*Original Research Article*

# A Comparative Study on Suitability of AHP and TOPSIS for Identifying optimal Conceptual Design of Bearing Puller




## Abstract

Design process of the bearing puller involves various stages that can be grouped into conceptualization of ideas based on design criteria and functional requirements. This is followed by concept generation and selection for optimal design. Concept selection is an important activity in engineering design process, because it involves decision making considering various factors. In this project, computer aided design of four bearing puller was developed after a thorough consideration of the design criteria and factors of an optimal design. Analytic Hierarchy Process (AHP) and Technique for order of preference by similarity to ideal solution (TOPSIS) were used in order to ascertain their suitability for selecting optimal design in engineering. The result obtained from the comparison process proves that both processes are suitable because there are no ties in the final selection of the optimal design concept. The AHP and TOPSIS shows the same design concept irrespective of the processes. This is an indication that both concept selection process considered the weight factor of the level of importance of functional requirement or design criteria. In view of this, it has been proven that whenever the weigh factor remains the same, both processes will give the same result, at least for the considered case. This result may vary when they are both applied for design process of other products


**Keywords**: Analytic Hierarchy Process, TOPSIS, Multicriteria Decision Making, Bearing Puller, Design Concept selection

## 1.0 Introduction

Design analysis is an integral part of any engineering design as it will tell if a proposed or conceptualized design can serve the purpose for which it was designed, or it will fail at the point of service [1]. The design process is highly iterative and requires evaluation of ideas, designing, and redesigning to achieve an optimal design. Engineering design process starts with concept generation [2-3]. A concept is simply an idea that is sufficiently developed. Concept generation at early stage is considered to be the most difficult, sensitive and critical design part in creating products. It greatly influences the cost, robustness, manufacturability, and development time of the final products. As a rule of thumb, the cost of engineering changes increases by ten times when changes are made in a later stage [4-5]. The stage of concept generation and evaluation should minimize the possibility of misrepresenting a solution, which may actually be effective, and consider different ramification of a final decision. It is a vital and important stage in product development as it is often carried out multiple times using different methods throughout the design process. The task in the conceptual phase encompasses specifications of functional requirements, generation of design concepts using drafting tools, and selection of concepts. In the specification stage, the functional requirements of the product are analyzed alongside with the financial and manufacturing requirements [6].

Analytic Hierarchy Process (AHP) is a multi-criteria-decision making methodology which involves measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. The concept with the highest priority is regarded as the best concept. This method is used in order to determine the overall score or priority of each concept relative to other concepts, and functional requirements. The priority for each concept is equal to the principal right eigenvector [7-8]. The Technique for order preference by similarity to ideal solutions (TOPSIS) is a multi-attribute based on the concepts that the chosen alternative should have the shortest Euclidean distance from ideal solution and the farthest from negative ideal solution. The ideal solution in this method is such that the hypothetical solution for which all attribute values correspond to the maximum attribute values in the database comprising the satisfying solution. Invariably, it gives a solution that is not only closest to the hypothetically best, but farthest from hypothetically worst [9]. The aim of this article is to a carry out a comparative study on the application of AHP and TOPSIS for the design process of bearing puller in order to ascertain if the two multi-attribute decision models will obtain the same results on the choice of optimal design concept. Hence, the design criteria, functional requirements and sub-factors required for the optimal design of a bearing puller are identified and CAD models of different design concepts of bearing puller was developed for the comparative analysis. The AHP and TOPSIS process was applied to compare the design concepts in order to ascertain the suitability of the two processes in selecting the optimal design [10].

The bearing puller has got lots of application in the automobile industry, aircraft as well in production machines used in manufacturing processes. It is also required in the installation and removal of gears in a gear box. Since manufacturing plants and equipment run with gears, maintenance operations are often required in replacing worn out gears or bearing. The use of bearing puller reduces manual work, thereby saving human energy that could be expended in hammering. It is cost effective and increases productivity. Most importantly, it prevents damage to the bearing that may result from hammering. The surface of the bearing and the shaft is preserved against indentations. In addition to its importance, the safety of both operator and machine elements are guaranteed. In the hydraulic bearing puller machine, pressure is developed with the aid of the integrated hand pump. It uses highly viscous oil which is passed to the cylinder through the hose. The translational movement of the piston is controlled by hand lever or an automated oil release valve. The knob is used in adjusting the speed of the piston that pushes the shaft as the jaws fitly clamp on the bearing for pulling [11].

The AHP provides a convenient approach for solving complex MCDM problems in engineering by decomposing the decision-making problem into a system of hierarchies of objectives, attributes and alternatives [12]. An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. Olabanji and Mpofu [13], affirmed that AHP is used to select from competing alternatives, allocation of scarce resources, and forecasting, but in the cases analyzed, it was observed that it is used mainly to weigh criteria and selecting and ranking alternatives. Olabanji, [14] opined that the main problem with the pairwise comparisons is how to quantify the linguistic choices selected by the decision maker during their evaluation. All the methods which use the pairwise comparisons approach eventually express the qualitative answers of a decision maker into some numbers which, most of the time, are ratios of integers. The Analytic Hierarchy Process is a strategic decision-making tool to justify optimum selection [15]. Machine tool selection has strategic implications that contribute to the manufacturing strategy of a manufacturing organization. In such a case, it is important to identify and model the links between machine tool alternatives and manufacturing strategy. Hierarchical decision structures are formed in the application of the AHP and Analytic Network Process (ANP) approaches. Ranking scores which are used to rank the alternatives are obtained as outcomes of the applications.

Application of the AHP approach also enabled the incorporation of interdependencies among the components of decision structures [16-17].

The TOPSIS model proposes that the best concept or choice in any decision making should have the shortest distance from the ideal solution, and the farthest from the negative-ideal solution [18]. It is a multi-criteria decision-making tool has been successfully applied to the areas of supplier evaluation and selection, facility location selection, robot selection, inter-company comparison, expatriate host country selection, partner selection, risk assessment, operating system selection, software outsourcing problems, customer evaluation, weapon selection, performance evaluation, etc., [19]. Roszkowska, [20] proposed that TOPSIS technique is helpful for decision makers to structure the problems to be solved, conduct analyses, comparisons and ranking of the alternatives. The classical TOPSIS method solves problems in which all decision data are known and represented by crisp numbers [21-22]. Most real-world problems, however, have a more complicated structure. According to Wang *et al.*, [23], supplier selection or evaluation is the process of finding the supplier who is able to provide the customer with the products or services that have the right quality, the right price, the right quantity and at the right time. The TOPSIS model is a powerful technique that is used whenever an alternative is required to be selected among others, regardless of suitability of the desired alternative. In the past decade, TOPSIS has been successfully applied to the areas of supplier evaluation and selection, inter-company comparison, expatriate host country selection, risk assessment, facility location selection, robot selection, operating system selection, software outsourcing problems, partner selection, customer evaluation, weapon selection, performance evaluation [19, 24].

## 2.0 Methodology

Figure 1 shows the framework containing the design factors and sub factors and the four conceptual designs of the bearing puller. The TOPSIS and AHP methods were applied separately and the results were compared.

### 2.1 Design and Functional Requirements of Bearing Pulling Machine

When selecting a puller for use, it is important to consider these three basic features:

**2.2 Spread:** is the distance between the jaws. The puller's spread needs to be greater than the diameter of the bearing being pulled.

**2.3 Reach:** The Reach is the distance between the bottom of the base and the jaw flats. The puller's reach must be equal or exceed the same distance of the part being pulled. The reach which is a function of the length of the jaw/legs is inversely proportional to the clamping force. Careful adjustment should be made to achieve fast and efficient separation of bearing-shaft for the safety of both the user and the bearing.

**2.4 Capacity:** It refers to is the amount of force the puller is capable of producing. Typically, the capacity required for a job can be determined by using the shaft diameter of the part being pulled. For hydraulic pullers, the capacity in tons should be 0.28 to 0.4 times the shaft diameter. The specification chart below serves as guide in selecting a bearing puller capacity for use.

However, in the design of bearing pullers, to meet certain standard and specification of functional requirement, some other factors are worth consideration. To avoid variability and ensure fairness in evaluating each design, the factors and some sub-factors, common to the designs are further discussed.

### 2.5 Clamping/Pulling Force

**i. Jaw length**: it refers to the length of the puller legs. There is an inverse relationship between the jaw length and the amount of pulling force. With a shorter jaw, the pulling strength of the bearing puller is greater and vice versa. However, design consideration should allow for adjustability of the jaw length based on the variation in the reach the puller it is expected to serve.

**ii. Gripping force control**: the geometry of the puller jaw to some extent has direct effect on the grip of the bearing puller. For effective gripping, the jaw geometry is better designed with flat tips, especially in case of the 3-jaw puller.

**iii. Bearing seat/Pulling Jaw geometry**: the bearing seat provides convenience for separation. It is placed behind the part to secure a gripping surface, even when the clearance are extremely limited. Its size is adjustable to accommodate various bearing diameter. In case of the pulling jaws, the thicker the jaw edge, the greater the pulling force.

**iv. Hydraulic force**: the hydraulic force produced during pulling to some extent depends on the size of the cylinder. More fluid pressured in the cylinder means more force. For special industrial purpose, hydraulic puller with large hydraulic cylinders is used to achieve sufficient pulling force.

**v. Stability in operation:** the stability of the bearing puller during operation greatly depends on the design complexity and jaw, pulling leg geometry. The three-jaw bearing puller has more stability than the two-jawbearing puller. However, the two-legged bearing puller with splitter provides greater balance during operation.

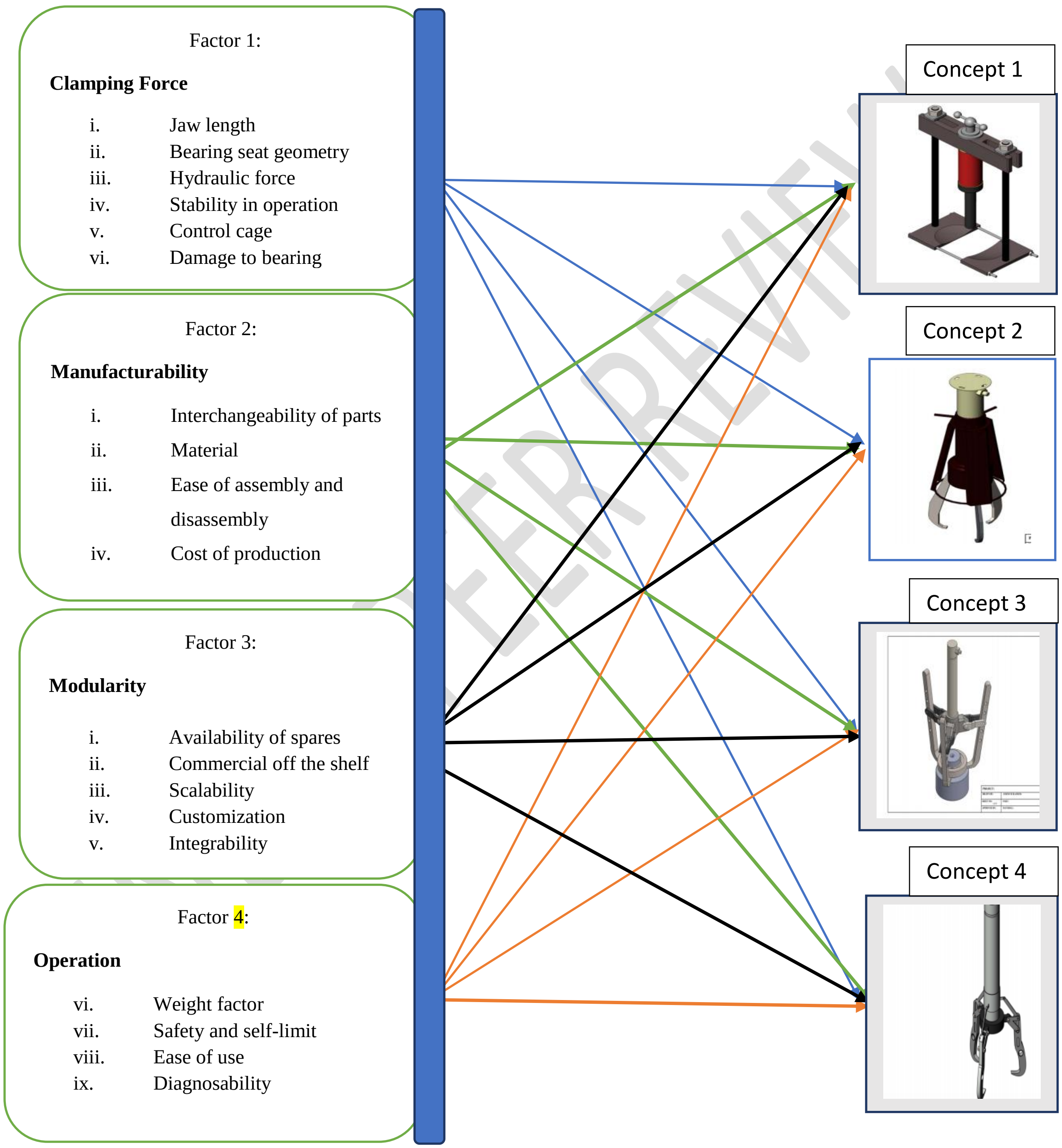
Factor 1:
Clamping Force
i. Jaw length
ii. Bearing seat geometry
iii. Hydraulic force
iv. Stability in operation
v. Control cage
vi. Damage to bearing
Factor 2:
Manufacturability
i. Interchangeability of parts
ii. Material
iii. Ease of assembly and disassembly
iv. Cost of production
Factor 3:
Modularity
i. Availability of spares
ii. Commercial off the shelf
iii. Scalability
iv. Customization
v. Integrability
Factor 4:
Operation
vi. Weight factor
vii. Safety and self-limit
viii. Ease of use
ix. Diagnosability
Concept 1
Concept 2
Concept 3
Concept 4

Figure 1. Framework for the application of the AHP and TOPSIS to the conceptual designs of Bearing puller

**vi. Control cage:** the control cage functions as to prevent the legs/ jaws from spreading beyond limits during operation. It provides safety and precision of asserted force. Observation also shows that the control cage helps to augment the applied force.

**vii. Damage to bearing:** a major reason for engaging the use of bearing puller machine in pulling bearings is to overcome the effect of damage caused by hammering in the traditional method. The configuration of the jaw during design can help prevent damage to bearing during operation.

### 2.6 Manufacturability

**i. Interchangeability of parts:** this refers to the flexibility of the design components to adapt for use in another model of design. In design for manufacturability, standardization is necessary to avoid variation in spares and accommodate for interchangeability of one part in one machine to another.

**ii. Material:** in engineering, one major consideration in design is the selection of material from which a component is to be produced. It determines the strength and failure of the component or machine. The material commonly used for most hydraulic bearing pullers are design with chromium steel. This calls for high strength in pulling

**iii. Ease of assembly and disassembly:** when designing a machine or component, the designer bears in mind the ease of assembly and disassembly. Design for assembly implies conformity for assembly to avoiding damage of parts during assembly or disassembly and complexity of components should be reduced.

**iv. Cost of production:** this is a function of the complexity in design, cost of raw materials, direct or indirect labour cost. The cost of producing the 3-jaw puller is greater than that for 2-jaw puller. However, the complexity of the geometry of the jaw puller will increase the cost beyond that of a bearing puller with rods as pulling legs.

**v. Complexity of design:** the 3-jaw bearing puller has a complex design compared to the 2-legged bearing puller. This increases the cost of machining and time for production.

### 2.7 Modularity

Modularity is the degree with which components of a system can be separated or combined. This is a major consideration in designing for assembly and manufacturing.

**i. Availability of spares:** an optimum design is one in which the parts are readily available for replacement in the market or stores. This accounts for standardization of parts

**ii. Commercial off the shelf:** before embarking on manufacturing or adopting a design, the designer or manufacturer is faced with a make or buy decision. Given some production conditions such as availability of labour, skills, machine availability and utilization, design complexity, raw material etc. there is need to balance cost with time of production.

**iii. Scalability:** this refers to the capacity of a machine to accommodate variability in use. The bearing puller can be scaled to pull various bearing diameter. The 2-legged bearing puller is limited in the size of the bearing that can be pulled, though the bearing sit is adjustable. However, the operation of the 3-jaw bearing puller is self-adjustable upon clamping.

**iv. Customization:** customized machines increase precision, efficiency and effectiveness during operation. However, they are limited in operation adaptability. Customization will increase cost of production for a specific purpose as such design will be robust. Most industrial bearing pullers are not customized due to variation in the standard sizes of bearings in a machine.

### 2.8 Operation

**i. Weight factor:** the number of component part, material used in production as well as the design complexity affects the weight of the bearing puller. The weight of the puller also determines the ease of use by operator(s).

**ii. Safety and self-limit:** the safety of the machine is of high consideration during operation. This covers for both operator and the bearing itself. Bearing puller with modularized hydraulic cylinder is less safe for use compared to the ones with separate cylinder.

**iii. Ease of use:** the configuration of the bearing puller greatly determines the ease of use. This is dependent on the modularity of parts. Bearing puller with separate hydraulic cylinder will require two hand at use for effective and safe operation compared to that which has the cylinder directly integrated on top of the bearing puller.

**iv. Diagnosability:** This is the capability to easily detect and diagnose or troubleshoot defect in a system or machine. A very complex system is difficult to diagnose due to intricacy and number of part counts. An optimal design should easily be diagnosable and repairable in the shortest possible time.

## 3.0 Implementation of the TOPSIS and AHP Methods

### 3.1 TOPSIS Method

Each functional requirement is ranked considering experts opinion according to their level of importance using the scale of importance, each concept is scored on the scale of 1 to 5, and their corresponding percentage weight calculated. Also, the sub-functions are also carefully considered and evaluated relative to their importance in each designs concept. The percentage weight score of the function is presented in Table 1. Also, the sub-functions are also carefully considered and evaluated relative to their importance in each designs concept. Also, the design concepts were evaluated considering the average grades of the experts opinion for all the functional requirements as shown in Tables 2 to 5.

Table 1: Percentage weight score relative importance of functional requirement in Bearing Puller

| Functional Requirements/Ranking | Score | Percentage rating % |
|---|---|---|
| Clamping force | 4 | 25.00 |
| Manufacturability | 3 | 18.75 |
| Modularity | 4 | 25.00 |
| Operation | 5 | 31.25 |

Table 2: Concept evaluation with respects to clamping force

| Concept/ factors | Jaw length | Bearing seat | Hydraulic force | Stability | Control cage | Damage to work piece | Overall score |
|---|---|---|---|---|---|---|---|
| Concept 1 | 3 | 5 | 3 | 3 | 1 | 4 | 19 |
| Concept 2 | 3 | 3 | 3 | 4 | 5 | 3 | 21 |
| Concept 3 | 5 | 3 | 4 | 2 | 1 | 3 | 18 |
| Concept 4 | 4 | 4 | 4 | 4 | 3 | 4 | 23 |

Table 3. Concept evaluation with respects to Manufacturability

| Concept/ factors | Interchangeability of parts | Material | Ease of assembly & disassembly | Cost | Complexity of Design | Overall score |
|---|---|---|---|---|---|---|
| Concept 1 | 4 | 3 | 4 | 3 | 3 | 17 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Concept 2 | 3 | 3 | 2 | 2 | 2 | 12 |
| Concept 3 | 3 | 5 | 5 | 3 | 4 | 20 |
| Concept 4 | 4 | 4 | 3 | 4 | 3 | 18 |

Table 4. Concept evaluation with respects to Modularity

| | Availability of spares | Commercial off-the shelf | Scalability | Customizability | Integrability | Overall Score |
|---|---|---|---|---|---|---|
| Concept 1 | 3 | 4 | 3 | 3 | 3 | 16 |
| Concept 2 | 2 | 3 | | 4 | 2 | 14 |
| Concept 3 | 3 | 3 | 5 | 3 | 2 | 16 |
| Concept 4 | 2 | 3 | 4 | 4 | 3 | 16 |

Table 5. Concept evaluation with respects to Operation

| | Weight factor | Safety & self-limits | Ease of use/operation | Diagnosability | Overall score |
|---|---|---|---|---|---|
| Concept 1 | 4 | 4 | 2 | 4 | 14 |
| Concept 2 | 3 | 5 | 4 | 3 | 15 |
| Concept 3 | 4 | 2 | 2 | 5 | 13 |
| Concept 4 | 3 | 4 | 4 | 4 | 15 |

In the TOPSIS method, the basic principle is that the chosen alternative must have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Shirouyehzad and Dabestani, 2011). The procedure for computation and evaluation is given below:

i. Construct the normalized matrix: each element in the decision matrix is divided by the summation on corresponding colon
ii. Construct the weighted Normalized Decision Matrix
iii. Determine the Ideal and Negative-ideal Solution
iv. Calculate the separation measure
v. Calculate the relative closeness to the ideal solution

Table 6.Decision Matrix considering all the Functional Requirement

| Concepts/Functional Requirements | Clamping/Pulling force | Manufacturability | Modularity | Operation |
|---|---|---|---|---|
| Concept 1 | 19 | 17 | 16 | 14 |
| Concept 2 | 21 | 12 | 14 | 15 |
| Concept 3 | 18 | 20 | 16 | 13 |
| Concept 4 | 23 | 18 | 16 | 13 |

Table 7. Normalized Decision matrix

| Concepts/Functional Requirements | Clamping/Pulling force | Manufacturability | Modularity | Operation |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Concept 1 | 0.467 | 0.499 | 0.515 | 0.508 |
| Concept 2 | 0.516 | 0.353 | 0.451 | 0.544 |
| Concept 3 | 0.442 | 0.666 | 0.515 | 0.472 |
| Concept 4 | 0.565 | 0.529 | 0.515 | 0.472 |

Table 8. Weighted Normalized Decision Matrix

| Concepts/Functional Requirements | Clamping/Pulling force | Manufacturability | Modularity | Operation |
|---|---|---|---|---|
| Concept 1 | 0.117 | 0.093 | 0.129 | 0.159 |
| Concept 2 | 0.129 | 0.066 | 0.113 | 0.170 |
| Concept 3 | 0.110 | 0.012 | 0.129 | 0.148 |
| Concept 4 | 0.141 | 0.099 | 0.129 | 0.148 |

Table 9. Positive ideal solution, $A^+$

| Concepts/Functional Requirements | Clamping/Pulling force | Manufacturability | Modularity | Operation |
|---|---|---|---|---|
| Concept 1 | 0.117 | 0.093 | 0.129 | 0.159 |
| Concept 2 | 0.129 | 0.066 | 0.113 | 0.170 |
| Concept 3 | 0.110 | 0.012 | 0.129 | 0.148 |
| Concept 4 | 0.141 | 0.099 | 0.129 | 0.148 |

Table 10. Negative-ideal solution, $A^-$

| Concepts/Functional Requirements | Clamping/Pulling force | Manufacturability | Modularity | Operation |
|---|---|---|---|---|
| Concept 1 | 0.117 | 0.093 | 0.129 | 0.159 |
| Concept 2 | 0.129 | 0.066 | **0.113** | **0.170** |
| Concept 3 | **0.110** | **0.012** | 0.129 | 0.148 |
| Concept 4 | 0.141 | 0.099 | 0.129 | 0.148 |

Table 11. Separation measures and closeness to Ideal solution

| **Concepts** | $Si^+$ | $Si^-$ | $Si^- + Si^+$ | $Ci$ | **Concept Ranking** |
|---|---|---|---|---|---|
| Concept 1 | 0.037 | 0.083 | 0.12 | 0.691 | 2nd |
| Concept 2 | 0.062 | 0.057 | 0.119 | 0.479 | 3rd |
| Concept 3 | 0.089 | 0.027 | 0.116 | 0.233 | 4th |
| Concept 4 | 0.012 | 0.098 | 0.110 | 0.891 | 1st |

### 3.2 AHP Method

According to Olabanji and Mpofu, [7], the functions are ranked based on five levels. These levels are; *highly important*, *important*, *very necessary*, *necessary*, *and not necessary*. These levels are ranked with scores. Similarly, the concepts are rated on a level score ranging from *very good*, *good*, *average*, *fair and poor* with the same score as the function ranking. The functional requirements are rated with respect to the degree of the necessity in the final optimal design. No functional requirement was rated below the rank of very necessary, because all functions are needed in the optimal design. Having established that a good design one which considers both factors and sub-factors, in order to eliminate possibility of biasness in evaluation, the factors are compared to one another relative to their functional need in a typical bearing puller according to their scale of importance. Using the fundamental scale of pairwise comparison, each concept is compared, and their corresponding priorities are computed. The concept with the highest priority is chosen as the best concept. The priority for each concept is equal to the principal right eigenvector. In order to quantify the comparison between the concepts, each functional requirement is scored using the fundamental scale of pairwise comparison as shown in Table 12.

Table 12. Fundamental Scale for pairwise comparison

| Intensity of Importance | Definition | Brief Description |
|---|---|---|
| 1 | Equal Importance | Two concepts or functions contribute equally to the selection of best concept |
| 3 | Moderate importance | Examination of features and judgment slightly favour one concept or function over another |
| 5 | Strong importance | Examination of features and judgment strongly favour one concept or function over another |
| 7 | Very strong or Demonstrated importance | A concept or function is favored very strongly over another, and its dominance is demonstrated in practice |
| 9 | Extreme importance | The evidence favouring one concept or function numerically when it is difficult to describe by words |
| 2,4,6 | Compromise between the above values | Interpolation of compromise judgment on concepts or Function numerically when it is difficult to describe bywords |
| Reciprocals of above | If the concept or functional requirement has one of the above non-zero numbers assigned to it when compared with another concept or function, then the later concept has the reciprocal value when compared with the initial concept or function. | A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit |

The pairwise comparison matrix, normalized pairwise comparison of the design concepts based on clamping force, manufacturability, modularity and operation is presented in Table 13 alongside the principal eigen value and consistency index. Also, the comparison for the functional requirements is also presented in Table 13. The results of the ranking using AHP is presented in Table 14.

Table 13. Concept selection using the AHP method

| Design factors/Functional requirements | | Design Concepts | | | | | | | | | Principal Eigen Value $\lambda max$ | Consistency index, $C_I$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pairwise Matrix | | | | | Normalized Matrix | | | | | |
| | | C1 | C2 | C3 | C4 | | C1 | C2 | C3 | C4 | | |
| Clamping force F1 | C1 | 1 | 1/5 | 3 | 1/7 | C1 | 0.075 | 0.031 | 0.188 | 0.096 | 4.63 | 0.21 |
| | C2 | 5 | 1 | 5 | 1/5 | C2 | 0.376 | 0.156 | 0.313 | 0.135 | | |
| | C3 | 1/3 | 1/5 | 1 | 1/7 | C3 | 0.025 | 0.031 | 0.063 | 0.096 | | |
| | C4 | 7 | 5 | 7 | 1 | C4 | 0.525 | 0.781 | 0438 | 0.676 | | |
| | Sum | 13.3 | 6.4 | 16 | 1.48 | Sum | 0.098 | 0.245 | 0.054 | 0.605 | | |
| | | Pairwise Matrix | | | | | Normalized Matrix | | | | | |
| | | C1 | C2 | C3 | C4 | | C1 | C2 | C3 | C4 | | |
| Manufacturability F2 | C1 | 1 | 7 | 1/5 | 1/3 | C1 | 0.135 | 0.291 | 0.122 | 0.074 | 5.319 | 0.43 |
| | C2 | 1/7 | 1 | 1/9 | 1/7 | C2 | 0.199 | 0.047 | 0.068 | 0.032 | | |
| | C3 | 3 | 9 | 1 | 3 | C3 | 0.420 | 0.375 | 0.608 | 0.671 | | |
| | C4 | 3 | 7 | 1/3 | 1 | C4 | 0.420 | 0.292 | 0.203 | 0.223 | | |
| | Sum | 7.142 | 24 | 1.644 | 4.47 | Sum | 0.155 | 0.087 | 0.519 | 0.284 | | |
| | | Pairwise Matrix | | | | | Normalized Matrix | | | | | |
| | | C1 | C2 | C3 | C4 | | C1 | C2 | C3 | C4 | | |
| Modularity F3 | C1 | 1 | 5 | 1 | 1 | C1 | 0.313 | 0.313 | 0.313 | 0.313 | 4.013 | 0.0043 |
| | C2 | 1/5 | 1 | 1/5 | 1/5 | C2 | 0.063 | 0.063 | 0.063 | 0.063 | | |
| | C3 | 1 | 5 | 1 | 1 | C3 | 0.313 | 0.313 | 0.313 | 0.313 | | |
| | C4 | 1 | 5 | 1 | 1 | C4 | 0.313 | 0.313 | 0.313 | 0.313 | | |
| | Sum | 3.2 | 16 | 3.2 | 3.2 | Sum | 0.313 | 0.063 | 0.313 | 0.313 | | |
| | | Pairwise Matrix | | | | | Normalized Matrix | | | | | |
| | | C1 | C2 | C3 | C4 | | C1 | C2 | C3 | C4 | | |
| Operation F4 | C1 | 1 | 1/3 | 3 | 1/3 | C1 | 0.136 | 0.124 | 0.250 | 0.132 | 4.135 | 0.045 |
| | C2 | 3 | 1 | 3 | 1 | C2 | 0.409 | 0.375 | 0.250 | 0.395 | | |
| | C3 | 1/3 | 1/3 | 1 | 1/5 | C3 | 0.045 | 0.124 | 0.083 | 0.079 | | |
| | C4 | 3 | 1 | 5 | 1 | C4 | 0.409 | 0.375 | 0.417 | 0.395 | | |
| | Sum | 7.33 | 2.66 | 12 | 2.53 | Sum | 0.161 | 0.357 | 0.083 | 0.399 | | |
| Functional Requirement/ Design factors | | | | | | | | | | | | |
| | | Pairwise Matrix | | | | | Normalized Matrix | | | | | |
| | | F1 | F2 | F3 | F4 | | F1 | F2 | F3 | F4 | | |
| | F1 | 1 | 3 | 1 | 1/3 | F1 | 0.188 | 0.250 | 0.188 | 0.177 | 4.558 | 0.186 |
| | F2 | 1/3 | 1 | 1/3 | 1/5 | F2 | 0.062 | 0.083 | 0.062 | 0.108 | | |
| | F3 | 1 | 3 | 1 | 1/3 | F3 | 0.188 | 0.250 | 0.188 | 0.177 | | |
| | F4 | 3 | 5 | 3 | 1 | F4 | 0.563 | 0.417 | 0.563 | 0.538 | | |
| | Sum | 5.33 | 12.0 | 5.33 | 1.86 | Sum | 0.201 | 0.079 | 0.295 | 0.520 | | |

Table 14. Results of the AHP method

| **Functional Requirements** | | **Design Concepts** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C1 | | C2 | | C3 | | C4 | |
| Functions | function priorities (x) | concept priority (C1) | concept priority with respect to function priority (xC1) | concept priority (C2) | concept priority with respect to function priority (xC2) | concept priority (C3) | concept priority with respect to function priority (xC3) | concept priority (C4) | concept priority with respect to function priority (xC4) |
| Clamping force | 0.201 | 0.098 | 0.020 | 0.245 | 0.049 | 0.054 | 0.010 | 0.605 | 0.121 |
| Manufacturability | 0.079 | 0.155 | 0.012 | 0.087 | 0.007 | 0.519 | 0.041 | 0.284 | 0.014 |
| Modularity | 0.295 | 0.313 | 0.092 | 0,063 | 0.019 | 0.313 | 0.092 | 0.313 | 0.092 |
| Operation | 0.520 | 0.161 | 0.084 | 0.357 | 0.186 | 0.083 | 0.043 | 0.399 | 0.207 |
| Summation | ∑ X= 1.00 | ∑C1= 0.727 | ∑xC1= 0.208 | ∑C2= 0.752 | ∑ xC2= 0.261 | ∑C3= 0.969 | ∑ xC3= 0.186 | ∑C4= 1.601 | ∑ xC4= 0.342 |
| Ranking of Concepts | | **Third** | | **Second** | | **Fourth** | | **First** | |

## 4.0 Results and Discussion

The analysis considered the relative importance of each sub-functions, functional requirement to an optimal design of a bearing puller. The priority of each of the concepts relative to the importance of each functional requirement in the optimal design of a bearing puller is also considered. It is clear from Figure 2 that design concept 4 has the highest ranking than other concepts, while design concept 3 still has the least ranking using the TOPSIS method. The order in which the design concepts are ranked is in four, one, two, three. The ideal positive solution provides variation that tends to reduce the weight score of the design concepts. By determining the negative ideal solution, it is observed that concept 2 has the highest score (negative) of operational function as highlighted in Table 9. The concept with the highest score on the ideal solution has the greatest priority relative to the functional requirement. In this case, design concept 4 is the closest to the ideal solution and is also selected as the optimal design.

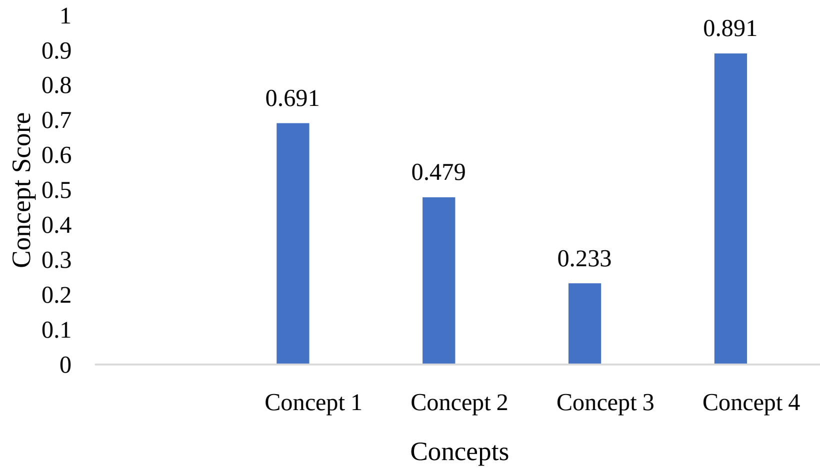


Fig 2: Concept Ranking in the TOPSIS method

Considering the analysis of AHP, there is a laudable difference in the performance of the design concept when the availability of the functional requirements is considered in the concepts. This difference reduces when comparison is made between concepts based on the importance of functional requirement in the optimal design. In view of this, it can be hypothetically stated that a design concept that will be selected or regarded as optimal should be screened by considering the functional requirement and design criteria required in the design objective. The reduction in the difference is due to the fact that the pairwise comparison reduced the weight score and assigned priorities to the concepts based on the functional requirements. Figure 3 reveals that concept 4 has the greatest clamping force and operation requirement than other concepts, making it the most ideal or optimal design. This is influenced by the weighted score of its operational function scoring 0.207, and clamping force, 0.12 on the concept evaluation and ranking table as shown in Figure 3. However, Concept 3 which provides the least stability and operation function emerged as the least in ranking, making it the least considerable or worst design. By evaluating concept relative to the design requirement, concept four has the highest score and priority followed by concept two, then concept one and lastly, concept three. Further pairwise comparison of the alternative concepts reveals that concept four emerges as the optimal design followed by concept two then concept one and lastly, concept three. The figure 3 below presents the concept scores, and their order of ranking.

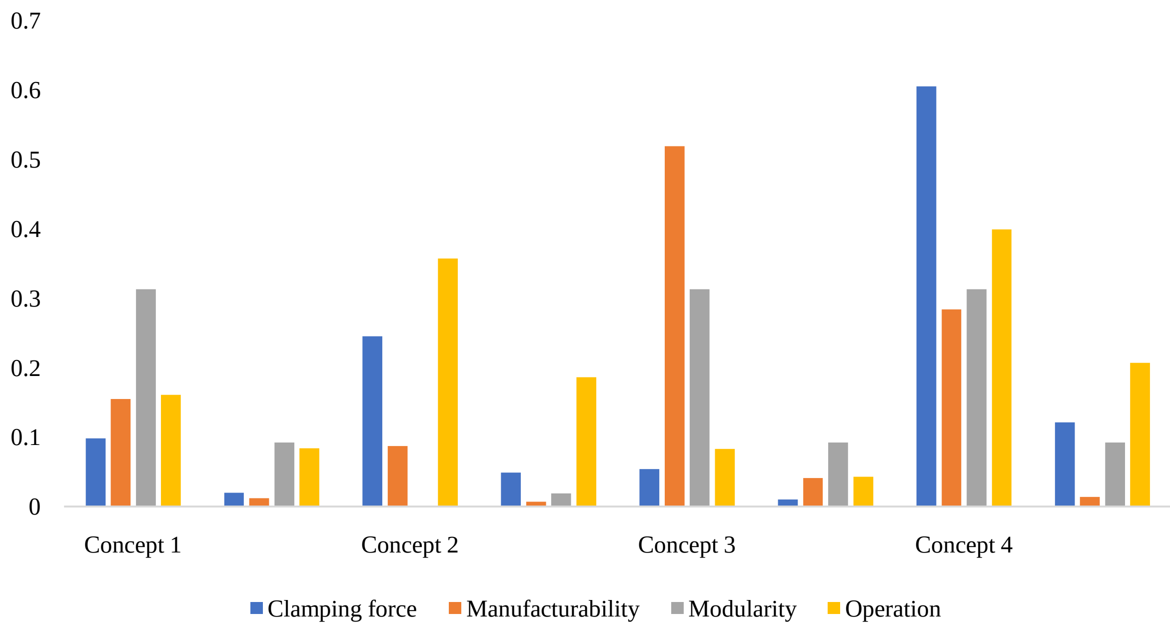


Fig 3: Concept Ranking based on the AHP method

In essence, from the analysis done, it can be concluded that the decomposition of the functional requirements into various sub-factors will assist the designer to ascertain the level of design criteria available in the design concept. Furthermore, the use of multi-criteria decision-making tools such as AHP and TOPSIS will enable designer to choose an optimal design, considering the content of the selection process. The advantage of the AHP and TOPSIS methods is that, they create a platform where the design engineer can see the performance of the design alternatives relative to the functional requirement before selecting the optimal design. This will assist in deciding on which function to improve in any of the design concepts in order to improve the design.This implies that the values obtained from the analysis is a function of the weight factors appointed to each functional requirement with respect to their level of importance in the optimal design of the bearing puller. However, if the content of the selection implies that more weight should be given to a particular functional requirement than others, different from the one carried out in this analysis, then the result that will be obtained will vary from that of this present study**.**

## 5.0 Conclusion

According to this study, we can conclude that both AHP and TOPSIS are suitable in the selection of optimal design of bearing puller. Having established that design concept 4 is the optimal design for the hydraulic bearing puller, it is noteworthy that concept selection in engineering design cannot be carried out based on intuition or decision maker's best guess. It is of high importance to adopt the multi-criteria decision-making tool to enact a fair concept judgment in the face of multiple functions. The use of

TOPSIS further reveals the consistency of concept 4 as the optimal design, confirming the result derived from the use of AHP, without wavering. Furthermore, this investigation shows that in the selection and manufacture of a bearing puller, based on demand, modification/variation can be made as to which functional need or requirement should be given priority, which can be incorporated in the design stage as well as the production process. Such analysis helps to understand the classes of design, their operational strength, and their service condition in order to avoid failure during operation. Both multi-criteria decision-making tools can also be employed in several other fields such as supplier selection, plant location and design, system designs, as well as maintenance.

## References


1. Kamal. M., Al-Subhi, Al-Harbi (2001), "Application of the AHP in project management", International Journal of Project Management, Vol.19, No.1 , pg 19-27.

2. Olabanji, O.M. and K. Mpofu, (2020). Pugh matrix and aggregated by extent analysis using trapezoidal fuzzy number for assessing conceptual designs.*Decision Science Letters*. **9**(1): p. 21-36.

3. Olabanji, O.M. and K. Mpofu, (2019). Decision Analysis for Optimal Design Concept: Hybridized Fuzzified Weighted Decision Matrix and Fuzzy TOPSIS Using Design for X Tools.*Procedia CIRP*. **84**: p. 434-441.

4. Olabanji, O.M. and K. Mpofu, (2020). Fusing Multi-Attribute Decision Models for Decision Making to Achieve Optimal Product Design.*Foundations of Computing and Decision Sciences*. **45**.

5. Olabanji, O.M. and K. Mpofu, (2021). Appraisal of conceptual designs: Coalescing fuzzy analytic hierarchy process (F-AHP) and fuzzy grey relational analysis (F-GRA).*Results in Engineering*. **9**: p. 100194.

6. Olabanji, O.M., (2018). Reconnoitering the suitability of fuzzified weighted decision matrix for design process of a reconfigurable assembly fixture.*International Journal of Design Engineering*. **8**(1): p. 38-56.

7. Olabanji O., Mpofu K. (2014), Comparison of Weighted Decision Matrix, and Analytical Hierarchy Process for CAD design of Reconfigurable Assembly Fixture. Industrial Engineering Department, Tshwane University of Technology, Pretoria, South Africa. Procedia CIRP 23 (2014) pg. 264 – 269.

8. Kamal, A.A. and SalhiehSa‟Ed, M., 2013. A Fuzzy Based Approach for New Product Concept Evaluation and Selection. Industrial Engineering Letters, 3(12), pg.1-16.

9. Olabanji, O.M. and K. Mpofu, (2019). Adopting hybridized multicriteria decision model as a decision tool in engineering design.*Journal of Engineering, Design and Technology*. **18**(2): p. 451-479.

10. Okudan, G.E. and S. Tauhid, Concept selection methods–a literature review from 1980 to 2008. International Journal of Design Engineering, 2008. 1(3): p. 243-277.

11. Rakesh Y. Suryawanshi Pranay S. Ramteke (2015), Design and Fabrication of Hydraulic Bearing Puller and Pusher, International Journal for Innovative Research in Science & Technology| Volume 1, Issue 11

12. Hambali. A. (2011), Concurrent Decisions on Design Concept and Material Using Analytical Hierarchy Process at the Conceptual Design Stage. SAGE,Vol 19(2): p. 11.

13. Olabanji, O.M. and K. Mpofu, (2020). Hybridized fuzzy analytic hierarchy process and fuzzy weighted average for identifying optimal design concept.*Heliyon, Elsevier*. **6**(1): p. 1-13.

14. Olabanji, O.M., (2022). Improving the Computational Process for Identifying Optimal Design Using Fuzzified Decision Models.*International Journal of Fuzzy System Applications IGI Global*. **11**(1): p. 1-21.

15. Olabanji, O. and K. Mpofu, (2023). Extending the application of fuzzy COPRAS to optimal product design.*Procedia CIRP*. **119**: p. 182-192.

16. Olabanji, O.M., (2020). Fuzzified Synthetic Extent Weighted Average for Appraisal of Design Concepts.*International Journal of Research in Industrial Engineering*. **Vol. 9**(No. 2): p. 190-208.

17. Olabanji, O.M. and K. Mpofu, (2021). Design concept evaluation technique via functional link matrix and fuzzy VIKOR based on left and right scores.*Production & Manufacturing Research*. **9**(1): p. 116-139.

18. Wang YM, Elang TMS, (2006),"Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment", Expert Systems, vol.31, pp 309-319.

19. Jiang J., Chen Y.W., Tang D.W., Chen Y.W, (2010), "TOPSIS with belief structure for group belief multiple criteria decision making", international journal of Automation and Computing, vol.7,no.3,pg 359-364.

20. Roszkowska E. (2007**),** Multi-Criteria Decision-Making Models by Applying the TOPSIS Method To Crisp and Interval Data; Multiple Criteria Decision Making (6); pp. 200-230

21. Kang, Y. and Tang, D., 2014. An approach to product solution generation and evaluation based on the similarity theory and ant colony optimization. International Journal of Computer Integrated Manufacturing, 27(12), pg.1090-1104.

22. Olabanji, O.M. (2020). 'Appropriateness of fuzzy weighted average and fuzzy TOPSIS based on leftand right scores for optimal conceptual design', *Int. J. Fuzzy Computation andModelling*, Vol. 3, No. 2, pp.120–144.

23. Wang J. *et al*., (2006), Review On Multi-Criteria Decision Analysis Aid in Sustainable Energy Decision-Making. Renew Sustain Energy Rev 13:2263–2278.

24. Shirouyehzad H., Dabestani R., (2011), "Evaluating Projects Based on Safety Criteria; Using TOPSIS", 2011 2nd International Conference on Construction and Project Management IPEDR vol.15 Singapur.