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Design Concept Selection via Fuzzy TOPSIS

Oloye Charles Olatunji

Mechanical Engineering Technology Department Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria
Author's E-mail: olatunjisunday69@gmail.com

***Abstract* - This article describes the assessment of design concepts in order to identify the optimal concept before detail design and fabrications can be carried out. The task of identifying the design features and sub features necessary or required for optimal performance of the design is achievable by virtue of undergoing the concept selection process. In this article, concept selection via fuzzy TOPSIS method is carried out. Various design features and sub features necessary for optimal performance of a pipe bending machine was identified and the fuzzy TOPSIS model was applied to identify the optimal design from a set of alternative designs of the pipe bending machine. The decision process considered the weights of the design features which has a role to play in the final values obtained from the decision. The application to pipe bending machine shows that fuzzy TOPSIS is a practicable tool for assessing design concepts.**

Keywords: Fuzzy TOPSIS, Design concept selection, Pipe bending machine, Multicriteria decision making.

1. Introduction

Designing involves the creation of an object, system or setup which may be a new invention or an improvement. They are made through a step-by-step creative process because it involves the introduction of an idea or a development to solve a target problem in a scientific manner. These ideas are called concepts. In most cases, the design concepts are the result or outcome of several brainstorming ideas that proffer solution to the problem in different methods. Design problems are usually more vaguely defined and the solution to a design problem is therefore open ended, since there are many possible creative ideas that can be developed to solve the problem. (Okudan and Shirwaiker 2006, Olabanji and Mpofu 2014, Olabanji 2018).

Further, the traditional process of pipe bending (getting one end stuck and forcefully bending from the other end) is very stressful and it wastes a lot of time, it is necessary to fabricate a machine to bend pipes conveniently and efficiently. Considering a pipe bending machine used as a case study in this article, it is a device used for bending specific standard or various sizes of metal pipes with part which includes source of power (like hydraulic), former, ram/shaft, frames and stands sometimes. The principle employed in this tube bender is that the length of material to be bent is held against a semi-circular groove round a cylindrical block while a roller with a similar groove is rolled round the block concentrically with its axis(Olabanji 2020, Olabanji and Mpofu 2020a).

The fabrication of pipe bending machine cannot be done without a valid design concept but the resulting challenge is to know if this design concept is optimal. The design of this mechanism strictly follows engineering design processes, but as stated above, there is no specific design for a purpose, various design concepts apply to the fabrication of pipe bending machine(Olabanji and Mpofu 2021). To have an optimal design concept, there should be various designs using different ideas and choose an optimal one as it will be too expensive and uneconomical to work with all design concepts when just one is needed, choosing involves assessing all functional requirements which are hard to analyze without a proper knowledge of multi-criteria decision making tools but these criteria must be cleverly decided, they have to be beneficial to manufacturers and must also consider the customers demand(Olabanji and Mpofu 2020b, Olabanji and Mpofu 2021).

The challenge now is to choose an optimal design concept before fabrication and to do this, Multi-Criteria Decision Making (MCDM) tools are very usefultools. This MCDM tools includes; Weight Decision Matrix, Analytic Hierarchy Process, Fussy comparisons, Technique for Order of Preference by Similarity in Ideal Solution (TOPSIS), ELECTRE, Analytic Network Process and others. Weight Decision Matrix (WDM) is a Multi-Criteria Decision-Making tool that has been used for the purpose of selecting optimal design concepts for various machines and even operations in other fields. When dealing with conceptual selection in engineering generally, the Matrix of Decisions cannot be overlooked as is it a crucial method which is very basic is nature, the analyses in order of magnitude of desired priorities (Girod et al. 2003, Akay et al. 2011). The Analytic Hierarchy Process (AHP), has also been used by several research works for selection of efficient concepts in various applications and has also been applied to other operational analyses in some cases. The Analytic hierarchy process has proven extremely applicable since its inception and acceptance in years past, it has been used to tackle a wide range of decision-making issues through graduated level of evaluation (Mattson and Messac 2003, Derelöv 2009, Hambali et al. 2009). For the purpose of this article the fuzzy TOPSIS method will be considered because of its versatility, ease of application and identification of optimal design concept based on closeness to ideal positive design. Its simplicity reduces stress from prolonged and unnecessary calculations or tiring process of overtime brainstorming which wears down creativity and is not proper for scientific conclusions (Olabanji and Mpofu 2021, Olabanji 2022).

2. Methodology

In order to simplify the analysis, consider (*i*) number of design alternatives or concepts (d_{AC}) from which it is desired to select an optimal design (d_o) considering *n* number of design attributes (d_{An}) having a dimensionless sets of sub features or sub factors (d_{sf}). The relative significance of the sub features and the availability of the sub features in each design alternative can be described using a triangular fuzzy number (TFN) which membership function $\mu_a(x)$ is contained in [0 1] and defined as(Olabanji and Mpofu 2019, Olabanji and Mpofu 2020c);

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

Where $l \le a \le u$ and *l*,*a* and *u* represent the lower, modal and upper values of the fuzzy number *M* respectively (Olabanji 2020). The TFNs adopted are tabulated in Table 1 (Wang 2001, Wang 2002).

Assigning TFNs to the relative significance of the sub features and assessing the availability of the sub features in the alternative design concepts based on the parts analysis of each concept will produce a comparison matrix which aggregate will form a basis for the analysis of the relative importance of the design attributes. This aggregate will be a weight function of the significance of the sub features. In essence, the rating of the sub features considering a particular design attribute will be of the form of a triangular fuzzy matrix whose judgment matrix $\tilde{B}=\left\{\tilde{b}_{sfk}^{s}\right\}$ of n define set of design attributes can be presented as(Akay et al. 2011, Afful-Dadzie et al. 2016);

Table 1: TFN for Rating and Ranking design attributes and Sub features respectively

Linguistic Terms for Rating of Relative Significance of Design Attributes and Sub Features in the Optimal Design	Linguistic Terms for Ranking of Availability of Sub Features in the Alternative Design Concepts	Crisp Value of Ranking or Rating	Triangular Fuzzy Scale Membership Function
Highly Important	Very High	5	2.5 3.0 3.5
Important	High	4	2.0 2.5 3.0
Very Necessary	Medium	3	1.5 2.0 2.5
Necessary	Low	2	1.0 1.5 2.0
Not Necessary	Very Low	1	0.5 1.0 1.5

$$\tilde{B}_{sf}=\begin{pmatrix} \tilde{b}_{sf1}^{1} & \tilde{b}_{sf1}^{2} & \dots\dots\dots\dots \tilde{b}_{sf1}^{s} \\ \tilde{b}_{sf2}^{1} & \tilde{b}_{sf2}^{2} & \dots\dots\dots\dots \tilde{b}_{sf2}^{s} \\ & & \\ \tilde{b}_{sfk}^{1} & \tilde{b}_{sfk}^{2} & \dots\dots\dots\dots \tilde{b}_{sfk}^{s} \end{pmatrix} \tag{3}$$

Where $\tilde{b}_{ij}$ is a TFN that can be represented by $\left(l_{ij}\ \ a_{ij}\ \ u_{ij}\right)$ as presented in equation 1. For *i=1, 2, 3…. k, j=1, 2, 3……s.* A weighted aggregate of all the sub features under each design attribute is necessary to provide a basis for comparison using the weights of the relative importance of the design attribute. A matrix of all the weighted aggregate of all the sub features $\tilde{W}=\left\{W_{sfi}^{\,j}\right\}$ for *n* number of design attributes can be represented by (Aryanezhad et al. 2011);

$$W_{Sf_n}=\begin{pmatrix} \tilde{B}_{sf1}^{1} & \tilde{B}_{sf1}^{2} & \text{..........}\ \tilde{B}_{sf1}^{j} \\ \tilde{B}_{sf2}^{1} & \tilde{B}_{sf2}^{2} & \text{..........}\ \tilde{B}_{sf2}^{j} \\ \\ \tilde{B}_{sfi}^{1} & \tilde{B}_{sfi}^{2} & \text{...........}\tilde{B}_{sfi}^{j} \end{pmatrix} \tag{4}$$

Where $\tilde{B}_{ij}$ is a TFN that is equal to the cumulative aggregate of all the sub features in a design attribute for a particular design alternative. In order to normalize the triangular fuzzy matrix, consider a fuzzy number $y_{ij}=(l_{ij}\ \ a_{ij}\ \ u_{ij})$ for $\left(i=1.....n\ \ j=1.....m\right)$ the normalization process can be represented as; (Aryanezhad et al. 2011, Mokhtarian 2011, Mokhtarian and Hadi-Vencheh 2012).

$$\left(y_{ij}\right)_N=\left[\left(l_{ij}\right)_N\ \ \left(a_{ij}\right)_N\ \ \left(u_{ij}\right)_N\right] \tag{5}$$

$$\left(y_{ij}\right)_N=\left[\frac{l_{ij}-l_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}},\ \frac{a_{ij}-l_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}},\ \frac{c_{ij}-l_j^{\text{Min}}}{\Delta_{\text{Min}}^{\text{Max}}}\right],\quad i=1,......n;\ \ j\in\Omega_b \tag{6}$$

$$\left(y_{ij}\right)_N=\left[\frac{u_{ij}-u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}},\ \frac{a_{ij}-u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}},\ \frac{l_{ij}-u_j^{\text{Max}}}{\Delta_{\text{Min}}^{\text{Max}}}\right],\quad i=1,......n;\ \ j\in\Omega_c \tag{7}$$

Where $l_j^{\text{Min}}=\text{Min}\ l_{ij}$ and $u_j^{\text{Max}}=\text{Max}\ u_{ij}$ for $i=1,......n$; $\Delta_{\text{Min}}^{\text{Max}}=u_j^{\text{Max}}-l_j^{\text{Min}}$. Also, Ω_b and Ω_c are sets of benefit and cost attributes respectively. In order to simplify the analysis, let the normalized weights of each design attributes be $(\tilde{W}_{dA})$. This can be expressed as a normalized TFN of the form $\left(\left(W_{dAl}\right)_N,\ \left(W_{dAa}\right)_N,\ \left(W_{dAu}\right)_N\right)$. This will represent the priority weights of the design attribute under consideration. Also, the normalized performance value of the ith alternative in terms of the nth design attribute in a TFN that can be represented as;

$$\begin{gathered}\left(\left(W_{1l}\right)_N\left(W_{1a}\right)_N\left(W_{1u}\right)_N\right)\left(\left(W_{2l}\right)_N\left(W_{2a}\right)_N\left(W_{2u}\right)_N\right)\left(\left(W_{3l}\right)_N\left(W_{3a}\right)_N\left(W_{3u}\right)_N\right)\left(\left(W_{nl}\right)_N\left(W_{na}\right)_N\left(W_{nu}\right)_N\right)\\ \tilde{W}_{dA}*W_{Sf_n}=\begin{pmatrix} \left(\tilde{B}_{sf_1}^{1}\right)_N & \left(\tilde{B}_{sf_1}^{2}\right)_N & \left(\tilde{B}_{sf_1}^{3}\right)_N & \text{....} & \left(\tilde{B}_{sf_1}^{n}\right)_N \\ \left(\tilde{B}_{sf_2}^{1}\right)_N & \left(\tilde{B}_{sf_2}^{2}\right)_N & \left(\tilde{B}_{sf_2}^{3}\right)_N & & \left(\tilde{B}_{sf_2}^{n}\right)_N \\ \left(\tilde{B}_{sf_3}^{1}\right)_N & \left(\tilde{B}_{sf_3}^{2}\right)_N & \left(\tilde{B}_{sf_3}^{3}\right)_N & & \left(\tilde{B}_{sf_3}^{n}\right)_N \\ \vdots & \vdots & \vdots & & \vdots \\ \left(\tilde{B}_{sf_j}^{1}\right)_N & \left(\tilde{B}_{sf_j}^{2}\right)_N & \left(\tilde{B}_{sf_j}^{3}\right)_N & & \left(\tilde{B}_{sf_j}^{n}\right)_N \end{pmatrix}\end{gathered} \tag{8}$$

Considering the weighted normalized performance value of the ith alternative in terms of the nth design attribute in equation 8, the fuzzy positive (A^*) and negative (A^-) ideal solutions for the design alternatives can be obtained from equations 24 and 25;

$$A^* = \left(v_1^*,\ v_2^*, \ldots\ldots v_n^*\right) \tag{24}$$

$$A^- = \left(v_1^-,\ v_2^-, \ldots\ldots v_n^-\right) \tag{25}$$

Where (v_n^*) is a vector TFN that is obtained from $v_n^* = \left(e,\ e,\ e\right)$ such that $e = \underset{i}{\mathrm{Max}} \left\{E_{ik}^{''}\right\}$ (for $i = 1, \ldots\ldots n$ and $k = 1, \ldots\ldots j$). $E_{ik}^{''}$ is the upper value TFN in the column of the weighted normalized decision matrix. Similarly, (v_1^-) is a vector TFN that is obtained from $v_n^- = \left(f,\ f,\ f\right)$ such that $f = \underset{i}{\mathrm{Min}} \left\{F_{ik}^{''}\right\}$ $e = \underset{i}{\mathrm{Max}} \left\{E_{ik}^{''}\right\}$ (for $i = 1, \ldots\ldots n$ and $k = 1, \ldots\ldots j$). $F_{ik}^{''}$ is the lower value TFN in the column of the weighted normalized decision matrix (Madi et al. 2015).

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 the ideal solutions and equation 2;

$$d_i^* = \sum_{i=1}^{n} \frac{1}{3}\left[\left(\tilde{v}_{in},\ v_n^*\right)\right] \tag{26}$$

$$d_i^- = \sum_{i=1}^{n} \frac{1}{3}\left[\left(\tilde{v}_{in},\ v_n^-\right)\right] \tag{27}$$

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;

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{28}$$

In essence, the design alternative with highest closeness coefficient represents the optimal design and is closest to the fuzzy positive ideal solution and farthest from fuzzy negative ideal solution (Matin et al. 2011, Balin et al. 2016).

3. Application to the Design of Pipe Bending Machine

A framework for examining the design attributes and sub features of the design concepts for pipe bending machine is presented in Figure 2. The weights of the design features (presented in Table 2) and sub features in the optimal design are considered from the parts analysis, predefined functional requirements of the pipe bending machine and expected performance of the optimal design. Exploded view of each design alternative is presented in Appendix A. In view of this, the TFNs for each design alternative based on the weights of the sub features in each design attributes are presented in Tables 3 to 6. The fuzzy decision matrix (Table 7) is obtained from the cumulative TFNs of the sub features from each design attributes. Further, the fuzzy decision matrix is normalized applying equations 5-7 in order to arrive at the normalized fuzzy decision matrix as presented in Table 8.

Table 2: Ranking Design Attributes

S/N	Design Features	TFN Value of Ranking
1	Functionality	2.5 3.0 3.5
2	Convertibility	1.5 2.0 2.5
3	Operation	2.0 2.5 3.0
4	Manufacturing	2.5 3.0 3.5

Table 3: TFNs of design alternatives based on Functionality

Design Concepts	**Functionality**							**Cumulative TFN of Sub Features**
	GF 2.5 3.0 3.5	***PS*** 2.5 3 3.5	***SG*** 2.0 2.5 3.0	***ST*** 1.5 2.0 2.5	***BF*** 2.0 2.5 3.0	***DW*** 2.5 3 3.5	***MF*** 1.5 2.0 2.5	
Concept 1	1.5 2.0 2.5	1.5 2.0 2.5	1.5 2.0 2.5	1.0 1.5 2.0	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	21.75 36.00 53.75
Concept 2	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	2.5 3.0 3.5	2.0 2.5 3.0	2.0 2.5 3.0	30.00 46.25 66.00
Concept 3	2.0 2.5 3.0	2.0 2.5 3.0	2.5 3.0 3.5	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.0 3.5	1.5 2.0 2.5	29.75 45.75 65.25
Concept 4	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	22.25 36.75 54.75

Table 4: TFNs of design concepts based on Convertibility

Design Concepts	**Convertibility**						**Cumulative TFN of Sub Features**
	SC 15 2.0 2.5	***CU*** 1.0 1.5 2.0	***FX*** 2.0 2.5 3.0	***MO*** 1.0 1.5 2.0	***CS*** 1.5 2.0 2.5	***IP*** 1.0 1.5 2.0	
Concept 1	1.0 1.5 2.0	1.5 2.0 2.5	1.5 2.0 2.5	2.5 3.0 3.5	1.5 2.0 2.5	2.0 2.5 3.0	12.75 23.25 36.75
Concept 2	1.5 2.0 2.5	1.0 1.5 2.0	1.5 2.0 2.5	2.5 3.0 3.5	2.5 3.0 3.5	1.5 2.0 2.5	14.00 24.75 38.50
Concept 3	1.0 1.5 2.0	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	14.50 25.50 39.50
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	1.5 2.0 2.5	13.25 23.75 37.25

Table 5: TFNs of design concepts based on Operation

Design Concepts	**Operation**					**Cumulative TFN of Sub Features**
	EU 2.5 3.0 3.5	***MO*** 2.0 2.5 3.0	***SH*** 2.5 3.0 3.5	***UL*** 2.0 2.5 3.0	***DT*** 1.5 2.0 2.5	
Concept 1	2.0 2.5 3.0	1.5 2.0 2.5	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	18.25 29.00 42.25
Concept 2	2.5 3.0 3.5	2.0 2.5 3.0	1.5 2.0 2.5	2.5 3.0 3.5	2.5 3.0 3.5	22.75 34.75 49.25
Concept 3	2.0 2.5 3.0	2.5 3.0 3.5	2.5 3.0 3.5	1.5 2.0 2.5	1.0 1.5 2.0	20.75 32.00 45.75
Concept 4	1.5 2.0 2.5	2.5 3.0 3.5	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	19.00 30.00 43.50

Table 6: TFNs of design concepts based on Manufacturing

Design Concepts	**Manufacturing**					**Cumulative TFN of Sub Features**
	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	
Concept 1	2.0 2.5 3.0	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	2.0 2.5 3.0	19.75 31.00 44.75
Concept 2	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.0 3.5	2.5 3.0 3.5	2.5 3.0 3.5	24.00 36.25 51.00
Concept 3	2.5 3.0 3.5	2.5 3.0 3.5	2.0 2.5 3.0	2.0 2.5 3.0	1.5 2.0 2.5	23.25 35.25 49.75

Concept 4	2.0 2.5 3.0	2.0 2.5 3.0	2.0 2.5 3.0	1.5 2.0 2.5	1.5 2.0 2.5	19.75 31.00 44.75

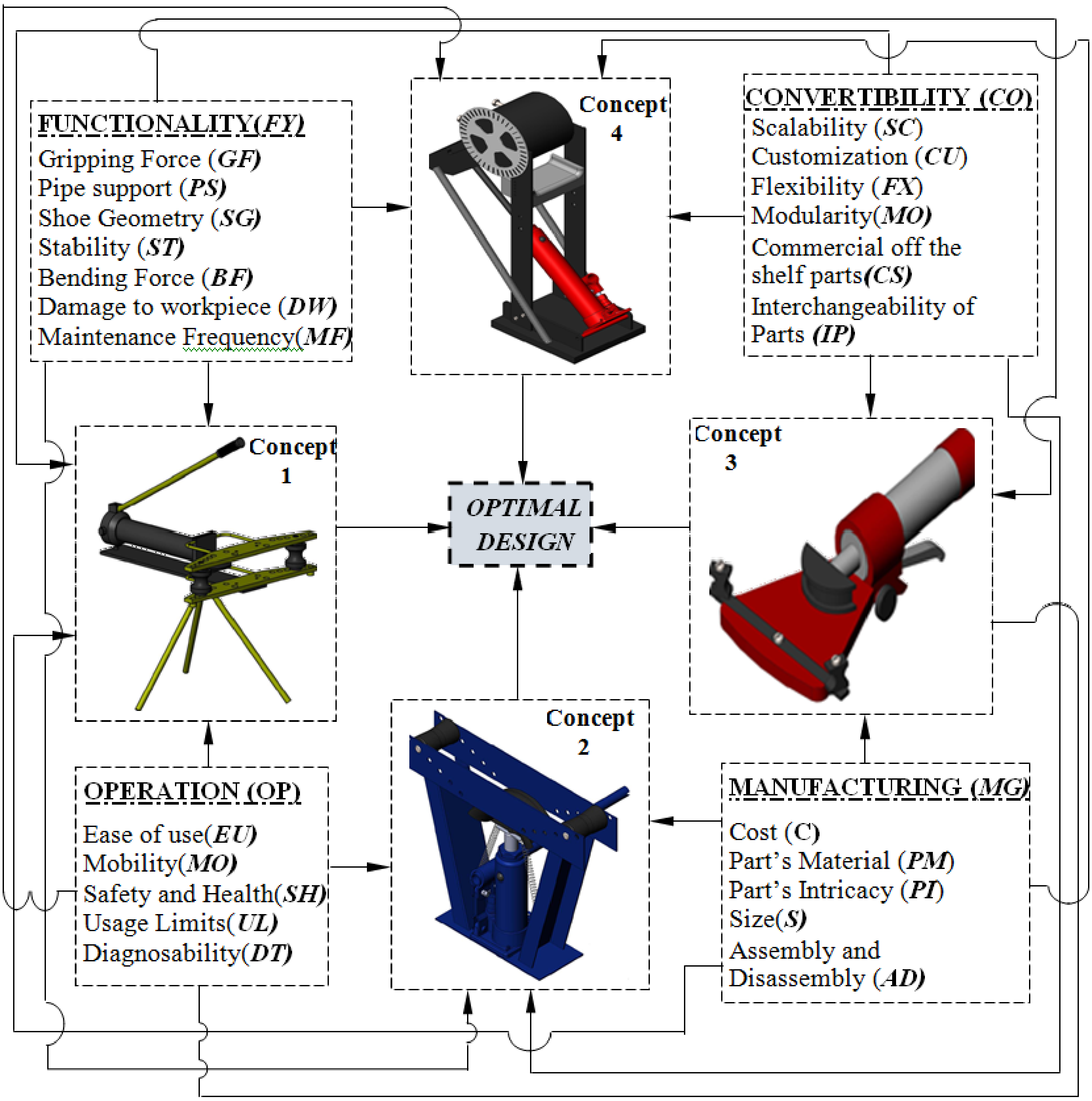

Figure 2: A framework describing the design attributes and sub features for conceptual designs of pipe bending machine (*Adopted from* Olabanji and Mpofu, 2021).

Table 7: Fuzzy Decision Matrix

Design Concepts	**Design Attributes**			
	FY 2.5 3.0 3.5	***CO*** 1.5 2.0 2.5	***OP*** 2.0 2.5 3.0	***MG*** 2.5 3.0 3.5
Concept 1	21.75 36.00 53.75	12.75 23.25 36.75	18.25 29.00 42.25	19.75 31.00 44.75
Concept 2	30.00 46.25 66.00	14.00 24.75 38.50	22.75 34.75 49.25	24.00 36.25 51.00
Concept 3	29.75 45.75 65.25	14.50 25.50 39.50	20.75 32.00 45.75	23.25 35.25 49.75
Concept 4	22.25 36.75 54.75	13.25 23.75 37.25	19.00 30.00 43.50	19.75 31.00 44.75

Table 8: Normalized Fuzzy Decision Matrix

Design Concepts	**Design Attributes**			
	FY 2.5 3.0 3.5	***CO*** 1.5 2.0 2.5	***OP*** 2.0 2.5 3.0	***MG*** 2.5 3.0 3.5
Concept 1	0.00 0.32 0.72	0.00 0.39 0.90	0.00 0.35 0.77	0.00 0.36 0.80
Concept 2	0.19 0.55 1.00	0.05 0.45 0.96	0.15 0.53 1.00	0.14 0.53 1.00
Concept 3	0.18 0.54 0.98	0.07 0.48 1.00	0.08 0.44 0.89	0.11 0.50 0.96
Concept 4	0.01 0.34 0.75	0.02 0.41 0.92	0.02 0.38 0.81	0.00 0.36 0.80

Considering the normalized performance value of the ith alternative in terms of the nth design attribute as presented in Table 8, multiplying the weights of each attribute with the normalized TFNs of the decision matrix will provide the weighted normalized fuzzy decision matrix as presented in Table 9.

Table 9: Weighted Normalized Fuzzy Decision Matrix

Design Concepts	**Design Attributes**			
	FY	***CO***	***OP***	***MG***
Concept 1	0.00 0.97 2.53	0.00 0.79 2.24	0.00 0.87 2.32	0.00 1.08 2.80
Concept 2	0.47 1.66 3.50	0.07 0.90 2.41	0.29 1.33 3.00	0.34 1.58 3.5
Concept 3	0.45 1.63 3.44	0.10 0.95 2.50	0.16 1.11 2.66	0.28 1.49 3.36
Concept 4	0.03 1.02 2.61	0.03 0.82 2.29	0.05 0.95 2.44	0.00 1.08 2.80

Also, from the weighted normalized fuzzy decision matrix, the fuzzy positive (A^{*}) and negative (A^{-}) ideal solutions for the design alternatives can be obtained from equations 24 and 25 as described in equations 40 and 41. Also the distances of each design alternatives from the positive and negative ideal solutions can be derived from equations 26 and 27 as shown in Table 10. The closeness coefficients of the design alternatives are obtained from these distances applying equation 28 as presented in Table 11.

$$A^{*}=\left[3.50 \quad 2.50 \quad 3.00 \quad 3.50\right] \tag{40}$$

$$A^{-}=\left[0.00 \quad 0.00 \quad 0.00 \quad 0.50\right] \tag{41}$$

Table 10: Distances of the design alternatives to the positive and negative ideal solutions

Design Alternatives	**Design Attributes**				**Cumulative Distances**
	FY	***CO***	***OP***	***MG***	
$d^{+}\left(\text{Concept 1},\ A^{+}\right)$	2.56	1.76	2.16	2.49	8.79
$d^{+}\left(\text{Concept 2},\ A^{+}\right)$	2.05	1.68	1.84	2.13	7.70
$d^{+}\left(\text{Concept 3},\ A^{+}\right)$	2.07	1.65	1.98	2.19	7.89
$d^{+}\left(\text{Concept 4},\ A^{+}\right)$	2.52	1.73	2.10	2.49	8.84
$d^{-}\left(\text{Concept 1},\ A^{-}\right)$	1.56	1.37	1.43	1.73	6.09
$d^{-}\left(\text{Concept 2},\ A^{-}\right)$	2.25	1.48	1.90	2.23	7.86
$d^{-}\left(\text{Concept 3},\ A^{-}\right)$	2.21	1.55	1.67	2.13	7.56
$d^{-}\left(\text{Concept 4},\ A^{-}\right)$	1.62	1.40	1.51	1.73	6.26

Table 11: Closeness Coefficient CC_i and Ranking of Design Alternatives

Design Alternatives	d^+	d^-	CC_i	*Ranking*
Concept 1	8.79	6.09	0.41	4
Concept 2	7.70	7.86	0.51	1
Concept 3	7.89	7.56	0.49	2
Concept 4	8.84	6.26	0.42	3

4. Conclusion

Identification of optimal design from a set of alternative design is necessary in order to obtain a robust design before simulation and fabrication. This process will assist the design engineer in identifying all the design requirements and features that are needed in the optimla design and how these features will be acquired from the optimal design before the detail design exercise is initiated. In this article the suitability and application of fuzzy TOPISIS which has been used in solving other real-life problems was considered using pipe bending design concepts as case studies. The reason for the application of fuzzy membership function is the fact that there is no precise way of determining values for the performance of the design concepts considering the design features and sub features and as such adopting a crisp value will make the decision process vague. Also, the decision process considered the weights of the design features and this also has a role to play in the final values obtained from the decision. Considering the application to pipe bending machine it can be concluded that fuzzy TOPSIS is a practicable tool for assessing design concepts.

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