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AHP METHOD AND APPLICATION EXAMPLE FOR THE ROBUST MULTI-CRITERIA DESIGN CONCEPT SELECTION

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ABSTRACT

This paper aims at giving an application of Analytical Hierarchy Process (AHP), a Multi Criteria Decision Making method for the selection of a motorcycle tire dismounting tool. Four criteria and four sub-criteria were identified for the selection of the best design concept from three alternative solutions. It was observed that a design concept-1 has received the highest score and selected design to proceed. The selection of the design concept is robust enough as the consistency on the decision made is within the allowable range of inconsistency which is less than 10%.

Keywords: AHP, design concept, concept selection.

INTRODUCTION

Concept selection is an activity in the product design process, where alternative concepts are compared and a decision is made to select the alternative(s) which proceed into the later phases of design [1]. Salonen and Perttula [2] described the concept selection as identifying the alternatives that best fulfill the decision-making criteria. Selection of design concepts is the essential and complex decision activity at the conceptual design stage as a poor design concept cannot be compensated by a well-detailed design and will incur a great redesign cost [3]. It influences all subsequent phases with regards to cost, quality, and performance of the end-product [4]. According to [5], the decision made at this stage contributes 80% to the production cost. Thus, that is the reason why concept selection is an area in design science that is under considerable interest continuously. The decision makers have to assess the design concepts in various aspects including the technical, cost, aesthetical, etc. normally with vague information about the design concept in hand. This may create difficulties for them to judge and it is a tedious activity. To ensure the selection of design concept is robust, the decision makers must certain with the decision of which design concept should they further developed.

To assist them in selecting the best design concept many different methods exist. The most common method is the selection charts. Possibly the simplest selection chart is a decisions matrix, where a number of design concepts are rated against a limited set of criteria, then each criterion is subjectively weighted, and the results are summed up to provide a total score for each solution [6]. Pugh's method, with extensions [7] assigns a datum solution and then all others are rated as better or worse on each product objective relative to the datum. Otto [8] extended this method by introducing numerical scoring procedures to assign degrees of better or worse with numbers that are weighted and summed. More complex methods such as the analytic hierarchy process (AHP) [9] use hierarchical groupings of criteria. AHP has been used in wide range of application including engineering, education, economic, etc [10]. Among these methods, the concept scoring and AHP methods are most commonly used in industry [2]. The strength of AHP method relies on the consistency index that determines the consistency of decision in solving the multi-criteria attribute thus reducing bias in decision-making [11]. In AHP, the problem is decomposed into hierarchies with the goal on the top hierarchy, followed by criteria and sub-criteria, and finally, the alternatives (in this case, the concepts) make up the bottom hierarchy. In order to achieve the goal, pairwise comparisons of all criteria are carried out to determine the relative importance of each criterion. Then pairwise comparisons are conducted between all alternatives separately for each criterion. Based on these comparisons an overall selection is made. Eigen values and Eigen vectors are used to ensuring that the decision maker's judgments are consistent in nature. Several reports [12, 13] have published on the application of AHP by academia in choosing the best design concept. Basically, the successful factor in AHP implementation relies on experience and knowledge of decision makers in particular to determine the factors influencing the decision [14]. In this paper, the robust multi-criteria concept selection using AHP is presented in order to select the most promising design concept for motorcycle tire dismounting tool and demonstrates the certainty of the decision made.

OVERVIEW OF AHP DECISION-MAKING METHOD

Establishment of a structural Hierarchy [15]

A complex decision is decomposed into a hierarchy descending from an overall objective to several levels from criteria, sub-criteria to the lowest level. The overall goal of the decision is placed at the top level of the hierarchy. The criteria and the sub-criteria that contribute to the decision are represented at the intermediate levels. Finally, the alternative solutions are placed at the lowest level of the hierarchy. A hierarchy can be constructed by

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creative thinking, recollection and using people's perspectives [16].

Establishment of comparative judgments [15]

The next step after the development of structural hierarchy is to determine the priorities of elements at each level. A set of comparison matrices of all elements in a level with to respect to an element of the immediately superior level is constructed. The pairwise comparisons are based on how much important of element A than element B. The preference element is quantified using a nine-point scale that is shown in Table-1.

Table-1. Saaty's Ratio scale for pairwise comparison of importance of weights of criteria.

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favor one over the other
5	Essential importance or strong	Experience and judgment strongly favor one over another
7	Very importance strong	An element is strongly favored and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one element over another is one of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	Comprise is needed between two judgments
Reciprocals	When activity i compared to j is assigned one of the above numbers, the activity j compared to is assigned its reciprocal	
Rational	Ratios arising from forcing consistency of judgments	

Synthesis of priorities and measurement of consistency [15]

The pairwise comparisons generate the matrix of rankings for each level of the hierarchy after all matrices are developed and all pairwise comparisons are obtained, Eigenvectors (relative weights) are obtained. Presume, to compare a set of 'n' objects in pairs for the relative weights. Represent the objects by $a_1, a_2, \ldots, a_n$ and their weights by $w_1, w_2, \ldots, w_n$. The pairwise comparisons can be represented by a matrix as in Table-2.

Table-2. Matrix containing weights.

	a_1	a_2	…	a_n
a_1	w_1/w_1	w_1/w_2		w_1/w_n
a_2	w_2/w_1	w_2/w_2		w_2/w_n
. . .				
a_n	w_n/w_1	w_n/w_2		w_n/w_n

The matrix shown in Table-2 has positive entries everywhere and satisfies the reciprocal property $a_{ji} = 1/a_{ij}$. It is called a reciprocal matrix. If this matrix is multiply to the transposed vector $w^T = (w_1, w_2, \ldots, w_n)$ the vector nw is obtained. Our problem takes the form Aw= nw. Started with the assumption that w was given. But if only had A and wanted to recover w, we would have to solve the system (A - nI) w = 0 in the unknown w. This has a nonzero solution if n is an eigenvalue of A, i.e., it is a root of the characteristic equation of A. But A has unit rank since every row is a constant multiple of the first row. Thus all the eigenvalue λ_i, i=1, 2,…..n of A are zero except one. Also, it is known that, $\sum_{i=1}^{n} \lambda_i = tr(A) = n$, and $\lambda_1 = \lambda_{max}$. The solution w of this problem is any column of A. These solutions differ by a multiplicative constant. However, this solution is normalized so that its components sum to unity. The result is a unique solution no matter which column is used. The matrix A satisfies the fundamental consistency property.

The consistency ratio is calculated as per the following steps; i) calculate the Eigenvector or the relative weights and λ_{max} for each matrix of order n, ii) compute the consistency index for each matrix of order n by the formulae CI = $(\lambda_{max} - n)/(n - 1)$, iii) the consistency ratio is then calculated using the formulae CR = CI / RI ,where RI (Table-3) is a known random consistency index obtained from a large number of simulation runs and varies depending upon the order of the matrix.

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Table-3. Average random index (RI) based on matrix size [16].

Size of matrix (n)	**Random consistency index** (RI)
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

The acceptable CR range varies according to the size of the matrix i.e. 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix and 0.1 for all larger matrices, for $n \geq 5$ [16] if the value of CR is equal to, or less than that value it implies that the evaluation of the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. If CR is more than that acceptable value, the inconsistency of the judgments within the matrix has occurred and the evaluation process should be reviewed.

CASE STUDY: THE USE OF AHP IN THE CONCEPT SELECTION OF MOTORCYCLE TIRE DISMOUNTING TOOL

Defining the problem

An existing tool for dismounting motorcycle tire is not user-friendly to the one-handed user. Based on the brainstorming method three (3) design concepts of the motorcycle tire dismounting tool were generated as the option of the solution to the defined problem. Thus, it is necessary to select the best design concept by the application of AHP. To facilitate design engineer to perform the pair-wise comparison in the later step the three (3) models of design concept (Figure-1) were developed using CATIA V5 solid modeling software for ease of property predictability.

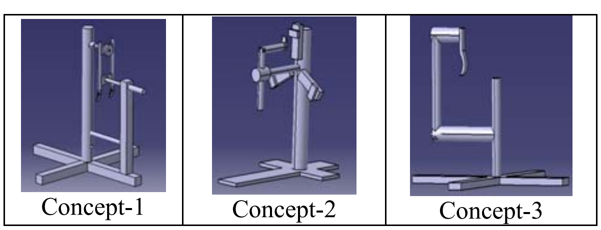

Figure-1. Solution options for motorcycle tire dismounting tool.

Development of Hierarchy Model

In this section, a hierarchy model for structuring concept design decision for AHP application was developed. There is four levels of hierarchy decision process of the selection a motorcycle tire dismounting tool as depicted in Figure-2. At the level-I, the objective or the overall goal of the decision was stated at the top level of the hierarchy. In particular, the objective goal of this application was to select the best design concept of motorcycle tire dismounting tool. In level-II, the main customer requirements that influence on the chosen of the best design concept for the motorcycle tire dismounting tool are represented. In this study, the main customer requirements considered were; *performance, ease of use, construction* and *cost*. Then in level-III, the corresponding attributes of the product to design requirement (level-II) have listed. For instance, there are four (4) attributes contributes to the *ease of use* criterion which are; *operation step (OS), locking mechanism (LO), working posture (WP)* and *operation mode (OM)*. Meanwhile, the corresponding attributes for the *construction requirement* are *OM* and *LO*. The mapping of the customer requirements to product attributes was carried out by experienced design engineers and the complete mapping for this tool is tabulated in Table-4. Level IV - Finally, the four alternative solutions that are potentially met the objective of the project were listed in the level IV of the hierarchy, which the alternative solutions is shown in Figure-1.

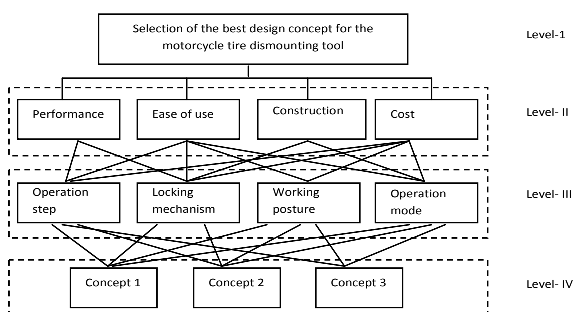

Figure-2. Hierarchy model of the selection of motorcycle tire dismounting tool.

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Table-4. Mapping of customer requirement to design attribute for motorcycle tire dismounting tool.

Customer requirement	**Product attribute**			
	Operation mode (OM)	**Locking mechanism** (LO)	**Working posture** (WP)	**Operation steps** (OS)
Ease of use E)	x	x	x	x
Performance (P)		x		x
Construction (S)	x	x		
Cost (C)	x	x	x	x

A. Construction of pair-wise comparison matrix

One of the major strength of AHP is the use of pair-wise comparison to derive the accurate ratio of priorities. In this study, the pair-wise comparison matrix (size n x n) was constructed for the customer requirement (Level-II), product attribute (Level-III) and alternative solution (Level- IV) as it is used to generate a matrix of the relative importance of criteria at each level.

B. Performing judgment of pair-wise comparison

The relative important of two selected criteria were compared in the pair-wise comparison stage. There are n x (n-1)/2 numbers of comparisons were done to complete the development of matrices. The judgment of the relative importance of two selected criteria was carried based on the experience and knowledge of design engineers. The scales of 1, 3, 5, 7 and 9 were used to for the comparison in AHP as to ensure the decision is made at a higher level of confidence. The upper triangular matrix (Table-2) was filling up based on the following rules: as *performance* is somewhat more importance than *each of use* then a=3. Reciprocal is automatically assigned to each pairwise comparison as the *construction* is less importance than *cost* then b=1/3 (Table-5).

Table-5. Pair-wise comparison of criteria with respect to overall goal.

Goal	**P**	**E**	**S**	**C**
Performance (P)	1	a=3	5	3
Ease of use (E)	1/3	1	3	1
Construction (S)	1/5	1/3	1	b=1/3
Cost (C)	1/3	1	3	1
	1.867	5.333	12.000	5.333

C. Synthesizing the pairwise comparison

The average normalized column was used to calculate the priority vector. Th element of each column of Table-5 was divided by the sum of the column. Then the element in each row was added and averaged. The summarize of the calculation is shown in Table-6.

Table-6. Synthesized matrices for the customer requirement.

	P	**E**	**S**	**C**	**Total row**	**Priority vector (PV)**
Performance (P)	0.536	0.563	0.417	0.563	2.077	0.519
Ease of use (E)	0.179	0.188	0.250	0.188	0.804	0.201
Construction (S)	0.107	0.063	0.083	0.063	0.315	0.079
Cost (C)	0.179	0.188	0.250	0.188	0.804	0.201

D. Evaluation of consistency

Since the comparison was carried out by human and based on vague information, some degree of in inconsistency is allowed in AHP. To ensure the judgment was made within the allowable inconsistency, the consistency of decision was measured by consistency ratio (CR). It is a ratio of consistency index (CI) to the random index (RI) for the same order matrices. The first step for computing CR was determining the eigenvalue (λ_m), followed by determining the CI. The example of λ_m computation for customer requirements in the motorcycle tire dismounting tool is shown below and summarised in Table-7.

Calculation of the new vector (NV)

$$0.519\begin{bmatrix}1\\1/3\\1/5\\1/3\end{bmatrix}+0.201\begin{bmatrix}3\\1\\1/3\\3\end{bmatrix}+0.079\begin{bmatrix}5\\3\\1\\3\end{bmatrix}+$$

$$0.201\begin{bmatrix}3\\1\\1/3\\1\end{bmatrix}=\begin{bmatrix}2.119\\0.812\\0.317\\0.812\end{bmatrix}$$

Once the new vector was obtained, the λ_m was calculated with the following formula, $\frac{1}{n}\sum_{i=1}^{n}\frac{NV_i}{PV_i}$

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$$\lambda_{max} = \left(\frac{2.119}{0.519} + \frac{0.812}{0.201} + \frac{0.317}{0.079} + \frac{0.812}{0.201}\right)/4$$

$$\lambda_{max} = (4.080 + 4.040 + 4.013 + 4.040) = 4.044$$

Then, the Consistency Index (CI) was calculated

$CI = \frac{(\lambda_{max} - n)}{(n-1)}$, n is the matrix size,

Therefore, $CI = \frac{(4.044-4)}{(4-1)} = 0.044$

Finally, Consistency Ratio (CR) was calculated

$$CR = \frac{CI}{RI} = \frac{0.044}{0.9} = 0.017$$

Since CR < 0.1 then the judgments is acceptable.

Table-7. Consistency tests for the customer requirements.

Customer requirement	P	E	S	C	Priority vector (PV)	New vector (NV)	NV/PV	
Performance (P)	1	3	5	3	0.519	2.119	4.080	Consistency index CI = (λ_m-n) / (n -1) =0.015
Ease of use (E)	1/3	1	3	1	0.201	0.812	4.040	
Construction (S)	1/5	1/3	1	1/3	0.079	0.317	0.079	Consistency ratio CR = CI/RI =0.017
Cost (C)	1/3	5	5	1	0.201	0.812	0.040	
					Total (Σ)		16.174	Acceptable because CI=1.7%<10%
				Maximum Eigenvalue (λ_m)			4.044	

Repetition of steps for AHP analysis

The steps in A until D were repeated for the attributes at level-III and IV as referred to Figure-2. The elements in Tables 8-12 represents the results of consistency test for the attributes at level-III and alternative solutions at level-IV for the concept selection of the motorcycle dismounting tool. Meanwhile, Table-13 provides the attributes of all alternative solutions for supporting decision maker to made pair wise comparison among alternative solutions. The overall score of each design concept is shown in Table-14.

Table-8. Consistency test for the design attributes with respect to performance requirement.

Attribute						
Performance (P)	LO	OS	Priority vector (PV)	New vector (NV)	NV/PV	
LO	1	1	0.500	1	2.00	Consistency index, CI = (λ_m-n)/(n -1) =0
OS	1	1	0.500	1	2.00	
			Total (Σ)		4.00	Consistency ratio CR = CI/CR = 0
			(λ_m)		2.00	Acceptable because CI=0%<10%

Table-9. Consistency test for the design attributes with respect to ease of use requirement.

Sub-criteria								
Ease of use	OM	LO	WP	OS	Priority vector (PV)	New vector (NV)	NV/PV	
OM	1	5	2	7	0.512	2.094	4.090	Consistency index CI =(λ_m-n)/(n -1) =0.015
LO	1/5	1	1/5	1	0.081	0.323	4.007	
WP	1/2	5	1	5	0.335	1.357	4.054	Consistency ratio CR = CI/CR = 0.017
OS	1/7	1	1/5	1	0.073	0.293	4.031	
Total					Total (Σ)		16.182	Acceptable because CI=1.7%<10%
					(λ_m)		4.045	

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Table-10. Consistency test for the design attributes with respect to construction requirement.

Sub-criteria						
Construction	**OM**	**LO**	**Priority vector** (PV)	**New vector** (NV)	**NV/PV**	
OM	1	3	0.750	1.500	2.000	Consistency index CI = (λ_m-n) / (n -1) =0
LO	1/3	1	0.250	0.500	2.000	
				Total (Σ)	4.000	Consistency ratio CR = CI/CR = 0
				(λ_m)	2.000	Acceptable because CI=0%<10%

Table-11. Consistency test for the design with respect to cost requirement.

Sub-criteria								
Cost	**OM**	**LO**	**WP**	**OS**	**Priority vector** (PV)	**New vector** (NV)	**NV/PV**	
OM	1	5	7	5	0.615	2.652	4.309	Consistency index CI = (λ_m-n) / (n -1) =0.054
LO	1/5	1	5	1	0.179	0.736	4.103	
WP	1/7	1/5	1	1/3	0.057	0.230	4.034	Consistency ratio CR = CI/CR = 0.06
OS	1/5	1	3	1	0.148	0.622	4.199	
						Total (Σ)	16.645	Acceptable because CI=6%<10%
						(λ_m)	4.161	

Table-12. Consistency test for the alternative solution with respect to operation mode, locking mechanism, working posture and operation step.

Operation mode (OM)	**Concept 1**	**Concept 2**	**Concept 3**	**PV**	**NV**	**NV/PV**	
Concept 1	1	3	1	0.429	1.286	3.000	CI=0
Concept 2	1/3	1	1/3	0.143	0.429	3.000	CR=0
Concept 3	1	3	1	0.429	1.286	3.000	
Locking mechanism (LO)	Concept 1	Concept 2	Concept 3	PV	NV	NV/PV	
Concept 1	1	3	9	0.600	2.025	3.057	CI=0.015
Concept 2	1/3	1	5	0.333	0.809	3.026	CR=0.025
Concept 3	1/9	1/5	1	0.067	0.192	3.005	
Working posture (WP)	Concept 1	Concept 2	Concept 3	PV	NV	NV/PV	
Concept 1	1	1	5	0.455	1.364	3.000	CI=0
Concept 2	1	1	5	0.455	1.364	3.000	CR=0
Concept 3	1/5	1/5	1	0.091	0.273	3.000	
Operation steps (OM)	Concept 1	Concept 2	Concept 3	PV	NV	NV/PV	
Concept 1	1	1/3	1/5	0.106	0.320	3.011	CI=0.019
Concept 2	3	1	1/3	0.260	0.790	3.033	CR=0.033
Concept 3	5	3	1	0.633	1.946	3.072	

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Table-13. Attribute of the alternative solution.

Sub-criteria / Design	Operation steps (OS)	Locking mechanism (LO)	Working posture (WP)	Operation mode (OM)
Concept 1	6 steps	Mechanical locking	standing	rotate the tire
Concept 2	5 steps	Rim clamping	standing	rotate the lever
Concept 3	3 steps	None	squatting	rotate the tire

Table-14. Overall priority vector for the alternative solutions with respect to the selection criteria.

				PV			Score (Wt1 x Wt2 x PV)		
Criteria	**Sub-criteria**	**Wt1**	**Wt2**	**C1**	**C2**	**C3**	**C1**	**C 2**	**C 3**
Performance	Operation steps	0.519	0.500	0.106	0.260	0.633	0.028	0.067	0.164
	Locking mechanism	0.519	0.500	0.600	0.333	0.067	0.156	0.086	0.017
Ease of use	Operation mode	0.201	0.512	0.429	0.143	0.429	0.044	0.015	0.044
	Locking mechanism	0.201	0.081	0.600	0.333	0.067	0.010	0.005	0.001
	Working posture	0.201	0.335	0.455	0.455	0.091	0.031	0.031	0.006
	Operation step	0.201	0.073	0.106	0.260	0.633	0.002	0.004	0.009
Simple construction	Operation mode	0.079	0.750	0.429	0.143	0.429	0.025	0.008	0.025
	Locking mechanism	0.079	0.250	0.600	0.333	0.067	0.012	0.007	0.001
Low cost	Operation mode	0.201	0.615	0.429	0.143	0.429	0.053	0.018	0.053
	Locking mechanism	0.201	0.179	0.600	0.333	0.067	0.022	0.012	0.002
	Working posture	0.201	0.057	0.455	0.455	0.091	0.005	0.005	0.001
	Operation step	0.201	0.148	0.106	0.260	0.633	0.003	0.008	0.019
		Total score					0.390	0.266	0.344
		Ranking					1	3	2

CONCLUSIONS

This paper presents the application of AHP in the selection process of a motorcycle dismounting tool. The selection is based on the 4 criteria (level II) and 4 sub-criteria (level III) for three design alternative. The CI for each comparison of criteria is checked based on the AHP. The adjustment of the assigned value for each comparison was carried out when the CI more than allowable inconsistency which varies dependent on the size of matrices. Finally, the concept-1 was selected the best design concept for the motorcycle tire dismounting tool as it receives the highest score as shown in Table-14. AHP have the capability to ensure the robust multi-criteria design concept selection with the assistance of the CI.

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