five aspects: performance (P), safety (S), cost (C), ergonomic (E) and maintenance (M).

### *3.2.3 Level III:*

The sub-criteria is represented at the third level of the hierarchy. There are five sub-criteria affecting the wheelchair performance: easy to transfer (ETT), easy to use (ETU), easy to storage (ETS), lightweight (LW) and strong framework (SF). Stability (ST) and no sharp edge (NSE) are sub-criteria that affect in terms of safety. While cost of material (CM) and cost of manufacturing process (CMP), easy to repair (ETR) and easy to dismantle (ETD), are sub-criteria affecting in terms of cost and maintenance respectively.

### *3.2.4 Level IV:*

Finally, at the lowest level of the hierarchy, the design concept (DC) alternatives of the wheelchair development are identified, which are the decision options as shown in Figure 2.

## 3.3 Step 3: Construct a Pair-wise Comparison Matrix

One of the major strengths of AHP is the use of pair-wise comparison to derive accurate ratio scale priorities. Pair-wise comparisons are fundamental to the AHP methodology [16]. Then, a pair-wise comparison matrix (size $n \times n$) is constructed for the lower levels with one matrix in the level immediately above. The pair-wise comparisons generate a matrix of relative rankings for each level of the hierarchy. The number of matrices depends on the number elements at each level. The order of the matrix at each level depends on the number of elements at the lower level that it links to.

## 3.4 Step 4: Perform Judgement of Pairwise Comparison

Pair-wise comparison begins with comparing the relative importance of two selected items. There are $n \times (n - 1)$ judgments required to develop the set of matrices in step 3. The decision makers have to compare or judge each element by using the relative scale pairwise comparison as shown in Table 1. The judgements are decided based on the decision makers' or users' experience and knowledge. The scale used for comparisons in AHP enables the decision maker to incorporate experience and knowledge intuitively. To do pairwise comparison, for instance as shown in Table 2, if performance (P) is strongly more important or essential over cost (C), then $a = 5$. Reciprocals are automatically assigned to each pair-wise comparison.

**Table 2** Pairwise comparison of criteria with respect to overall goal

| **Goal** | **P** | **S** | **C** | **E** | **M** |
|---|---|---|---|---|---|
| Performance (P) | 1 | 3 | $a = 5$ | 3 | 5 |
| Safety (S) | 1/3 | 1 | 3 | 1 | 3 |
| Cost (C) | 1/5 | 1/3 | 1 | 1/3 | 3 |
| Ergonomic (E) | 1/3 | 1 | 3 | 1 | 3 |
| Maintenance (M) | 1/5 | 1/3 | 1/3 | 1/3 | 1 |
| Total column | 2.067 | 5.667 | 10.333 | 6.333 | 15.0 |

### 3.5 Step 5: Synthesizing the Pairwise Comparison

To calculate the vectors of priorities, the average of normalized column (ANC) method is used [11]. ANC is to divide the elements of each column by the sum of the column and then add the element in each resulting row and divide this sum by the number of elements in the row ($n$). This is a process of averaging over the normalized columns. The summary results for this calculation are shown in Table 3. In mathematical form, the vector of priorities can be calculated as

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_i^n a_{ij}}, i, j = 1, 2, \ldots n \tag{1}$$

For instance, the calculation for the first priority vector as follows

Firstly, $\sum_i^n a_{ij}$ hence, $1 + 1/3 + 1/5 + 1/3 + 1/5 = 2.067$. Secondly, $\frac{a_{ij}}{\sum_i^n a_{ij}}$ hence, $1/2.067 = 0.484$. Thirdly, $\sum_{j=1}^{n}\frac{a_{ij}}{\sum_i^n a_{ij}}$ hence, $0.484 + 0.529 + 0.405 + 0.529 + 0.333 = 2.281$ and finally, divide this sum by the number of elements ($n = 5$) hence, $2.281/5 = 0.456$.

**Table 3** Synthesized matrix for the criteria

| Goal | P | S | C | E | M | Total row | Priority vector |
|---|---|---|---|---|---|---|---|
| Performance (P) | 0.484 | 0.529 | 0.405 | 0.529 | 0.333 | 2.281 | 0.456 |
| Safety (S) | 0.161 | 0.176 | 0.243 | 0.176 | 0.200 | 0.957 | 0.191 |
| Cost (C) | 0.097 | 0.059 | 0.081 | 0.059 | 0.200 | 0.496 | 0.099 |
| Ergonomic (E) | 0.161 | 0.176 | 0.243 | 0.176 | 0.200 | 0.957 | 0.191 |
| Maintenance (M) | 0.097 | 0.059 | 0.027 | 0.059 | 0.067 | 0.308 | 0.062 |
| | | | | | | Σ | 1.000 |

### 3.6 Step 6: Perform the Consistency

Since the comparisons are carried out through personal or subjective judgments, some degree of inconsistency may be occurred. To guarantee the judgments are consistent, the final operation called consistency verification, which is regarded as one of the most advantages of the AHP, is incorporated in order to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio [4]. The consistency is determined by the consistency ratio (CR). Consistency ratio (CR) is the ratio of consistency index (CI) to random index (RI) for the same order matrices. To calculate the consistency ratio (CR), there are three steps to be implemented as follows:

### *3.6.1 Firstly, Calculate the Eigenvalue* ($\lambda_{max}$)

To calculate the eigenvalue ($\lambda_{max}$), multiply on the right matrix of judgements by the priority vector or eigenvector, obtaining a new vector. The calculation to get a new vector is shown in Table 4.

**Table 4** Calculation to get a new vector

| | | | | | |
|---|---|---|---|---|---|
| 0.456 | 1<br>1/3<br>1/5<br>13<br>1/5 | + 0.191 | 3<br>1<br>1/3<br>1<br>1/3 | + 0.099 | 5<br>3<br>1<br>3<br>1/3 |
| | | | | | New vector |
| + 0.191 | 3<br>1<br>1/3<br>1<br>1/3 | +0.062 | 5<br>3<br>3<br>3<br>1 | = | 2.409<br>1.017<br>0.503<br>1.017<br>0.314 |

For instance, the calculation for the first row in the matrix is

$$0.456(1) + 0.191(3) + 0.099(5) + 0.191(3) + 0.062(5) = 2.409$$

Then, dividing all the elements of the weighted sum matrices or new vector by their respective priority vector element, hence

$$2.409/0.456 = 5.279;\ 1.017/0.191 = 5.312;\ 0.503/0.099 = 5.075;$$
$$1.017/0.191 = 5.312;\ 0.314/0.062 = 5.089$$

Then calculate the average of these values to obtain $\lambda_{max} = (5.279 + 5.312 + 5.075 + 5.312 + 5.089)/5 = 5.213$

### *3.6.2 Secondly, Calculate the Consistency Index (CI).*

$$CI = (\lambda_{max} - n) / (n-1) \tag{2}$$

Where $n$ is the matrix size.

CI = (5.213–5)/(5–1) = 0.053

### *3.6.3 Finally, Calculate the Consistency Ratio (CR).*

The CR can be calculated using the formula

$$CR = CI/RI \tag{3}$$

Selecting the appropriate value of random index (RI), for the matrix size of five using Table 5, RI = 1.12. Then calculate the consistency ratio (CR), CR = CI/RI = 0.053/1.12 = 0.05. As the value of CR is less than 0.1, the judgements are acceptable. If CR > 0.1, the judgement matrix is inconsistent. To obtain a consistent matrix, judgements should be reviewed and improved. The summary results for this calculation are shown in Table 6.

**Table 5** Random index of analytic hierarchy process [12]

| Size of matrix ($n$) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random index (RI) | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.58 |

**Table 6** The consistency test for the criteria

| **Goal** | **P** | **S** | **C** | **E** | **M** | **Priority vector (PV)** | **New vector (NV)** | **NV/PV** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| P | 1 | 3 | 5 | 3 | 5 | 0.456 | 2.409 | 5.279 | Consistency index CI = $(\lambda_{max} - n)/(n-1)$ = 0.053 | |
| S | 1/3 | 1 | 3 | 1 | 3 | 0.191 | 1.017 | 5.312 | | |
| C | 1/5 | 1/3 | 1 | 1/3 | 3 | 0.099 | 0.503 | 5.075 | Consistency Ratio CR = CI/RI = 0.05 | |
| E | 1/3 | 1 | 3 | 1 | 3 | 0.191 | 1.017 | 5.312 | | |
| M | 1/5 | 1/3 | 1/3 | 1/3 | 1 | 0.062 | 0.314 | 5.089 | | |
| | | | | | | Total (Σ) | | 26.067 | | |
| Maximum eigenvalue ($\lambda_{max}$) | | | | | | | | 5.213 | | |

## 3.7 Step 7: Step 3-6 Are Performed for All Levels in the Hierarchy Model

The elements in Tables 7-10 and Table 11 represent the consistency test for the sub-criteria and alternatives. As the value of CR for all sub-criteria and alternatives is less than 0.1, the judgements are acceptable.

**Table 7** The consistency test for the sub-criteria

| G/P | ETT | ETU | ETS | LW | SF | Priority vector (PV) | New vector (NV) | NV/PV | Consistency index (CI)= ($\lambda_{max}$–$n$)/($n$–1)= 0.087 |
|---|---|---|---|---|---|---|---|---|---|
| ETT | 1 | 3 | 5 | 3 | 3 | 0.415 | 2.283 | 5.501 | Consistency Ratio (CR)= CI/RI = 0.08 |
| ETU | 0.333 | 1 | 3 | 3 | 3 | 0.251 | 1.392 | 5.551 | |
| ETS | 0.200 | 0.333 | 1 | 0.333 | 0.200 | 0.056 | 0.295 | 5.259 | Note: As the value of CR is less than 0.1, the judgements are acceptable because CR < 0.1 |
| LW | 0.333 | 0.333 | 3 | 1 | 1 | 0.127 | 0.669 | 5.251 | |
| SF | 0.333 | 0.333 | 5 | 1 | 1 | 0.151 | 0.781 | 5.176 | |
| | | | | | | | total | 26.739 | |
| | | | | Maximum eigenvalue ($\lambda_{max}$) | | | | 5.348 | |

**Table 8** The consistency test for the sub-criteria

| G/S | ST | NSE | Priority vector | New vector (NV) | NV/PV | Consistency index (CI) = ($\lambda_{max}$ –$n$)/($n$–1) = 0.000 |
|---|---|---|---|---|---|---|
| ST | 1 | 3 | 0.750 | 1.500 | 2.000 | Consistency Ratio (CR) = CI/RI = 0.000 |
| NSE | 0.333 | 1 | 0.250 | 0.500 | 2.000 | |
| | | | | total | 4.000 | Note: As the value of CR is less than 0.1, the judgements are acceptable because CR < 0.1 |
| | Maximum eigenvalue ($\lambda_{max}$) | | | | 2.000 | |

**Table 9** The consistency test for the sub-criteria

| G/C | CM | CMP | Priority Vector (PV) | New vector (NV) | NV/PV | Consistency index (CI) = ($\lambda_{max}$ –$n$)/($n$–1) = 0.000 |
|---|---|---|---|---|---|---|
| CM | 1 | 3 | 0.750 | 1.500 | 2.000 | Consistency Ratio (CR) = CI/RI = 0.000 |
| CMP | 0.333 | 1 | 0.250 | 0.500 | 2.000 | |
| | | | | total | 4.000 | Note: As the value of CR is less than 0.1, the judgements are acceptable because CR < 0.1 |
| | Maximum eigenvalue ($\lambda_{max}$) | | | | 2.000 | |

**Table 10** The consistency test for the sub-criteria

| **G/M** | **ETR** | **ETD** | **Priority Vector (PV)** | **New vector (NV)** | **NV/PV** | Consistency index (CI) = $(\lambda_{max} - n)/(n-1)$ | 0.000 |
|---|---|---|---|---|---|---|---|
| ETR | 1 | 3 | 0.750 | 1.500 | 2.000 | Consistency Ratio (CR) = CI/RI | 0.000 |
| ETD | 0.333 | 1 | 0.250 | 0.500 | 2.000 | | |
| | | | | total | 4.000 | Note: As the value of CR is less than 0.1, the judgements are acceptable because CR < 0.1 | |
| | Maximum eigenvalue ($\lambda_{max}$) | | | | 2.000 | | |

**Table 11** The consistency test for the alternatives

| | **Priority vector/eigenvector** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GOAL** | | | | | | | | | | | |
| | **P** | | | | | **S** | | **C** | | **E** | **M** | |
| | **ETT** | **ETU** | **ETS** | **LW** | **SF** | **ST** | **NSE** | **CM** | **CMP** | | **ETR** | **ETD** |
| | | | | | | | | | | | | |
| DC-1 | 0.175 | 0.215 | 0.093 | 0.170 | 0.112 | 0.144 | 0.189 | 0.126 | 0.124 | 0.120 | 0.262 | 0.195 |
| DC-2 | 0.104 | 0.081 | 0.074 | 0.290 | 0.061 | 0.055 | 0.058 | 0.229 | 0.227 | 0.066 | 0.191 | 0.316 |
| DC-3 | 0.140 | 0.145 | 0.066 | 0.140 | 0.118 | 0.092 | 0.174 | 0.126 | 0.124 | 0.120 | 0.144 | 0.125 |
| DC-4 | 0.126 | 0.044 | 0.070 | 0.127 | 0.061 | 0.062 | 0.055 | 0.229 | 0.227 | 0.050 | 0.093 | 0.101 |
| DC-5 | 0.323 | 0.201 | 0.420 | 0.050 | 0.311 | 0.269 | 0.174 | 0.051 | 0.047 | 0.322 | 0.045 | 0.034 |
| DC-6 | 0.080 | 0.162 | 0.074 | 0.167 | 0.084 | 0.147 | 0.174 | 0.169 | 0.182 | 0.100 | 0.198 | 0.165 |
| DC-7 | 0.051 | 0.152 | 0.204 | 0.056 | 0.253 | 0.230 | 0.174 | 0.072 | 0.070 | 0.223 | 0.068 | 0.065 |
| | consistency test | | | | | | | | | | | |
| $\lambda_{max}$ | 7.500 | 7.638 | 7.172 | 7.315 | 7.307 | 7.617 | 7.027 | 7.436 | 7.437 | 7.388 | 7.654 | 7.490 |
| CI | 0.083 | 0.106 | 0.029 | 0.052 | 0.051 | 0.103 | 0.005 | 0.073 | 0.073 | 0.065 | 0.109 | 0.082 |
| RI | 1.320 | | | | | | | | | | | |
| CR | 0.063 | 0.081 | 0.022 | 0.040 | 0.039 | 0.078 | 0.003 | 0.055 | 0.055 | 0.049 | 0.083 | 0.062 |

## 3.8 Step 8: Develop Overall Priority Ranking

After the consistency calculation for all levels is completed, further calculation of the overall priority vector to select the best design concept must be performed. The elements/points in Table 12 represent priority vectors for criteria, sub-criteria and alternatives.

**Table 12** All priority vectors for criteria, sub-criteria and alternative

| | **Priority vector** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Goal** | | | | | | | | | | | |
| **Criteria** | **P** | | | | | **S** | | **C** | | **E** | **M** | |
| | **0.456** | | | | | **0.191** | | **0.099** | | **0.191** | **0.062** | |
| **Sub-criteria** | **ETT** | **ETU** | **ETS** | **LW** | **SF** | **ST** | **NSE** | **CM** | **CMP** | | **ETR** | **ETD** |
| | 0.415 | 0.251 | 0.056 | 0.127 | 0.151 | 0.750 | 0.250 | 0.750 | 0.250 | | 0.750 | 0.250 |
| Alternatives | | | | | | | | | | | | |
| DC-1 | 0.175 | 0.215 | 0.093 | 0.170 | 0.112 | 0.144 | 0.189 | 0.126 | 0.124 | 0.120 | 0.262 | 0.195 |
| DC-2 | 0.104 | 0.081 | 0.074 | 0.290 | 0.061 | 0.055 | 0.058 | 0.229 | 0.227 | 0.066 | 0.191 | 0.316 |
| DC-3 | 0.140 | 0.145 | 0.066 | 0.140 | 0.118 | 0.092 | 0.174 | 0.126 | 0.124 | 0.120 | 0.144 | 0.125 |
| DC-4 | 0.126 | 0.044 | 0.070 | 0.127 | 0.061 | 0.062 | 0.055 | 0.229 | 0.227 | 0.050 | 0.093 | 0.101 |
| DC-5 | 0.323 | 0.201 | 0.420 | 0.050 | 0.311 | 0.269 | 0.174 | 0.051 | 0.047 | 0.322 | 0.045 | 0.034 |
| DC-6 | 0.080 | 0.162 | 0.074 | 0.167 | 0.084 | 0.147 | 0.174 | 0.169 | 0.182 | 0.100 | 0.198 | 0.165 |
| DC-7 | 0.051 | 0.152 | 0.204 | 0.056 | 0.253 | 0.230 | 0.174 | 0.072 | 0.070 | 0.223 | 0.068 | 0.065 |

The elements in Table 13 represent the overall priority vector for seven design alternatives with respect to the sub-criteria. The overall priority vector can be obtained by multiplying the priority vector for the design alternatives by the vector of priority of the sub-criteria. An example of the overall priority calculation is as follows:

$$0.175(0.415) + 0.215(0.251) + 0.093(0.056) + 0.170(0.127) + 0.112(0.151) = 0.170$$

**Table 13** Overall priority vectors for sub-criteria with respect to the criteria

| | **Overall priority vector** | | | | |
|---|---|---|---|---|---|
| DC-1 | 0.170 | 0.156 | 0.125 | 0.120 | 0.245 |
| DC-2 | 0.114 | 0.056 | 0.228 | 0.066 | 0.222 |
| DC-3 | 0.134 | 0.112 | 0.125 | 0.120 | 0.139 |
| DC-4 | 0.093 | 0.060 | 0.228 | 0.050 | 0.095 |
| DC-5 | 0.262 | 0.246 | 0.050 | 0.322 | 0.042 |
| DC-6 | 0.112 | 0.154 | 0.173 | 0.100 | 0.190 |
| DC-7 | 0.116 | 0.216 | 0.071 | 0.223 | 0.067 |

The elements in Table 14 show the overall priority vector of the alternatives with respect to the criteria. The overall priority vector can be obtained by multiplying the priority vector for the design alternatives by the priority vector of the criteria. An example of the overall priority calculation is as follows:

$$0.170(0.456) + 0.156(0.191) + 0.125(0.099) + 0.120(0.191) + 0.245(0.062) = 0.158$$

**Table 14** Overall priority vector for the alternatives with respect to the criteria

| | **Priority vector** | | | | | |
|---|---|---|---|---|---|---|
| | **P** | **S** | **C** | **E** | **M** | **Overall Priority** |
| | **0.456** | **0.191** | **0.099** | **0.191** | **0.062** | |
| | | | | | | |
| DC-1 | 0.170 | 0.156 | 0.125 | 0.120 | 0.245 | 0.158 |
| DC-2 | 0.114 | 0.056 | 0.228 | 0.066 | 0.222 | 0.111 |
| DC-3 | 0.134 | 0.112 | 0.125 | 0.120 | 0.139 | 0.126 |
| DC-4 | 0.093 | 0.060 | 0.228 | 0.050 | 0.095 | 0.092 |
| DC-5 | 0.262 | 0.246 | 0.050 | 0.322 | 0.042 | 0.236 |
| DC-6 | 0.112 | 0.154 | 0.173 | 0.100 | 0.190 | 0.129 |
| DC-7 | 0.116 | 0.216 | 0.071 | 0.223 | 0.067 | 0.148 |

### 3.9 Step 9: Selection of the Best Design Concept

Table 15 shows the design concept-5 (DC-5) that has the highest value (0.236 or 23.6%) among the other design concepts that is appropriate for further development. The second highest is the design concept 1 (DC-1) with a value of 0.158 (15.8%), and the lowest value or last choice is the design concept 4 (DC-4) with a value of only 0.092 (9.2%). DC-5 is the preferred choice since it has the highest value among seven alternatives.

**Table 15** Result of selection

| **No.** | **Best Selection** | |
|---|---|---|
| 1 | DC-5 | **0.236** |
| 2 | DC-1 | 0.158 |
| 3 | DC-7 | 0.148 |
| 4 | DC-6 | 0.129 |
| 5 | DC-3 | 0.126 |
| 6 | DC-2 | 0.111 |
| 7 | DC-4 | 0.092 |

## 4.0 CONCLUSIONS

This paper presents the methodology of evaluating and selecting the most appropriate design concepts at conceptual design stage by implementing analytical hierarchy process (AHP). AHP can be used to help designers to evaluate and select the best design concept based on the criteria and sub-criteria aspects of a decision. The analysis reveals that the design concept-5 is the most appropriate for further development because it has the highest value (0.236 or 23.6%) among the other design concepts. Application of AHP for selecting conceptual design at conceptual design stage can improve quality of product and shorten product development process.

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