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ACHIEVING THE SELECTION OF OPTIMAL PRESS BRAKE DESIGN VIA A FUZZY TOPSIS APPROACH

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ABSTRACT

Selecting optimal design concept from several design alternatives is still a major challenge for engineers in the field of engineering design and it is important to select the optimal design in order to avoid delay and unnecessary cost during project execution. This article presents the selection of optimal design of press brake considering several design requirements and features. The adoption of the fuzzy TOPSIS methodology considered various design features that are categorized into several sub-features and weighted considering the functional requirements from the optimal design. The cumulative Triangular Fuzzy Number (TFN) of the design alternatives from the sub-features of all the design features are harnessed to develop a decision matrix from which the fuzzy positive and negative ideal solutions are obtained. The distances of the design alternatives to the fuzzy positive and negative ideal solutions are determined in order to obtain a closeness coefficient that is used to rank the design alternatives. The proximity in the final values of the closeness coefficients of the design alternatives demonstrates that the fuzzy TOPSIS approach apportioned ratings to the design alternatives based on availability of sub-features in the design concepts and the relevance of the design features to the functional requirement of the optimal design.

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1. INTRODUCTION

The importance of selecting appropriate press brake design for workshop operations cannot be exaggerated considering the fact that press brakes are important in workshops over a long period of time. Hence, there is a need to appraise different design concepts of press brakes considering the functional requirements and available design features. Design concept selection is the process of evaluating several design alternatives with respect to users' requirements and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development (Olabanji and Mpofu, 2020a; Balin *et. al*, 2016). Design concept selection requires picking the best design idea which best satisfies the functional requirement of the optimal design. Design concept selection is important in the development process when the production team must select subsystem concepts, components, production processes, and evaluate design life cycle (Olabanji and Mpofu, 2019a; Arjun *et. al*, 2016).

Multi-Criteria Decision Making (MCDM), is a tool that has been applied to many complex decisions including engineering design (Olabanji and Mpofu, 2020b). It is usually employed in solving problems that are characterized as a choice among alternatives. MCDM is one of the most considerable branches of Decision Making that refers to making decisions in the presence of multiple, usually conflicting, criteria. Basically, MCDM can be classified into two categories (Olabanji, 2018; Okudan and Tauhid, 2008); Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). The MADM is employed in making a choice from a set of alternatives within a discrete solution space. It utilizes Multi-Attribute Utility Theories (MAUT) such as Weighted Sum Model (WSM), Analytic Hierarchy Process (AHP), Weighted Average model (WA), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Elimination and Choice Translating Reality (ELECTRE) and Analytic Network Process (ANP) among others (Olabanji and Mpofu, 2020c; Olabanji, 2020). The MODM finds application when there are no discrete sets of explicitly defined alternatives. Examples of methods applied in MODM are linear programming approaches, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Goal Programming (GP). MODM provides search for an infinite set solution in a continuous space and it usually emerges at two stages which are implementation of higher-level strategic decisions at a more detailed operational level and generation of explicit set of alternatives for more detailed evaluation before a final decision is reached (Olabanji and Mpofu, 2014; Renzi *et. al*, 2017).

Equipment selection is an important task in design due to its operational cost, and also an integral part of manufacturing, planning and design. Equipment selection is not a well-defined process because it involves the interaction of several design features and sub-features. Besides, decisions are often complicated and may even embody contradictions. Therefore; equipment selection is considered as MCDM process, and suitable decision-making methods should be employed in this process. Also, the MCDM has all the characteristics of a useful decision support tool and it focuses on what is important, it is logical and consistent, and is easy to use. At its core MCDAM is useful for dividing the decision into smaller and more understandable parts by analyzing each part and integrating the parts to produce a meaningful solution. Further, the MCDM provides a unique ability for design engineers to consider and brainstorm about complex trade-offs among design alternatives (Girod *et. al*, 2003; Renzi and Leali, 2016).

The Fuzzy TOPSIS model is basically an application of the fuzzy set theory to the TOPSIS model. It is a decision-making process of finding the best option from all feasible alternatives (Madi. *et. al*., 2015; Olabanji and Mpofu, 2019b). Much of the decision making in the real-life situations take place in an environment in which goals, constraints and the consequences of possible actions are not known precisely and fuzzy set theory can be used to deal with imprecision in decision making. In classical multiple criteria decision-making (MCDM) methods, the ratings and the weights of the criteria are known precisely (Olabanji and Mpofu, 2020d). Owning to vagueness of the decision data, the crisp data are inadequate for real-life situations. Since human judgments including preferences are often vague and cannot be expressed by exact numerical values, the application of fuzzy concepts in decision making is deemed to be relevant (Cevdet and Cihan, 2011; Renzi *et. al*, 2015). In essence, the application of fuzzy set in the form of TFNs will assist in quantifying some design features and requirements relative to press brakes. Some of these features includes precision control of ram, velocity control, parallelism and forming pressures. Since human judgement including preferences are often vague and cannot be expressed by exact numerical valves, the application of fuzzy concepts in decision-making is deemed relevant in getting optimal design in manufacturing industries (Olabanji, 2020a).

The press brake represents a specific type of machine tool, essential in the performance of industrial manufacturing processes. Presses deliver energy through a force that acts over a distance or stroke. One important application is in metal forging manufacture. The energy of the press is used to close the die, forging the part within. Press machine tools apply force/energy to the work differently than drop hammers, (that deliver energy to the work through a collision). Press machines are also the primary machine tool used in metal extrusion and sheet metal fabrication processes (Olabanji *et. al.*, 2016). Hydraulic and mechanical presses are employed during sheet metal forming to the extent that sheet metal processes, in general, are often referred to as press working. Presses may be used in the manufacture of plastic parts. Machining operations, such as broaching, may also require presses. Press machine tools vary in size and in the amount of force they can output. The energy from a press is often used to do work requiring a tremendous amount of force, such as a large amount of plastic deformation of a sizable piece of metal. The method and nature by which a press machine will deliver its energy will vary, dependent on its type.

Hence, this article addresses the challenges of determining optimal design concept from a set of alternatives by providing a repeatable method that can be applied for subsequent designs. This implies that, research questions regarding which robust decision model can be employed for assessing alternative conceptual designs in order to identify optimal design concept will be addressed in as much as the design engineer has identified the design features and sub features required for characterizing the optimal or best design (Olabanji, 2020b; Yeo *et. al.*, 2004). Design analysis is an important part of any engineering design as it will indicate if a proposed or conceptualized design can serve the purpose for which it was designed, or it will fail at the point of service. This article is important as it will guide manufacturers before making a choice of design based on statistical analysis result, ranking order presented by the multi-criteria decision tools employed Fuzzy TOPSIS, in order to cut cost. It is important to avoid product failure at the point of service which can reduce the integrity of the manufacturer. The analysis carried out in this article will help identify the design that is best fit for the problems encountered in the course of pressing materials. Moreover, it encourages lean manufacturing process since the optimal design concept would have been selected and unnecessary costs and waste are eliminated before or during manufacture of the press brake. Since the design engineer may not be able to perform all analysis related to manufacturing of an equipment such as cost related factors, it is necessary to consider all factors, analyze and rank them before taking any decision on the optimal design.

2. METHODOLOGY

In order to simplify the analysis, it is necessary to identify the design features and sub-features that are required for consideration in order to obtain an optimal design as presented in Figure 1. Further, the procedures for implementing the Fuzzy TOPSIS considering the design alternatives is presented in Figure 2. Model equation for the TFN is presented in equation 1 and the respective linguistic terms for the membership function is shown in Table 1. A sub-decision matrix representing the aggregation of sub-features in the design alternatives is presented in equation 2. The cumulative of the sub-decision matrices is used to develop a decision matrix as presented in equation 3. In order to obtain a normalized decision matrix, equation 3 is normalized using equations 4 to 6. Further, the fuzzy positive, fuzzy negative and distances of the design alternatives to the positive ideal and negative ideal solutions are expressed in equations 7 to 10 respectively, while the closeness coefficient of the design alternatives to the ideal positive and negative solutions is presented in equation 11.

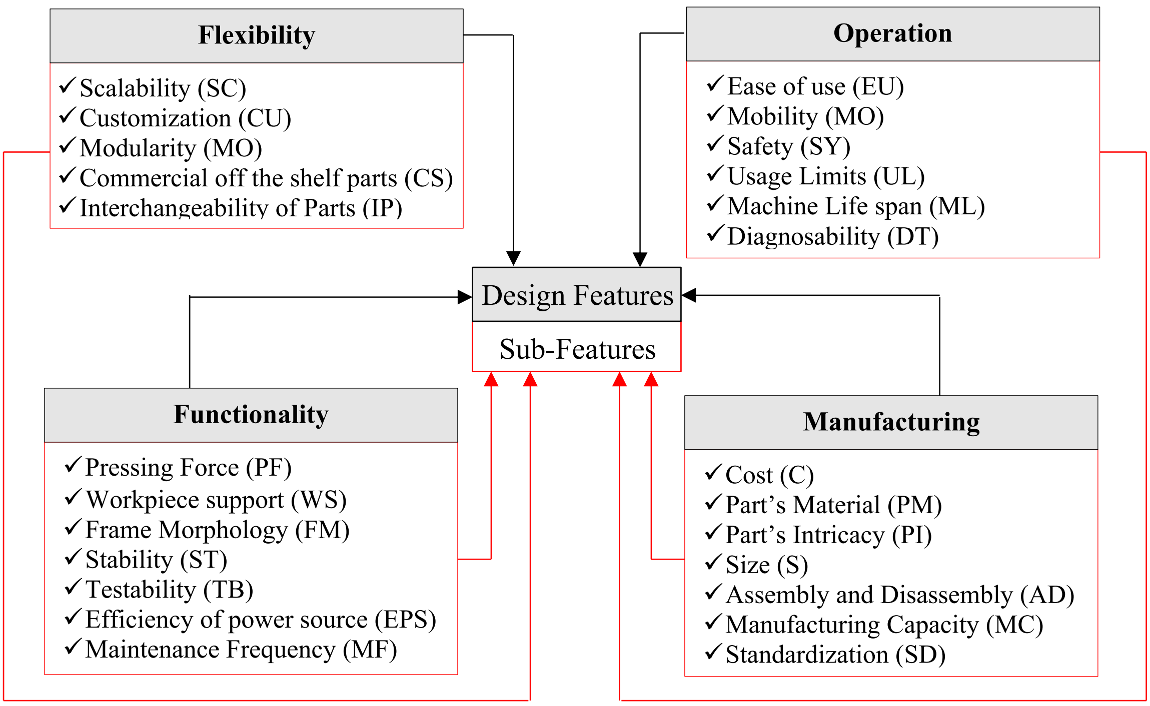

Figure 1. Design Features and Sub-features for Optimal Press Brake Design

$$\mu_m(y)=\begin{cases}0 & x<1,\\ \dfrac{1}{v-u}y-\dfrac{l}{v-u} & y\in[u \quad v],\\ \dfrac{1}{v-w}y-\dfrac{w}{v-w} & x\in[v \quad w],\\ 0 & y>w\end{cases} \tag{1}$$

Where $u \leq v \leq w$ and u, v and w represent the lower, modal and upper values of the fuzzy number M respectively (Olabanji, 2018; Olabanji and Mpofu, 2019c; Mir *et. al*, 2011). The TFNs adopted are tabulated in Table 1.

Table 1. TFN for Rating and Ranking Design Features and Sub-features respectively

Crisp Value of Rating	Triangular Fuzzy Scale Membership Function	Linguistic Terms for Ranking of availability of Sub-features in the Design concepts
1	0.5 1 1.5	Very low
2	1 1.5 2	Low
3	1.5 2 2.5	Medium
4	2 2.5 3	High
5	2.5 3 3.5	Very high

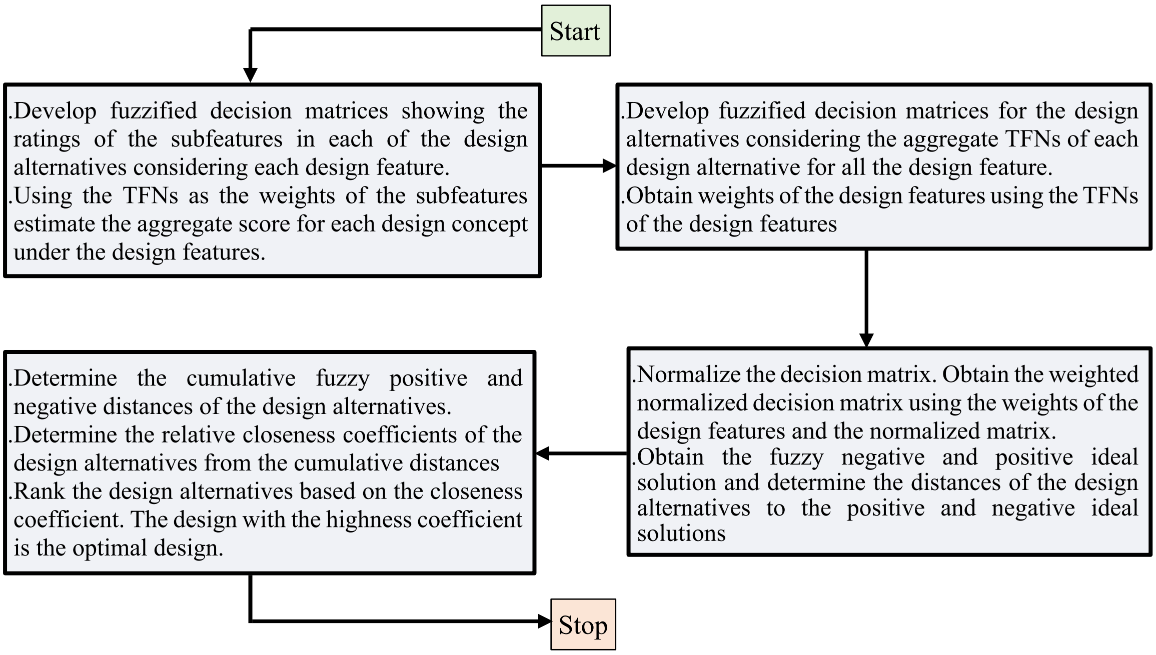

Figure 2. Fuzzy TOPSIS Implementation Process

$$D_{sf}=\begin{pmatrix} d^1_{sf1} & d^2_{sf1} & \dots\dots\dots & d^s_{sf1}\\ d^1_{sf2} & d^2_{sf2} & \dots\dots\dots & d^s_{sf2}\\ \\ d^1_{sfk} & d^2_{sfk} & \dots\dots\dots & d^s_{sfk}\end{pmatrix} \tag{2}$$

Where d_{ij} is a TFN that can be represented by $(u_{ij} \quad v_{ij} \quad w_{ij})$ as presented in equation 1. For *i*=*1, 2, 3…. k*, *j*=*1, 2, 3……s*. Also, a matrix for the weighted aggregate of all the sub features $W=\{W^j_{sfi}\}$ for *i* number of design features can be represented by;

$$W_{Sfi}=\begin{pmatrix} D^1_{sf1} & D^2_{sf1} & \dots\dots\dots & D^j_{sf1}\\ D^1_{sf2} & D^2_{sf2} & \dots\dots\dots & D^j_{sf2}\\ \\ D^1_{sfi} & D^2_{sfi} & \dots\dots\dots & D^j_{sfi}\end{pmatrix} \tag{3}$$

Where D_{ij} is a TFN that is equal to the cumulative aggregate of all the sub features in a design feature for a particular design alternative. In order to normalize the triangular fuzzy matrix, consider a fuzzy number $z_{ij} = (u_{ij} \ \ v_{ij} \ \ w_{ij})$ for $(i = 1.....n \ \ j = 1.....m)$ the normalization process can be represented as; (Olabanji and Mpofu, 2019b; Mehdi, *et. al*., 2012).

$$\left(z_{ij}\right)_N = \left[\left(u_{ij}\right)_N \ \ \left(v_{ij}\right)_N \ \ \left(w_{ij}\right)_N \ \right] \tag{4}$$

$$\left(z_{ij}\right)_N = \left[\frac{u_{ij} - u_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}, \ \frac{v_{ij} - u_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}, \ \frac{w_{ij} - u_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}\right], \quad i = 1,......n; \ j \in \Omega_b \tag{5}$$

$$\left(z_{ij}\right)_N = \left[\frac{w_{ij} - u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}}, \ \frac{v_{ij} - u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}}, \ \frac{u_{ij} - u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}}\right], \quad i = 1,......n; \ j \in \Omega_c \tag{6}$$

Where $u_j^{\text{Min}} = \text{Min}\, u_{ij}$ and $w_j^{\text{Max}} = \text{Max}\, w_{ij}$ for $i = 1,......n$; $\Delta_{\text{Min}}^{\text{Max}} = w_j^{\text{Max}} - u_j^{\text{Min}}$. Also, Ω_b and Ω_c are sets of benefit and cost attributes respectively. Considering the weighted normalized performance value of the *nth* alternative in terms of the *ith* design feature from equation 3, the fuzzy positive (F^*) and negative (F^-) ideal solutions for the design alternatives can be obtained from equations 7 and 8; (Shofwatul, and Imam, 2011; Mokhtarian, and Vencheh, 2012)

$$F^* = \left(c_1^*, \ c_2^*, ... \ c_n^*\right) \tag{7}$$

$$F^- = \left(c_1^-, \ c_2^-, ... \ c_n^-\right) \tag{8}$$

Where (c_n^*) is a vector TFN that is obtained from $c_n^* = (g, \ g, \ g)$ such that $g = {}^{\text{Max}}_{i}\left\{G_{ik}^{"}\right\}$ (for $i = 1,......n$ and $k = 1,......j$). $G_{ik}^{"}$ is the upper value TFN in the column of the weighted normalized decision matrix. Similarly, (c_1^-) is a vector TFN that is obtained from $c_n^- = (h, \ h, \ h)$ such that $h = {}^{\text{Min}}_{i}\left\{H_{ik}^{"}\right\}$ (for $i = 1,......n$ and $k = 1,......j$). $H_{ik}^{"}$ is the lower value TFN in the column of the weighted normalized decision matrix. The distance of each design alternative from the positive ideal (d_i^*) and negative ideal (d_i^-) solution is needed for computation of the relative closeness of the design alternatives to the optimal design. This distance can be obtained from equations 9 and 10; (Olabanji, 2020a; Shanliang, *et. al*, H. 2014)

$$d_i^* = \sqrt{\sum_{i=1}^{n}\left(c_{in} - c_n^*\right)^2} \tag{9}$$

$$d_i^- = \sqrt{\sum_{i=1}^{n}\left(c_{in} - c_n^-\right)^2} \tag{10}$$

The closeness coefficient (CC_i) represents the distances of the design alternatives to the fuzzy positive ideal solution (A^*) and fuzzy negative ideal solution (A^-) simultaneously. This can be obtained from equation 11;

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{11}$$

3. APPLICATION TO THE DESIGN OF PRESS MACHINES

Four design concepts of press machines are considered as design alternatives as presented in Figure 3 alongside the design features and sub-features presented in Figure 1. The ratings of the design alternatives considering all the sub-features of the four design features are presented in Tables 2 to 5. The cumulative of the design alternatives from Tables 2 to 5 is used to develop the fuzzified decision matrix as shown in Table 6. Applying equation 4 on the decision matrix and considering the weights of the design features in Table 6 yields the weighted normalized decision matrix in Table 7. Also, from the weighted normalized fuzzy decision matrix, the fuzzy positive (A^*) and negative (A^-) ideal solutions for the design alternatives can be obtained in equations 12 and 13 respectively. Also, the distances of each design alternatives from the positive and negative ideal solutions can be derived as shown in Table 8. The closeness coefficients of the design alternatives are obtained from these distances applying as presented in Table 9.

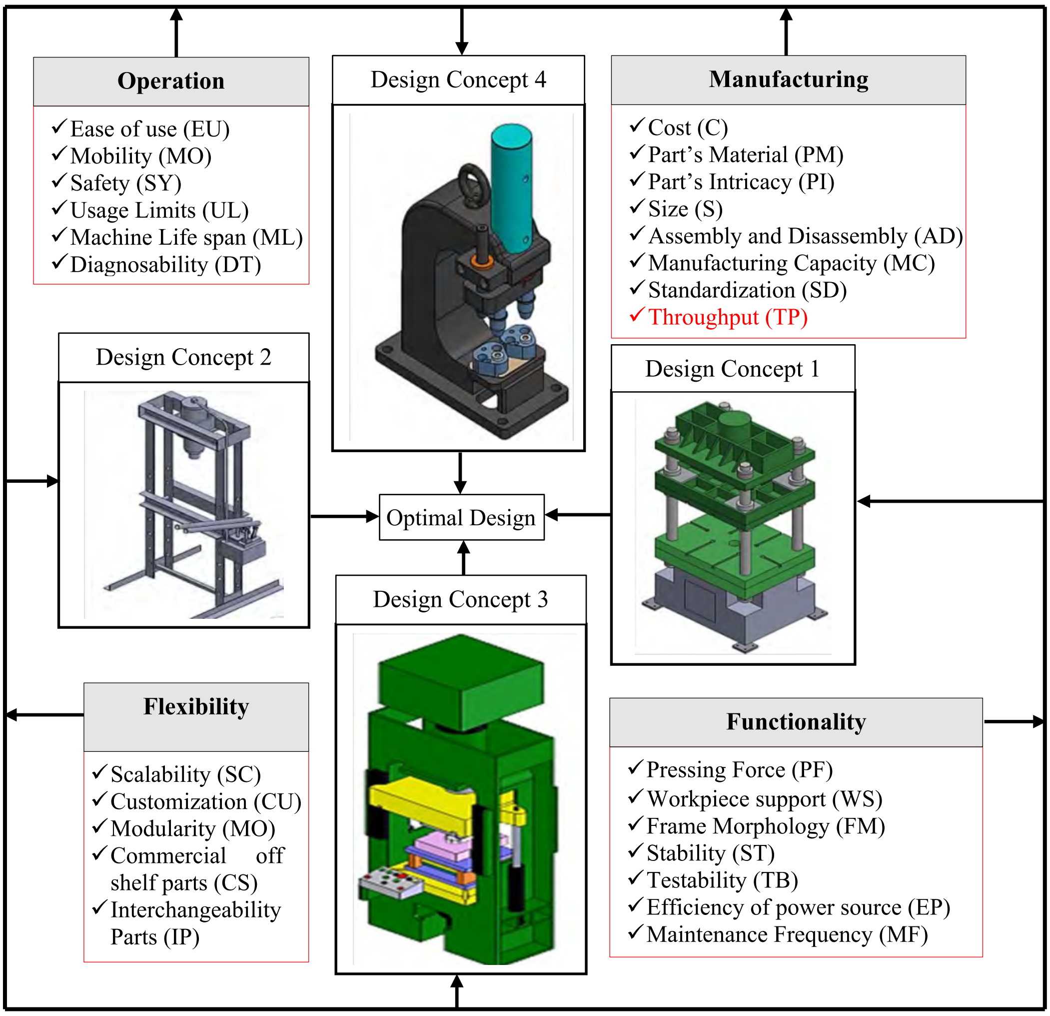

Figure 3. Framework for Implementing Fuzzy TOPSIS in the identification Design of press brake

4. RESULTS AND DISCUSSION

The decision analysis considered four design features with several sub-features for different design concepts of press machines in order to identify an optimal design. The priority of each of the concepts relative to the importance of functional requirement in the optimal design is presented in Table 9. From Table 9, it can be observed that design concept three (3) is the optimal design despite the fact that other design alternatives have priority values that are closer to each other. This implies that the fuzzy TOPSIS method did not just allot values to the design alternatives in such a way that one design has extremely higher value than others as shown in Figure 4.

Also, in MCDM, a number of alternatives have to be evaluated and compared using several criteria. The aim of MCDM is to provide support to the decision-maker in the process of making the choice between alternatives. In this way, practical problems are often characterized by several conflicting criteria, and there may be no solution which satisfies all criteria simultaneously. Thus, the solution is a compromise solution according to the decision-maker's preferences. In this sense, TOPSIS is based upon the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the furthest from the Negative Ideal Solution (NIS). The final ranking is obtained by means of the closeness in

Table 2. TFN Ratings of Design Alternatives Based on Sub-features of Functionality

Design Concepts	***PF*** 2.5 3.0 3.5	***WS*** 2.5 3 3.5	***FM*** 2.0 2.5 3.0	***ST*** 1.5 2.0 2.5	***TB*** 1.5 2.0 2.5	***EP*** 2.0 2.5 3.0	***MF*** 1.5 2.0 2.5	**Cumulative**
Concept 1	2.5 3.0 3.5	2.5 3.0 3.5	1.5 2.0 2.5	2.5 3.0 3.5	2.5 3.0 3.5	2.0 2.5 3.0	1.5 2.0 2.5	28.50 44.25 63.50
Concept 2	1.5 2.0 2.5	1.0 1.5 2.0	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	0.5 1.0 1.5	2.0 2.5 3.0	20.25 34.25 48.75
Concept 3	2.0 2.5 3.0	2.0 2.5 3.0	1.0 1.5 2.0	2.0 2.5 3.0	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	24.50 39.25 57.50
Concept 4	2.0 2.5 3.0	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.0 3.5	2.5 3.0 3.5	2.0 2.5 3.0	1.5 2.0 2.5	27.00 41.00 59.75

Table 3. TFN Ratings of Design Alternatives Based on Sub-features of Flexibility

Design Concepts	**SC** 15 2.0 2.5	**CU** 1.0 1.5 2.0	**MO** 2.0 2.5 3.0	**CS** 1.5 2.0 2.5	**IP** 1.0 1.5 2.0	**Cumulative**
Concept 1	1.5 2.0 2.5	2.0 2.5 3.0	1.0 1.5 2.0	2.0 2.5 3.0	2.0 2.5 3.0	11.25 20.25 31.75
Concept 2	2.0 2.5 3.0	1.0 1.5 2.0	2.5 3.0 3.5	1.5 2.0 2.5	2.5 3.0 3.5	13.75 23.25 35.25
Concept 3	1.5 2.0 2.5	2.5 3.0 3.5	2.0 2.5 3.0	2.5 3.0 3.5	2.0 2.5 3.0	14.50 24.50 37.00
Concept 4	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	1.5 2.0 2.5	12.00 21.00 32. 50

Table 4. TFN Ratings of Design Alternatives Based on Sub-features of Manufacturing

Design Concepts	**C** 2.5 3.0 3.5	**PM** 2.0 2.5 3.0	**PI** 2.0 2.5 3.0	**S** 2.5 3.0 2.5	**AD** 2.0 2.5 3.0	**MC** 2.5 3.0 2.5	**SD** 2.0 2.5 3.0	**Cumulative**
Concept 1	2.5 3.0 3.5	2.0 2.5 3.0	1.5 2.0 2.5	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.5 3.0 3.5	34.5 51.75 66.5
Concept 2	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.0 3.5	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	2.0 2.5 3.0	26.5 35.75 49.5
Concept 3	2.5 3.0 3.5	2.0 2.5 3.0	2.0 2.5 3.0	2.5 3.0 3.5	2.0 2.5 3.0	2.5 3.0 3.5	2.0 2.5 3.0	30.5 54.5 63.25
Concept 4	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	31.0 44.25 61.5

Table 5. TFN Ratings of Design Alternatives Based on Sub-features of Operation

Design Concepts	EU 2.5 3.0 3.5	MO 2.0 2.5 3.0	SY 2.5 3.0 3.5	UL 2.0 2.5 3.0	DT 1.5 2.0 2.5	ML 2.0 2.5 3.0	Cumulative
Concept 1	2.0 2.5 3.0	1.5 2.0 2.5	2.0 2.5 3.0	2.0 2.5 3.0	1.5 2.0 2.5	2.5 3.0 3.5	24.25 37.75 54.23
Concept 2	2.5 3.0 3.5	2.5 3.0 3.5	2.5 3.0 3.5	2.0 2.5 3.0	1.0 1.5 2.0	1.5 2.0 2.5	26.00 39.75 56.50
Concept 3	1.5 2.0 2.5	2.0 2.5 3.0	1.5 2.0 2.5	2.5 3.0 3.5	2.5 3.0 3.5	1.5 2.0 2.5	25.25 36.75 53.25
Concept 4	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	1.5 2.0 2.5	2.0 2.5 3.0	2.0 2.5 3.0	21.75 34.75 50.75

Table 6. Fuzzified Decision Matrix

Design Concepts	Functionality 2.0 2.5 3.0	Flexibility 2.5 3.0 3.5	Operation 1.5 2.0 2.5	Manufacturing 2.5 3.0 3.5
Concept 1	28.50 44.25 63.50	11.25 20.25 31.75	24.25 37.7554.25	34.5 51.75 66.50
Concept 2	20.25 34.25 48.75	13.75 23.25 35.25	26.00 39.75 56.5	26.5 35.75 49.5
Concept 3	24.50 39.25 57.50	14.50 24.50 37.00	25.25 36.7553.25	30.5 54.50 63.25
Concept 4	27.00 41.00 59.75	12.00 21.00 32.50	21.75 34.7550.75	31.0 44.25 61.5

Table 7. Weighted Normalized Fuzzy Decision Matrix

Design Concepts	Functionality	Flexibility	*Manufacturing*	Operation
Concept 1	0.38 1.38 **3.00**	**0.00** 1.05 2.76	0.50 1.89 **3.50**	0.10 0.92 2.35
Concept 2	**0.00** 0.80 1.98	0.22 1.41 3.25	**0.00** 0.69 2.03	0.18 1.04 **2.50**
Concept 3	0.18 1.10 2.58	0.32 1.53 **3.50**	0.25 2.10 3.22	0.15 0.86 2.27
Concept 4	0.32 1.20 2.73	0.07 1.14 2.90	0.27 1.32 3.08	**0.00** 0.74 2.07

$$A^{+} = [3.00 \;\; 3.50 \;\; 3.50 \;\; 2.50] \quad (12) \qquad A^{-} = [0.00 \;\; 0.00 \;\; 0.00 \;\; 0.00] \quad (13)$$

Table 8. Distances of the Design Alternatives to the Positive and Negative Ideal Solutions

Design Alternatives	***Functionality***	***Flexibility***	***Manufacturing***	***Operation***	**Cumulative Distances**
$d^{+}(\text{Concept 1}, A^{+})$	1.78	2.50	1.96	1.66	7.90
$d^{+}(\text{Concept 2}, A^{+})$	2.23	2.25	2.56	1.59	8.63
$d^{+}(\text{Concept 3}, A^{+})$	1.98	2.16	2.05	1.66	7.85
$d^{+}(\text{Concept 4}, A^{+})$	1.87	2.43	2.26	1.78	8.34
$d^{-}(\text{Concept 1}, A^{-})$	1.92	1.70	2.31	1.46	7.39
$d^{-}(\text{Concept 2}, A^{-})$	1.23	2.05	1.24	1.57	6.09
$d^{-}(\text{Concept 3}, A^{-})$	1.62	2.21	2.22	1.40	7.45
$d^{-}(\text{Concept 4}, A^{-})$	1.73	1.79	1.27	1.94	6.73

Table 9. Closeness Coefficient $_iCC$ and Ranking of Design Alternatives

Design Alternatives	d^{+}	d^{-}	CC_i	*Ranking*
Concept 1	7.90	7.39	0.483	2nd
Concept 2	8.63	6.09	0.414	4th
Concept 3	7.85	7.45	0.487	1st
Concept 4	8.34	6.73	0.446	3rd

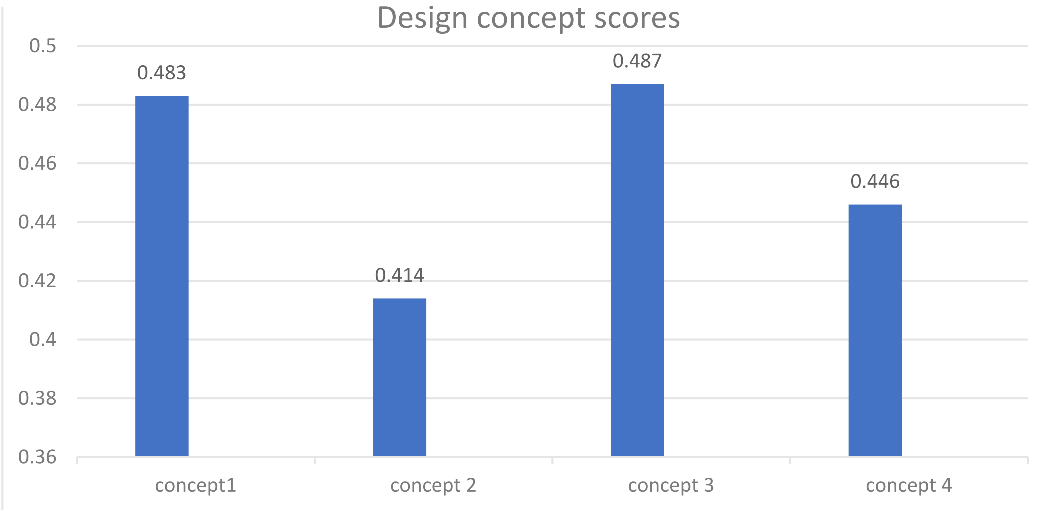

Figure 4. Chart for design concepts priority values

5. CONCLUSION

Considering the results obtained from the application of Fuzzy TOPSIS to the design of press machines, it can be hypothetically stated that TOPSIS is suitable in the selection of optimal design. Since human judgement including preferences are often vague and cannot be expressed by exact numerical values, the application of fuzzy concepts in decision-making is deemed relevant in getting optimal design in manufacturing. 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 reveals the consistency of concept 3 as the optimal design. Furthermore, this investigation shows that in the selection and manufacture of a press machine based on demand, modification/variation can be made as to which functional need or requirement should be given priority, which can be corrected in the design stage as well as the production process. Such analysis will help to understand the classes of design, their operational strength, and their service condition in order to avoid failure during operation. TOPSIS as 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. From the analysis of Fuzzy TOPSIS, it is recommended that multi-criteria decision tools are of extreme importance and should be adopted in taking critical decisions before any design selection or manufacturing is carried out. To ease the iteration and computation process, a model/software could be developed in subsequent research to make the tools (TOPSIS) more appealing, acceptable and flexible for future work.

REFERENCES

Arjun Raj, A. and Vinodh, S. (2016). "A case study on application of ORESTE for agile concept selection", Journal of Engineering, Design and Technology, Vol. 14 No. 4, pp. 781-801.

Balin, Abit, Demirel, Hakan, Alarcin, Fuat, 2016. A novel hybrid MCDM model based on fuzzy AHP and fuzzy TOPSIS for the most affected gas turbine component selection by the failures. J. Mar. Eng. Technol. Vol. 15 No. 2, pp. 69–78.

Cevdet, G. and Cihan, M. (2011). 'An integrated fuzzy logic approach to customer-oriented product design', *Journal of Engineering Design*, Vol. 22, No. 2, pp.113–127.

Girod, M., Elliott, A., Burns, N.D. and Wright, I. (2003). "Decision-making in conceptual engineering design: an empirical investigation", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 217 No. 9, pp. 1215-1228.

Madi, E., Garibaldi, J.M. and Wagner, C. (2015). 'A comparison between two types of fuzzy TOPSIS method', *2015 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, 9–12 October, 2015, Kowloon, Hong Kong.

Mehdi, A-A., Javadian, N. and Kazemi, M.

(2012) 'A new fuzzy positive and negative ideal solution for fuzzy TOPSIS', *WSEAS Transactions on Circuits and Systems*, Vol. 11, No. 3, pp.92–103.

Mir, B., Aryanezhad, M.J., Tarokh, M.N.M. and Zaheri, F. (2011). 'A fuzzy TOPSIS method based on left and right scores', *International Journal of Industrial Engineering & Production Research*, Vol. 22, No. 1, pp.51–62.

Mokhtarian, M.N. and Vencheh, A.H. (2012) 'A new fuzzy TOPSIS method based on left and right scores: an application for determining an industrial zone for dairy products factory', *Applied Soft Computing*, Elsevier, Vol. 12, No. 1, pp.2496–2505.

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

Olabanji, O. M. (2020b). Fuzzified synthetic extent weighted average for appraisal of design concepts, International Journal of Research in Industrial Engineering Vol. 9 No. 2, pp. 190–208.

Okudan, G.E. and Tauhid, S. (2008), "Concept selection methods – a literature review from 1980 to 2008", International Journal of Design Engineering, Vol. 1 No. 3, pp. 243-277.

Olabanji O. M, and K. Mpofu, (2019a). Pugh matrix and aggregated by extent analysis using trapezoidal fuzzy number for assessing conceptual designs, Decision Science Letters Vol. 9 No. 1 pp. 21–36.

Olabanji, O. M. and K. Mpofu, (2019b). Adopting hybridized multicriteria decision model as a decision tool in engineering design. *Journal of Engineering, Design and Technology*. Vol. 18 No. 2: pp. 451-479.

Olabanji O. M and K. Mpofu, (2019c). Decision analysis for optimal design concept: hybridized fuzzified weighted decision matrix and fuzzy TOPSIS using design for X tools, Procedia CIRP 84. pp. 434–441.

Olabanji, O. M and K. Mpofu, (2020a). hybridized fuzzy analytic hierarchy process and fuzzy weighted average for identifying optimal design concept. *Heliyon, Elsevier*. Vol. 6 No. 1 pp. 1-13.

Olabanji, O. M. and K. Mpofu, (2020b). Fusing Multi-Attribute Decision Models for Decision Making to Achieve Optimal Product Design, Foundations of Computing and Decision sciences, Vol. 45 No. 4: pp. 305-337.

Olabanji, O. M. and K. Mpofu, (2020c) Appraisal of conceptual designs: Coalescing fuzzy analytic hierarchy process (F-AHP) and fuzzy grey relational analysis (F-GRA), Results in Engineering, Elsevier Vol. 9 No. 1. 100194, pp. 1-16.

Olabanji, O. M. and K. Mpofu, (2020d). Design Sustainability of Reconfigurable Machines, IEEE Access Vol. 8. No. 1: pp. 215956-215976.

Olabanji, O. M, Mpofu, K. and Battaïa, O. (2016). "Design, simulation and experimental investigation of a novel reconfigurable assembly fixture for press brakes", The International Journal of Advanced Manufacturing Technology, Vol. 82 Nos 1/4, pp. 663-679.

Olabanji, O. M. and Mpofu, K. (2014). "Comparison of weighted decision matrix, and analytical hierarchy process for CAD design of reconfigurable assembly fixture", CIRP Conference on Assembly Technologies and Systems Procedia CIRP 23, pp. 264-269.

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, Vol. 8 No. 1, pp. 38-56.

Renzi, C. and F. Leali, A multicriteria decision-making application to the conceptual design of mechanical components. *Journal of Multi-Criteria Decision Analysis*. 23(3-4): p. 87-111, 2016.

Renzi, C., F. Leali, and L. Di Angelo, A review on decision-making methods in engineering design for the automotive industry. *Journal of Engineering Design*. 28(2): p. 118-143, 2017.

Renzi, C., F. Leali, M. Pellicciari, A.O. Andrisano, and G. Berselli, Selecting alternatives in the conceptual design phase: an application of Fuzzy-AHP and Pugh's Controlled Convergence. *International Journal on Interactive Design and Manufacturing* (IJIDeM). 9(1): p. 1-17, 2015.

Shanliang, Y., Ge, L. and Kedi, H. (2014) 'Group decision-making model using fuzzy-TOPSIS method for FMS evaluation', *Advances in Automatic Control*, pp.37–45, ISBN: 978-960-474-383-4.

Shofwatul, U. and Imam, R. (2011) 'A fuzzy TOPSIS multiple-attribute decision making for scholarship selection', *TELKOMNIKA*, Vol. 9, No. 1, pp.37–46.

Yeo, S., M. Mak, and S. Balon, Analysis of decision-making methodologies for desirability score of conceptual design. *Journal of Engineering Design*. 15(2): p. 195-208, 2004