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MATERIAL SELECTION FOR DENTAL IMPLANT - IF VIKOR MCDM TECHNIQUE

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Abstract

Decision-making is the process of finding the best option among the feasible alternatives. Material selection is a complex multiple criteria decision-making (MCDM) problem, which considers several alternatives as well as conflicting criteria. Material selection may be a critical decision and one among the foremost important factors is to think about the planning. Selection of the proper material, which may be the most vital problem that material engineers frequently encounter. This paper aims to decide on the suitable material selection for the dental implant using the Intuitionistic Fuzzy VIKOR MCDM technique. Material alternatives and criteria have been chosen suitable for the discussion. At the end of the discussion, it was found the best material to be used in the design of the implant is chromium cobalt according to the Intuitionistic Fuzzy VIKOR MCDM technique.

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1. Introduction

In multi-criteria deciding (MCDM) problem, a choice maker selects or ranks alternatives after qualitative or quantitative assessment of variety of interdependent or independent criteria. In real life situation preference information can be assessed in a qualitative way with vague or imprecise knowledge. The main aim of this paper is to evaluate the best material among the various alternatives considered for optimal design process of dental implant material. The use of dental implants has become widespread, and in particular the material used for dental implant plays a vital role since it affects the quality and lifetime of the implant. Material selection is one of the most important factors which ensure that the design in question has the optimum performance. Many classical MCDM methods have been proposed by researchers in literature, such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method [22]. The VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje in Serbian, meaning multiattribute optimization and compromise solution) method [12]. The PROMETHEE (Preference ranking Organization Method for Enrichment Evaluations) method [9], and ELECTRE (Elimination and Choice Translating reality) method [4]. Among these methods, VIKOR is shown to have some advantages over others by several researchers. Hu-Chen Liu et al. introduced a hybrid technique using induced aggregation operators and the VIKOR method to deal with the material selection problem involving conflicting criteria and further compared the ranking order with different induced aggregation operators [23]. The VIKOR method has wide application in many areas, such as design, mechanical engineering, and manufacturing [23], [11], [18]. Logistics and supply chain management and many more fields [3]. Since Zadeh put forward the concept of fuzzy sets in 1965, fuzzy numbers (triangular fuzzy numbers and trapezoidal fuzzy numbers) have been applied in MCDM problems to deal with uncertainty in the actual decision-making process. Jamil Ahmad et al. used the fuzzy linguistic VIKOR method for supplier selection problems and defuzzification done [21]. However, the hesitancy factor was not taken into consideration in the above-mentioned studies. Therefore, hesitation has an impact on the final decision taken in an uncertain environment. Atanassov extended fuzzy sets to intuitionistic fuzzy sets (IFS) which consider membership, non-membership, and degree of hesitancy at the same time. Researchers focus on the IF-VIKOR method to solve MCDM problems to deal with uncertainty in decision-making. Yunna Wu and Shuai Geng proposed IFS (Intuitionistic Fuzzy Set)-VIKOR method to evaluate the alternative coal suppliers [20]. Wan et al. put forward a new VIKOR method for the MCDM problem with TIFSs [19]. Roostae et al. used the extended VIKOR method to solve the supplier selection problem under an intuitionistic fuzzy environment [13]. Distance is an important fundamental concept of IFSs and plays a significant role in the VIKOR method. This paper's objective is to use distance measure, which captures IFS information effectively, by using intuitionistic fuzzy entropy [10].

2. Literature Review

Chitrasen Samantra et al., used fuzzy VIKOR method by representing the ratings and weight as triangular fuzzy numbers for supplier selection problems [14]. Bekir Agirgun integrated AHP and VIKOR in fuzzy rough sets and obtained the ranking for supplier selection problem [1]. Jamil Ahmada et al., used fuzzy linguistic VIKOR method for supplier selection problem and defuzzification done [2]. M. Koray CETIN, analyzed the performance of banking firms which are traded in ISE and obtained a ranking using VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) which is a compromise ranking method used as a multi-criteria decision making (MCDM) technique [5]. The intuitionistic fuzzy entropy-based TOPSIS method combined with GRA techniques is applied for the choice of sustainable building materials [7]. It is discussed that among the MCDM methods, the ranking performance of VIKOR method is the best method to select materials on the criterion having the maximum priority value [6]. An effort is taken to prioritize the best dental implant material by the fuzzy AHP method based on characteristics of the dental implant [15]. Three important criteria in fulfilling the purpose of material selection have been chosen and analyzed using simple entropy-based simple additive weighting and the AHP method [16]. The ranking method for selecting the priority parameter for manufacturing an axle for a motorcycle is explored using AHP and ANP [17]. To select the most suitable material for specific applications in diverse fields the use of MCDM methods such as VIKOR, PROMETHE, and TOPSIS have been reported in the literature [8].

3. Preliminaries

A. Intuitionistic Fuzzy set (IFS)

An intuitionistic fuzzy set A in the universe of discourse X is defined as follows

$$A = \{\langle x, \mu_A(x), \vartheta_A(x)\rangle / x \in X\} \tag{1}$$

Where $\mu_A(x), \vartheta_A(x) : X \to [0, 1]$ respectively represent the membership and non-membership functions on condition that $0 < \mu_A(x) + \vartheta_A(x) \leq 1$. Additionally, IFS introduces a third construct $\pi_A(x)$, the intuitionistic fuzzy index which expresses whether or not x belongs to A.

$$\pi_A(x) = 1 - \mu_A(x) + \vartheta_A(x) \tag{2}$$

The intuitionistic index in (2) measures the hesitancy degree of element x in A where it becomes obvious that $0 < \pi_A(x) < 1$, for each $x \in X$. A small value of $\pi_A(x)$ implies that information about x is more certain. On the other hand, a higher value of the hesitancy degree $\pi_A(x)$ means the information that x holds is more uncertain. An intuitionistic fuzzy set can therefore fully be defined as:

$A = \{\langle x, \mu_A(x), \vartheta_A(x), \pi_A(x)\rangle / x \in X\}$ where $\mu_A \in [0, 1], \vartheta_A \in [0, 1]$,

$\pi_A \in [0, 1]$. π_A is also frequently referred to as the degree of hesitancy of x to A. It expresses the degree of uncertainty in the assessment as to whether x is, or is not, a member of IFS.

B. Stepwise algorithm for proposed IF-VIKOR method

For a MCDM problem with n alternatives $A_i (i = 1, 2, \ldots, m)$, the performance of the alternative A_i concerning the attribute $C_j (j = 1, 2, \ldots, n)$, is assessed by a decision organization with several decision-makers $D_q (q = 1, 2, \ldots, l)$. The corresponding weights of attributes are denoted by

$\omega_j (j = 1, 2, \ldots, n), 0 \leq \omega_j \leq 1, \sum_{j=1}^{n} \omega_j = 1,$ and the weights of DMs are denoted by $\lambda_q (q = 1, 2, \ldots, l)$, $0 \leq \lambda_q \leq 1$, $\sum_{q=1}^{l} \lambda_q = 1$. This algorithm can be used for MCDM problem with intuitionistic fuzzy information, it includes seven steps.

Step 1. Frame the information regarding assessment:

Assume that DMs $D_q (q = 1, 2, \ldots, l)$, provide their opinion of the alternatives A_i concerning each attribute C_j by using IFNs $x_{ij}^{q} = (u_{ij}^{q}, v_{ij}^{q}, \pi_{ij}^{q})$ or linguistic values represented by IFNs. Then, the assessments given by D_q can be expressed as

$$D^{(q)} = \begin{bmatrix} x_{11}^{(q)} & \ldots & x_{1n}^{(q)} \\ \vdots & \ddots & \vdots \\ x_{m1}^{(q)} & \ldots & x_{mn}^{(q)} \end{bmatrix} \tag{1}$$

Step 2. Find the weights of DMs.

According to the degree of fuzziness and non-specificity of assessments provided by DMs. In this step DM weight $\lambda_q (q = 1, 2, \ldots, l)$ can be acquired by intuitionistic fuzzy entropy measure objectively. The lower the degree of fuzziness and non-specificity is, the smaller the entropy is and the bigger the weight of DM is and vice versa. The intuitionistic fuzzy entropy of assessments provided by D_q can be obtained as follows:

$$E_q = \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{\min (u_{ij}^{(q)}, v_{ij}^{(q)}) + \pi_{ij}^{(q)}}{\max (u_{ij}^{(q)}, v_{ij}^{(q)}) + \pi_{ij}^{(q)}} \tag{2}$$

Then the weight of DM D_q can be defined as follows:

$$\lambda_q = \frac{1 - E_q}{l - \sum_{q=1}^{l} E_q}, \text{ where } l \text{ is the number of } DM_s. \tag{3}$$

Step 3. Establish the aggregated intuitionistic fuzzy decision matrix.

All individual decision matrixes $D^{(q)}$ can be converted into an aggregated decision matrix as follows:

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

Where $x_{ij} = (v_{ij}, \vartheta_{ij}, \pi_{ij})$, $u_{ij} = 1 - \prod_{q=1}^{l} (1 - u_{ij}^{q})^{\lambda_q}$, $v_{ij} = \prod_{q=1}^{l} (v_{ij}^{q})^{\lambda_q}$, $\pi_{ij} = 1 - u_{ij} - v_{ij}$.

Step 4. Find the weights of attributes.

Similar to step 2, the unknown weight of attribute $\omega_j (j = 1, 2, \ldots, n)$, can be determined by entropy measure to effectively reduce the subjective randomness. The entropy with respect to C_j.

$$E_j = \frac{1}{m} \sum_{i=1}^{m} \frac{\min(u_{ij}, v_{ij}) + \pi_{ij}}{\max(u_{ij}, v_{ij}) + \pi_{ij}} \tag{5}$$

Then the weight of attribute C_j can be defined as follows:

$$\omega_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j} \tag{6}$$

where n is the number of attributes.

Step 5. Find the best and worst value.

The best value x_j^+ and the worst value x_j^- for each attribute C_j can be defined as follows:

$$x_j^+ = \begin{cases} \max\limits_{i=1, 2, \ldots, m} x_{ij}, \text{ for benefit attribute } C_j \\ \min\limits_{i=1, 2, \ldots, m} x_{ij}, \text{ for cost attribute } C_j, \end{cases} j = (1, 2, \ldots, n) \tag{7}$$

$$x_j^- = \begin{cases} \min\limits_{i=1, 2, \ldots, m} x_{ij}, \text{ for benefit attribute } C_j \\ \max\limits_{i=1, 2, \ldots, m} x_{ij}, \text{ for cost attribute } C_j, \end{cases} j = (1, 2, \ldots, n)$$

Step 6. Compute the values S_i, R_i, Q_i

$S_i \rightarrow$ group utility value $R_i \rightarrow$ the individual regret value $Q_i \rightarrow$ the compromise value

$$S_i = \sum_{j=1}^{n} \omega_j \left(\frac{d(x_j^+, x_{ij})}{d(x_j^+, x_j^-)} \right) \quad R_i = \max_{j\omega j} \left(\frac{d(x_j^+, x_{ij})}{d(x_j^+, x_j^-)} \right)$$

$$Q_i = \gamma \left(\frac{S_i - S^*}{S^- - S^*} \right) + (1 - \gamma) \left(\frac{R_i - R^*}{R^- - R^*} \right) \tag{8}$$

where $S^- = \max_i S_i$, $S^* = \min_i S_i$, $R^- = \max_i R_i$, $R^* = \min_i R_i$, γ is the coefficient of decision mechanism, the compromise solution can be chosen by either $(\gamma > 0.5)$, $(\gamma = 0.5)$, or $(\gamma < 0.5)$.

Step 7. Rank the alternatives and derive the compromise solution.

Sort S_i, R_i, Q_i in ascending order and generate three ranking lists $S_{[\cdot]}, R_{[\cdot]}, Q_{[\cdot]}$. Then, the alternative $A^{(1)}$ that ranks the best in $Q_{[\cdot]}$ (minimum value) and fulfills following two conditions simultaneously would be the compromise solution.

Condition 1 (acceptable advantage)**.**

$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{m-1}$, where $A^{(1)}$ and $A^{(2)}$ are the top two alternatives in Q_i.

Condition 2 (acceptable stability)**.** The alternative $A^{(1)}$ should be the best ranked by S_i and R_i.

If the above conditions cannot be satisfied simultaneously, there exist multiple compromise solutions.

(i) alternatives $A^{(1)}$ and $A^{(2)}$ if only condition is not satisfied.

(ii) alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(u)}$ if condition 1 is not satisfied, where $A^{(u)}$ is got by the relation $Q(A^{(u)}) - Q(A^{(1)}) < \frac{1}{m-1}$ for the maximum.

4. Application and Results

The aim of this study is to determine the best material for use in dental implant design. Five criteria C1-(young's modulus), C2-yield strength, C3-hardness, C4-Cost of the material, and C5-Corrosion of the material. Among the five chosen, three criterions (C_1, C_2, C_3) are benefit and two (C_4, C_5) are cost criteria. The benefit criteria are to be maximized; cost criteria are to be minimized. For a better design, the values of benefit criteria should be high when compared to the values of cost criteria. After preliminary screening four alternative materials Titanium (A1), Nickel (A2), Nickel titanium (A3), Chromium Cobalt (A4) are taken for further study. Three decision makers (DMs) are used to evaluate and select the appropriate alternative based on the criteria.

Algorithm.

Step 1. The alternatives A_i are assessed by the decision makers (DM) based on the criteria C_j represented by linguistic rating variables in terms of IFNs (Table 3).

Table 3. Linguistic terms for rating the alternatives with IFNs.

Linguistic variables	IFNs
Extremely Good (EG)	(0.95, 0.05, 0.00)
Good (G)	(0.80, 0.10, 0.10)
Medium good (MG)	(0.65, 0.25, 0.10)
Medium (M)	(0.50, 0.40, 0.10)
Extremely poor (EP)	(0.05, 0.95, 0.00)
Poor (P)	(0.20, 0.70, 0.10)
Medium poor (MP)	(0.35, 0.55, 0.10)

Table 4. Rating of the alternatives from DMs.

Attributes	DM1				DM2				DM3			
	A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4
C1	MG	M	MG	MP	G	MP	M	MG	M	G	M	G

C2	G	MP	G	G	G	MG	M	M	G	G	G	MG
C3	MP	MG	M	M	MP	M	G	MG	MP	MG	EG	MG
C4	MG	M	EG	M	G	M	MG	MG	MG	M	G	M
C5	M	G	MG	MG	M	G	MG	P	MG	MG	G	MG

Step 2. Using (2) and (3), the weights of DMs can be obtained as $\lambda_1 = 0.3585$, $\lambda_2 = 0.3508$, $\lambda_3 = 0.2884$.

Step 3. By using (4) the aggregated decision matrix is obtained as follows

$D =$

$$\begin{bmatrix} (0.68163, 0.20716) & (0.80000, 0.10000) & (0.35000, 0.55000) & (0.71275, 0.18090) & (0.54890, 0.34929) \\ (0.57887, 0.30007) & (0.62818, 0.25463) & (0.60303, 0.29513) & (0.50000, 0.40000) & (0.76496, 0.13025) \\ (0.56001, 0.33798) & (0.72360, 0.16315) & (0.81378, 0.13458) & (0.85174, 0.10779) & (0.68163, 0.20716) \\ (0.62818, 0.25463) & (0.67518, 0.21250) & (0.60226, 0.29588) & (0.55916, 0.3384) & (0.53137, 0.35960) \end{bmatrix}$$

Step 4. Using (5) and (6) the weights of the attributes are obtained as

$$\omega_1 = 0.26802,\ \omega_2 = 0.08161,\ \omega_3 = 0.26165,\ \omega_4 = 0.24355,\ \omega_5 = 0.14518.$$

Step 5. By using (7) the best and the worst values of attribute ratings is calculated.

Best values: $x_1^+ = (0.68163,\ 0.20716)$, $x_2^+ = (0.80000,\ 0.10000)$, $x_3^+ = (0.81378,\ 0.13458)$, $x_4^+ = (0.50000,\ 0.40000)$, $x_5^+ = (0.53137,\ 0.35960)$.

Worst values: $x_1^- = (0.56001,\ 0.33798)$, $x_2^- = (0.62818,\ 0.25463)$, $x_3^- = (0.35000,\ 0.55000)$, $x_4^- = (0.85174,\ 0.10779)$, $x_5^- = (0.76496,\ 0.13025)$

Step 6. Choosing $\gamma = 0.5$, the values of S_i, R_i, Q_i for each alternative is obtained.

Table 5. The values of S, R, Q for all alternatives by the IF-VIKOR method.

value	A1	A2	A3	A4
S	0.41764	0.592	0.47422	0.40119
R	0.26165	0.246	0.26802	0.16939
Q	0.51084	0.891	0.69149	0

Step 7. From Table 5 we have $Q_4 < Q_1 < Q_3 < Q_2$ which implies A_4 (minimum value) ranks best in terms of Q. In addition, $Q_1 - Q_4 = 0.51084 \geq 0.25$. A_4 is also best ranked by S_i and R_i which shows that A_4 is the unique compromise solution for this problem.

5. Conclusion

Since the IF-VIKOR method is an effective MCDM method to obtain a compromise solution, and IFSs are an effective tool to depict fuzziness and non-specificity in assessment information, this paper combines them to deal with those material selection problems in which the importance are described in crisp value forms. To illustrate the feasibility and effectiveness of the IF-VIKOR, material selection for dental implant problem is considered in this work and the best material to be used in design of dental implant is chromium cobalt according to Intuitionistic Fuzzy VIKOR MCDM technique.

References

[1] B. Ağırgün, Supplier selection based on fuzzy rough-AHP and VIKOR, Nevşehir Üniversitesi Fen Bilim. Enstitü Derg. 2(2) (2012), 1-11.

[2] J. Ahmad, J. Xu, M. Nazam and M. Kashif, A fuzzy linguistic VIKOR multiple criteria group decision making method for supplier selection, Int. J. Sci. Basic Appl. Res. 19(1) (2015), 1-16.

[3] G. Akman, Evaluating suppliers to include green supplier development programs via fuzzy c-means and VIKOR methods, Comput. Ind. Eng. 86 (2015), 69-82.

[4] R. Benayoun, B. Roy and B. Sussman, ELECTRE: Une méthode pour guider le choix en présence de points de vue multiples, Note Trav. 49 (1966).

[5] M. K. Cetin, Multi-Criteria analysis of banks' performances, Int. J. Econ. Financ. Stud. 2 (2010), 73-78.

[6] S. Chakraborty and P. Chatterjee, Selection of materials using multi-criteria decision-making methods with minimum data, Decis. Sci. Lett. 2 (2013), 135-148.

[7] C. H. Chen, A new multi-criteria assessment model combining GRA techniques with intuitionistic fuzzy entropy-based TOPSIS method for sustainable building materials supplier selection, Sustain 11(8) (2019), 22-65.

[8] I. Emovon and O. S. Oghenenyerovwho, Application of MCDM method in material selection for optimal design: A review, Results Mater. 7 (2020), 100-115.

[9] W. De Keyser and P. Peeters, A note on the use of PROMETHEE multicriteria methods, Eur. J. Oper. Res. 89(3) (1996), 457-461.

[10] X. Luo and X. Wang, Extended VIKOR method for intuitionistic fuzzy multiattribute decision-making based on a new distance measure, Math. Probl. Eng. (2017), pp. 16.

[11] P. P. Mohanty and S. Mahapatra, A compromise solution by VIKOR method for ergonomically designed product with optimal set of design characteristics, Procedia Mater. Sci. 6 (2014), 633-640.

[12] S. Opricovic, Multicriteria optimization of civil engineering systems, Fac. Civ. Eng. Belgrade 2 (1998), 5-21.

[13] R. Roostaee, M. Izadikhah, F. H. Lotfi and M. Rostamy-Malkhalifeh, A multi-criteria intuitionistic fuzzy group decision making method for supplier selection with VIKOR method, Int. J. Fuzzy Syst. Appl. 2 (2012), 1-17.

[14] C. Samantra, S. Datta and S. S. Mahapatra, Application of fuzzy based VIKOR approach for multi-attribute group decision making (MAGDM) a case study in supplier selection, Decis. Mak. Manuf. Serv. 6(1-2) (2012), 25-39.

[15] S. Satapathy, M. Pradhan and B. B. Nayak, Selection of material for dental implant selection of material for dental implant, AIP Conf. Proc. 2273 (2020), 50056.

[16] E. Senyigit and B. Demirel, The selection of material in dental implant with entropy based simple additive weighting and analytic hierarchy process, Sigma J. Eng. Nat. Sci. Muhendis. Ve Fen Bilim. Derg. 36(3) (2018), 731-740.

[17] A. S. P. G. Ta and R. K. Srivastava, Application of AHP and ANP methods for selection of best material for an Axle, Int. J. Innov. Res. Sci. Eng. Technol. 4 (2015), 2894-2901.

[18] G. Vats and R. Vaish, Piezoelectric material selection for transducers under fuzzy environment, J. Adv. Ceram. 2 (2013), 141-148.

[19] S. P. Wan, Q. Y. Wang and J. Y. Dong, The extended VIKOR method for multi-attribute group decision making with triangular intuitionistic fuzzy numbers, Knowledge-Based Syst. 52 (2013), 65-77.

[20] Y. Wu, H. Xu and S. Geng, Research on the optimization of coal suppliers based on intuitionistic fuzzy set and TOPSIS method, Energy Educ., Sci. Technol. Part A Energy Sci. Res. 32 (2014), 6811-6828.

[21] Z. Wu, K. Xu and L. Zhong, A Consensus Based VIKOR Method Using the 2-Tuple Linguistic Model, In J. Xu, S. Nickel, V. Machado and A. Hajiyev, (eds.), Proceedings of the Ninth International Conference on Management Science and Engineering Management, Advances in Intelligent Systems and Computing, Springer, Berlin, Heidelberg vol. 362 (2015). https://doi.org/10.1007/978-3-662-47241-5_37

[22] K. P. Yoon and C. L. Hwang, Multiple Attribute Decision Making: An Introduction 1, (1995).

[23] X. Y. You, J. X. You, H. C. Liu and L. Zhen, Group multi-criteria supplier selection using an extended VIKOR method with interval 2-tuple linguistic information, Expert Syst. Appl. 42 (2015), 1906-1916.