APPLICATION OF ANALYTICAL HIERARCHY PROCESS TO THE SELECTION OF AUTOMOBILE SCREW JACK

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ABSTRACT
In this study, Analytical Hierarchy Process (AHP) was employed to determine the most preferred among four existing automobile screw jacks. The criteria considered were safety, ease of use, portability, capacity and cost. Pairwise comparison matrices of the different design concepts were obtained through a survey conducted using a well-planned questionnaire. A total of 56 auto technicians including mechanics, vulcanizers and drivers within Benin City metropolis participated as research subjects. Pairwise comparison matrices for the respective criteria as well as pairwise comparison matrices for the alternatives with respect to each criterion were obtained by finding the mean of the response of the respondents. Analysis put forward shows that that the scissor jack with side support is the most preferred with an overall priority value of 0.304. The capacity of the screw jack was returned as the most important criteria in screw jack selection. Sensitivity analysis shows that the decision is consistent when the weights of the criteria were perturbed.

Keywords: AHP, screw jack, pairwise comparison, Kendall coefficient of concordance, eigenvalue

1. INTRODUCTION

It is quite a difficult task when selecting the right design concepts among many options in product development process. According to Xu et al (2007), implementing appropriate evaluation and decision tools should be considered at the conceptual design stage that involves many complex decision-making tasks. One of the useful tools that can be employed in decision making is the Analytic Hierarchy Process (AHP). The AHP, developed at the Wharton School of Business by Dr. Saaty, 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 address multi-criteria decision making problems 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 (Xu, 1985). Generally, implementing AHP is based on experience and knowledge of the experts to determine the factors affecting the decision process. According to Hajeeh and Al-othman (1985), AHP is an intuitive method for formulating and analyzing decisions whereas Cheng and Li (1985) cited that AHP approach is a subjective methodology.

The analytic hierarchy process has been introduced by a number of researchers for concept design selection namely Bandelas and Anthony (2004), Hambali et al (2008) and Hambali et al (2009). Sivaros et al (2014) solved the problem of selection of appropriate unique keylessgrill locking system which complies with customer and technical requirements using analytic hierarchy process. Moreover, Hambali et al (2009) applied analytic hierarchy process in selection of automobile composite bumper beam. AHP has been applied by Mansor et al (2013) in selecting material of thermoplastic matrix for hybrid natural fibre/glass fibre polymer composites. Laemlaksakul and Bangsarantrip (2008) presented the use of AHP to furniture design selection problem. An economic analysis using combined simulation and AHP has been used to reach a final decision of conceptual design by Ayag (2005)

Automobile technicians and private owners of cars use the screw jack frequently. Specifically for auto technicians, the device is deployed on a daily basis. The choice of a screw jack that meets their need is a daunting one requiring consideration of a number of criteria. In this study, the application of AHP as a guide in selecting the best design concept among four existing designs is presented using the following criteria namely, safety, ease of Use, portability, capacity and cost.

2 SCREW JACKS

A screw **jack** is a mechanical device used as a lifting tool to lift heavy loads or apply great forces. It consists of a screw and a nut. The nut is fixed in a cast iron frame and remains stationary. A **mechanical jack** employs a screw thread for lifting heavy equipment. The most common form is a **car jack**, **floor jack** or **garage jack** which lifts vehicles so that maintenance can be performed. Mechanical jacks are usually rated for a maximum lifting capacity (for example, 1.5 tons or 3 tons). More powerful jacks use hydraulic power (hydraulic jacks) to provide more lift over greater distances and can be rated for many tons of load. A hydraulic jack uses a fluid, which is incompressible, that is forced into a cylinder by a pump plunger. Hence oil is used since it is self-lubricating and stable. The examples of screw jacks considered are:

i. scissors car jack (SCJ)
ii. motorized screw jack (MSJ)
iii. two arm screw jack (TAJ)
iv. scissors car jack with side support (SJWS)

2.1 SCISSORS CAR JACK (SCJ)

It consists of two upper and lower arms with a powered crack, a small base and a load platform. The threaded rod is rotated with the help of a power crack. Scissor car jacks usually use mechanical advantage to raise an automobile by manually rotating a power screw to move two hinged joints together, increasing the height of the assembly thereby forcing the automobile upward.

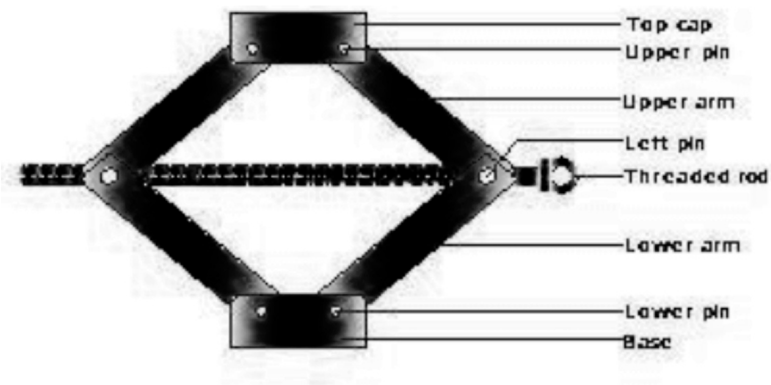

Figure 1: Scissors car jack

2.2 ELECTRICALLY OPERATED SCISSORS CAR JACK (MSJ)

It consists of two upper and lower arms with an electrical motor, a large base and a small load platform**.** Electrically operated scissor car jacks (motorized screw jack) are powered by 12 volt electricity supplied directly from the cigarette lighter receptacle of the car. The electrical energy is used to power these car jacks to raise and lower automatically. Electric jacks require less effort from the motorist for operation.

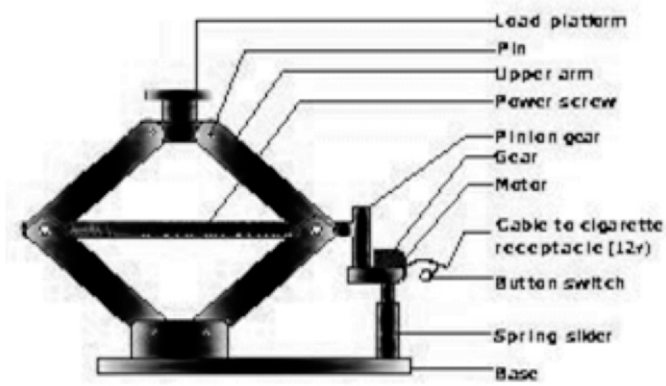

Figure 2: Electrical operated scissors car jack

2.3 TWO ARM SCREW JACK (TAJ)

A special screw jack consisting of two arms: one lower arm and one upper arm, a power crack, a small base and a load platform. Raising or lowering is achieved by manually rotating the power screw with a crack.

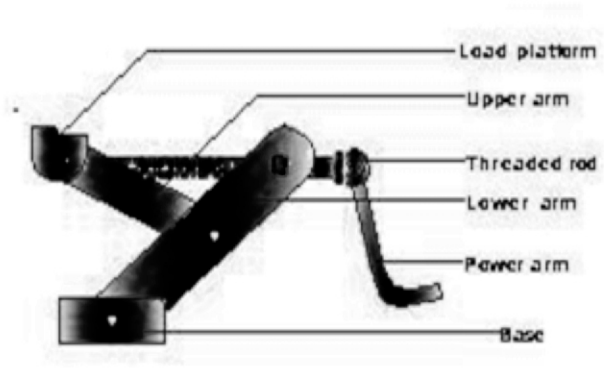

Figure 3: Two arm screw jack

2.4 SCISSORS CAR JACK WITH SIDE SUPPORT (SJWS)

It consists of a-four arm jack with side support as well as large base and load platform. Is a scissor car jack with side support and extended base making tipping less likely and collapse prevention though with an additional weight.

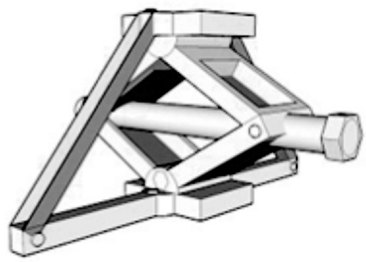

Figure 4: Scissors car jack with side support

3 METHODOLOGY

In other to obtain weights priority vectors for the criteria and alternatives with respect to each criterion, a survey was conducted using a well-planned questionnaire administered to experienced users (mechanics, vulcanizers and drivers) within Benin City. The ranking method as used by Inglehart and Abramson (1993) was implemented in the questionnaire. This method asks respondents to rank all given alternatives in a question, from the most preferred to the least, thus allowing researchers to identify a respondent's preference order for all alternatives. The order of rankings is as follows

Judgement	Number rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1

2, 4, 6, and 8 are intermediate values

3.1 DESIGN CONCEPTS EVALUATION CRITERIA

The following criteria were selected for the analysis of the different design concepts, namely safety, ease of use, portability, capacity and cost. These factors were obtained from interaction with users of screw jacks as the pertinent factors which influence the choice of a screw jack.

3.2. RESEARCH RESPONDENTS

Addresses of automobile mechanic workshops were collected from the secretariat of the National Automobile Technician Association (NATA) Uwelu and Ikpoba-Hill branches in Benin City. A total of 140 addresses were collected. A visit to these mechanic workshops reveals that some of these mechanics have relocated hence only 60 could be reached. The questionnaires were given and self-administered to these 60 respondents out of which 56 questionnaires (representing 93%) were completely and correctly filled. From the survey, more than 70% of respondent have used at least 3 out of 4 of the jacks

3.3 GENERATION OF PAIRWISE COMPARISON MATRICES

The responses of the respondents were collated in tabular form. The respective entries in the pairwise comparison matrix were obtained by summing the responses of the respondents and finding the average.

3.4. MAXIMUM EIGENVALUE

Knowledge of the maximum eigenvalue of a pairwise comparison matrix is necessary when we investigate the consistency of the opinions of the experts. In finding the maximum eigenvector we employ Satty's method of normalized arithmetic averages (Cabala, 2010). The pairwise comparison matrix (A) is normalized to form a new matrix (B). The normalized matrix B= $[b_{ij}]$ is computed according to equation (1)

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

The eigenvector [w] is calculated by calculating the arithmetic average from the row of the normalized matrix according to equation (2)

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{2}$$

The maximum eigenvector (λ_m) is then computed according to equation (3)

$$\lambda_m = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i} \tag{3}$$

3.5. CONSISTENCY RATIO (CR)

To guarantee that the judgments of the respondents are consistent, it is important to determine the consistency ratio of the pairwise comparison matrices obtained after finding the average of respondents ranking. In order to compute the consistency ratio, the consistency index is computed using the expression

$$CI = \frac{\lambda_m - n}{n-1} \tag{4}$$

In equation 4, n represents the order of the pairwise comparison matrix. The consistency ratio is then computed by finding the ratio between the consistency index and a Random index (RI).

$$CR = \frac{CI}{RI} \tag{5}$$

The RI depends on the order of the matrix (n) and is obtained from Table 1

Table 1: Random Index

Matrix size (n)	1	2	3	4	5	6	7
Radom index (RI)	0	0	0.58	0.9	1.12	1.24	1.32

The consistency ratio is a very important parameter in analytical hierarchy process. If the consistency ratio of a pairwise comparison matrix is determined and it is found to be greater than 0.1, then the judgment of the expert is said to be inconsistent, necessitating revision of the evaluation of the expert.

3.6 KENDALL COEFFICIENT OF CONCORDANCE (W)

In other to determine the level of agreement among respondents ranking, Kendall Coefficient of Concordance was determined using the data obtained from the survey. Mathematically, it is given as according to (Lewis and Johnson, 1971) as:

$$W = \frac{12S}{m^2\left(n^3 - n\right)} \tag{6}$$

Where, S = sum of squared deviations
m = number of evaluators (respondents)
n = number of items being ranked

3.7. ANALYSIS OF DATA

The hierarchy of the problem is shown in Figure 5. The data obtained from the 56 respondents under each question in the questionnaire was averaged and used for the analysis.

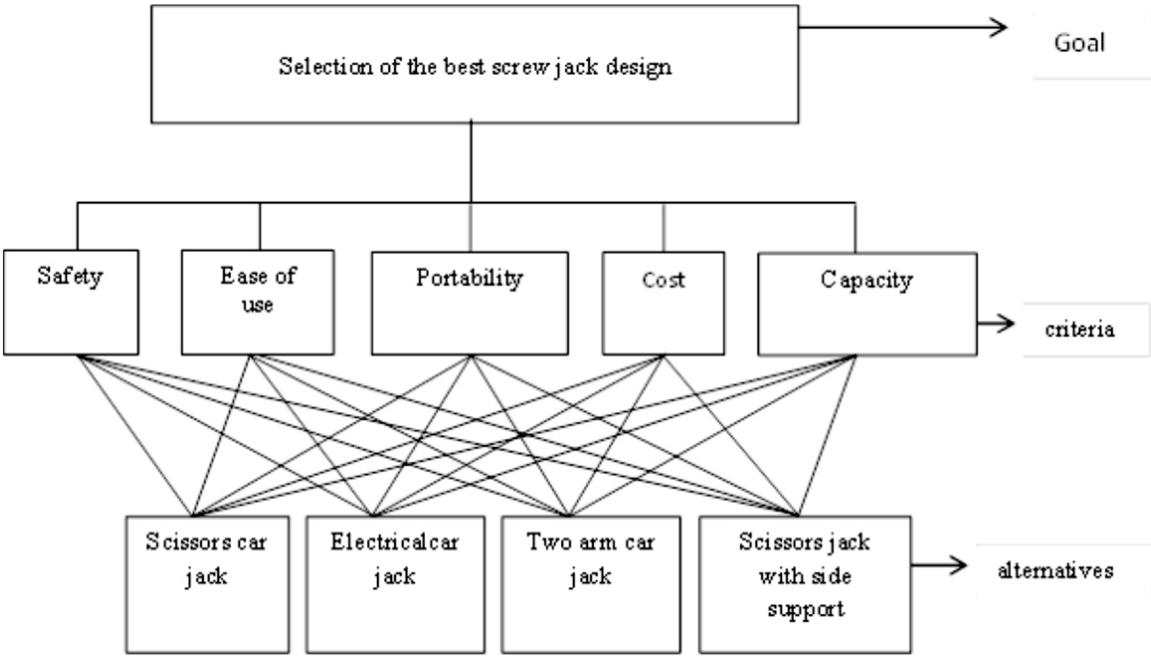

Figure 5: Hierarchical structure of decision problem

3.8 SENSITIVITY ANALYSIS

It is important to investigate the effect of perturbations on the decision which has been established using the analytic hierarchy process. To achieve this, the criteria weights are perturbed and the effect of the perturbation on the decision observed.

4.0 RESULTS

In order to check the agreement between the levels of importance given by each respondent for the different criteria, Kendall's coefficient of Concordance was computed. The coefficient of concordance of the ranking of the five criteria was 0.77. Since the value is greater than 0.5. The ratings of the respondents are in agreement. The pair-wise comparisons of the criteria obtained are shown in Table 2, while the pairwise comparisons of the alternatives with respect to each criterion are shown in Tables 3 to 7.

Table 2: Pairwise Comparison of Criteria

Criteria	Safety	Ease of use	Portability	Capacity	Cost
Safety	1.0000	1.6640	2.0100	0.8440	3.1970
Ease of use	0.6010	1.0000	1.2080	0.5070	1.9210
Portability	0.4980	0.8280	1.0000	0.4200	1.5900
Capacity	1.1850	1.9710	2.3810	1.0000	3.7870
Cost	0.3130	0.5210	0.6290	0.2640	1.0000

Table 3: Pairwise Comparison of Alternatives with respect to Safety

Safety	SCJ	MSJ	TAJ	SJWS
SCJ	1.000	0.524	1.307	0.621
MSJ	1.908	1.000	2.492	1.184
TAJ	0.765	0.401	1.000	0.545
SJWS	1.611	0.844	1.834	1.000

Table 4: Pairwise comparison of alternatives with respect to ease of use

Ease of use	SCJ	MSJ	TAJ	SJWS
SCJ	1.000	1.196	0.973	1.175
MSJ	0.836	1.000	0.813	0.982
TAJ	1.028	1.230	1.000	1.207
SJWS	0.851	1.019	0.828	1.000

Table 5: Pairwise Comparison of Alternatives with respect to Portability

Portability	SCJ	MSJ	TAJ	SJWS
SCJ	1.000	2.005	0.898	2.222
MSJ	0.499	1.000	0.448	1.109
TAJ	1.114	2.233	1.000	2.476
SJWS	0.450	0.902	0.404	1.000

Table 6: Pairwise Comparison of Alternatives with respect to Capacity

Capacity	SCJ	MSJ	TAJ	SJWS
SCJ	1.000	1.037	1.586	0.488
MSJ	0.964	1.000	1.528	0.470
TAJ	0.631	0.654	1.000	0.308
SJWS	2.050	2.126	3.250	1.000

Table 7:: Pairwise Comparison of Alternatives with respect to Cost

Cost	SCJ	MSJ	TAJ	SJWS
SCJ	1.000	2.113	0.768	1.384
MSJ	0.473	1.000	0.363	0.655
TAJ	1.303	2.752	1.000	2.103
SJWS	0.722	1.526	0.476	1.000

The priority vectors for each alternative with respect to the five criteria were obtained by normalizing the pairwise comparison matrices in Tables 3 to 7.

4.1. OVERALL PRIORITY RANKING

The overall priority vector was obtained by multiplying the priority vector for the design alternatives by the priority vector of the criteria. Table 8 shows the overall priority vector for the alternatives with respect to the five criteria.

Table 8: Overall Priority Vector for the Alternatives with respect to the Criteria

	Safety	Ease of use	Portability	Capacity	Cost	Priority
Alternatives/criteria weights	0.278	0.167	0.138	0.329	0.087	
Scissors screw jack	0.190	0.269	0.326	0.215	0.284	0.238
Motorized screw jack	0.363	0.225	0.163	0.208	0.134	0.241
Two arm screw jack	0.151	0.277	0.364	0.136	0.384	0.217
Scissors screw jack with Side support	0.296	0.229	0.147	0.441	0.198	0.304

5. DISCUSSION

The respective pairwise comparison matrices with respect to the criteria and the pairwise comparison of alternatives with respect to each criterion were obtained and subjected to consistency test. For all pairwise comparison matrices the consistency ratio was less than 0.1. This conferred reliability on the opinions of the research subjects. The result of further analysis shows that the capacity of the screw jack is the most important factor considered by potential buyers of screw jack. The reason for this may be because users want to be able to use the jack for vehicles of different sizes. Computation of the priority vector of criteria shows that cost is the least important factor considered. Table 8 shows that the scissors screw jack with side support has the highest priority value of 0.304. The second highest is the motorized screw jack with a value of 0.241 followed by the scissors screw jack with a value of 0.238 and finally the two arm screw jack with a value of only 0.217 (21.7%)***. The*** scissors screw jack with side support is the preferred choice since it has the highest value among four alternatives. However, in terms of cost, ease of use and portability, the two arm jack appears to be more preferred alternative while the motorized screw jack is the preferred alternative in terms of safety. It is important to investigate the effect of perturbations on the criteria weights to the final decision on the most preferred screw jack design. Specifically, we note that the weights of the different criteria obtained from the pairwise comparison of the criteria namely safety, ease of use, portability, capacity and cost are 0.278, 0.167, 0.138, 0.329 and 0.087 respectively. With this setting the analysis put forward the scissors screw jack with side support as the most preferred alternative. The priorities of the criteria were perturbed to safety (0.108), ease of use (0.21), portability (0.170), capacity (0.404) and cost (0.107) and the most preferred alternative was still the scissors screw jack with side support with a priority of 0.305. In order to rule out the possibility that the weight of capacity which was highest in the original analysis and in the sensitivity analysis carried out was responsible for the consistency in the decision, a further sensitivity analysis was carried out with the following setting of criteria weights, namely, safety (0.55), ease of use (0.13), portability (0.12), capacity (0.14) and cost (0.06). The result of this sensitivity analysis also showed that the scissors screw jack with side support was the most preferred with a priory value of 0.2859 as shown in Table 9

Table 9: Result of sensitivity analysis

	Safety	Ease of use	Portability	Capacity	Cost	Priority
Alternatives/criteria weights	0.550	0.130	0.120	0.140	0.060	
Scissors screw jack	0.190	0.269	0.326	0.215	0.284	0.2251
Motorized screw jack	0.363	0.225	0.163	0.208	0.134	0.2855
Two arm screw jack	0.151	0.277	0.364	0.136	0.384	0.2034
Scissors screw jack with Side support	0.296	0.229	0.147	0.441	0.198	0.2859

15. CONCLUSIONS

The analytic hierarchy process has been used to determine the most preferred screw jack design among four alternatives. The capacity of the jack is the most important consideration in making a choice for a screw jack. Analysis put forward shows that the scissors screw jack with side support is the most preferred alternative even with perturbations in the weights of the criteria.

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