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Parting curve selection and evaluation using a new Intuitionistic Fuzzy - TODIM MCDM approach.

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ABSTRACT

Parting curve selection and evaluation plays a major role in mold design in engineering field. Fuzzy based multiple criteria decision making (MCDM) is an effective tool for evaluating and ranking problems involving complex interconnected multiple criteria. Therefore, this paper proposes an intuitionistic fuzzy based TODIM MCDM approach to solve parting curve selection problem. In the proposed model, the ratings of alternatives and importance weights of criteria for parting curve selection are expressed in linguistic terms. The membership functions of fuzzy evaluations value in proposed model given in linguistic terms characterized by intuitionistic fuzzy numbers (IFNs). For making the procedure easier and practical, the normalized weighted ratings are defuzzified into crisp values by using Intuitionistic fuzzy weighted averaging (IFWA) operator to aggregate individual opinions of decision makers for group assessment. An example of parting curve selection and evaluation is given. The result shows that the proposed approach is very logical and effective in selecting the optimal parting curve for the molded part. Finally, the paper compares the proposed approach with another fuzzy MCDM approach to highlight the advantages and applicability of the method.

1. INTRODUCTION

Parting curve is a continuous closed curve on surfaces of the part where mold meet. From technical view point, parting direction is a direction along which mold pieces are separated. The contacting surfaces of mold pieces when assembled are termed parting surfaces. Parting direction, parting curve and parting surface are main factors that play decisive roles in entire structure and processing cost of mold. For many complex parts with free-form surfaces, several parting curves can be generated and designers decide which one is most suitable parting curve [1]. So, an important problem is to define appropriate criteria for choosing the best curve from the alternatives. The generation of parting curve is one of top priority works in field of parting-based design. Numerous approaches are ineffective when the molded parts are complex as most existing approaches are developed based on concepts of accurate measurement and crisp evaluations.

Ravi and Srinivasan [2] proposed a set of nine decision criteria for computer aided parting curve and surface design including projected area, flatness, draw, undercuts, dimensional stability and location of surfaces but did not give any suggestion to determine the weight coefficients of each criterion. Chakraborty and Reddy [3] proposed an algorithm using flatness of parting surface, draw depth and

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surface area of undercut for determination of parting direction, parting line and parting surface. But the coefficient weights were set to be unity in determining best parting direction which does not accurately reflect the role of each criterion. Yin et al [4] presented a method for mold ability analysis based on manufacturing using part geometry. Then fuzzy MCDM is chosen to choose alternatives based on draw depth, draft angle and volume of undercuts.

So, a hybrid fuzzy MCDM based optimization approach is required for selection of most suitable parting curve. Numerous approaches have been proposed to solve fuzzy MCDM problems. In this method, final evaluation values of alternatives are fuzzy numbers. For decision making a proper ranking approach is needed to defuzzify these fuzzy numbers. Many fuzzy number ranking approaches are proposed to defuzzify fuzzy numbers into crisp numbers but cannot guarantee a consistent result in every situation. Among the ranking approaches, the fuzzy-TODIM Combining fuzzy set theory and TODIM is a novel approach. TODIM is a discrete multi-criteria method founded on prospect theory [4]. The TODIM method has been successfully used and empirically validated in different applications. This method is based on a description, proved empirically, of how people make effective decisions when faced with risk.

Because the TODIM evaluation criteria are subjective, qualitative, and described with linguistic information, intuitionistic fuzzy set theory [5] provides a more desirable evaluation tool to assist managers. However, no study has jointly considered the intuitionistic fuzzy set theory and TODIM. By proposing a hybrid intuitionistic fuzzy set and TODIM approach, this study enables the qualitative measures in linguistic terms to be presented by IFSs and to be defuzzified subsequently into a crisp value by intuitionistic fuzzy weighted averaging (IFWA) operator for analysis. TODIM will then be applied to evaluate the alternatives using gain and loss functions.

The rest of the paper is organized as follows: Section 2 presents some basic notions and definitions of intuitionistic fuzzy sets and TODIM. Section 3 develops the hybrid Intuitionistic fuzzy-TODIM algorithm. Section 4 applies the proposed model to a parting curve evaluation and selection problem. Section 5 compares the proposed method with another fuzzy MCDM method. Conclusion and future direction of research are drawn in Section 6.

2. PRELIMINARIES

2.1. Let X be a fixed set. An Intuitionistic fuzzy set IFS [1] in fixed set X is defined as

$A = \{< x, \mu_A(x), \nu_A(x) > | x \in X\}$, which contains the membership function $\mu_A(x)$ and non-membership function $\nu_A(x)$ satisfying $0 \leq \mu_A(x) + \nu_A(x) \leq 1$.

In addition, $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is called the hesitation degree of $x \in X$.

2.2. For any three IFNs $\alpha = (\mu_\alpha, \nu_\alpha)$, $\alpha_1 = (\mu_{\alpha_1}, \nu_{\alpha_1})$ and $\alpha_2 = (\mu_{\alpha_2}, \nu_{\alpha_2})$ the following operations laws [9] are valid:

(1) $\alpha_1 \oplus \alpha_2 = (\mu_{\alpha_1} + \mu_{\alpha_2} - \mu_{\alpha_1}\mu_{\alpha_2}, \nu_{\alpha_1}\nu_{\alpha_2})$

(2) $\alpha_1 \otimes \alpha_2 = (\mu_{\alpha_1}\mu_{\alpha_2}, \nu_{\alpha_1} + \nu_{\alpha_2} - \nu_{\alpha_1}\nu_{\alpha_2})$

(3) $\lambda\alpha = (1 - (1 - \mu_\alpha)^\lambda, (\nu_\alpha)^\lambda)$

(4) $\alpha^\lambda = ((\mu_\alpha)^\lambda, 1 - (1 - \nu_\alpha)^\lambda)$

2.3. Let $\alpha = (\mu_\alpha, \nu_\alpha)$, be a IFNs, a score function S [11] of intuitionistic fuzzy value can be expressed as:

$S(\alpha) = \mu_\alpha - \nu_\alpha$, $S(\alpha) \in [-1,1]$ to measure the score of IFN α .

2.4. Let $\alpha = (\mu_\alpha, \nu_\alpha)$, be IFNs, an accuracy function H [12] of an intuitionistic fuzzy value can be represented as $H(\alpha) = \mu_\alpha + \nu_\alpha$, $H(\alpha) \in [0,1]$ to evaluate the degree of accuracy of IF value α.

2.5. For comparing any two IFNs $\alpha_1 = (\mu_{\alpha_1}, \nu_{\alpha_1})$ and $\alpha_2 = (\mu_{\alpha_2}, \nu_{\alpha_2})$, the following method [9] was proposed based on the score function and accuracy function

If $S(\alpha_1) < S(\alpha_2)$ then

If $S(\alpha_1) = S(\alpha_2)$, and

(1) $H(\alpha_1) < H(\alpha_2)$ then $\alpha_1 < \alpha_2$;

(2) $H(\alpha_1) = H(\alpha_2)$ then $\alpha_1 = \alpha_2$.

2.6. Following the conceptions and operations of IFNs, [10] introduced the IFWA operator as follows. Let $\alpha_i = (\mu_{\alpha_i}, \nu_{\alpha_i}), i = 1,2,3, \ldots . n$ be a collection of IFNs and IFWA: $\Omega^n \longrightarrow \Omega$, then

$$IFWA_w(\alpha_1, \alpha_2, .., \alpha_n) = w_1\alpha_1 + w_2\alpha_2 + .. + w_n\alpha_n$$

$$= 1 - \prod_{i=1}^{n} (1 - \mu_{\alpha_i})^{w_i}, \prod_{i=1}^{n} (\mu_{\alpha_i})^{w_i})$$

called an IFWA operator of dimension n, where $w = (w_1, w_2, .. w_n)^T$ is the weight vector of α_i.

2.7. Prospect theory: (Known as TODIM in Portuguese) The value function used in this theory is described in form of a power law expressed as:

$v(x) = \begin{cases} x^{\alpha} & if\ x \geq 0 \\ -\theta(-x)^{\beta} & if\ x < 0 \end{cases}$ where are parameters related to gains and losses, respectively. The parameters α and β represents a characteristic that is, steeper for losses than for gains when considering cases for which risk aversion $\theta > 1$.

3. MODEL ESTABLISHMENT

The method uses paired comparisons between the criteria by using technically simple resources to eliminate occasional inconsistencies resulting from these comparisons.

TODIM allows value judgments to be performed on a verbal scale using a criteria hierarchy, fuzzy value judgments and interdependence relationships among the alternatives TODIM then calculates the partial dominance matrices and the final dominance matrix.

The first calculation that the decision makers must define is a reference criterion (typically the criterion with the greatest importance weight).

Assuming that a MCDM problem has l decision makers DM_k $(k = 1,2,..,l)$, m alternatives A_i $(i = 1,2,\dots..,m)$, and n decision criteria C_j $(j = 1,2,\dots..,n)$. Each decision maker DM_k is provided with a weight λ_k satisfying

$$\sum_{k=1}^{l} \lambda_k = 1.$$

Step 1: Aggregate the DMs opinion to construct an intuitionistic fuzzy decision matrix.

Let $r_{ij}^k = (\mu_{ij}^k, \nu_{ij}^k)$ be the IFN provided byDM_k on assessment of A_i with respect to C_j.

The aggregated intuitionistic fuzzy rating of alternatives with respect to each criterion is calculated based on IFWA operator as:

$$r_{ij} = IFWA\left(r_{ij}^1, r_{ij}^2, \dots. r_{ij}^l\right) = [1 - \prod_{k=1}^{l} (1 - \mu_{ij}^k)^{\lambda_k}, \prod_{i=1}^{n} (v_{ij}^k)^{\lambda_k}]$$

Step 2: Determine the weights of criteria.

Let $w_j^k = (\mu_j^k, v_j^k)$ be the weight of criterion C_j given by kth decision maker DM.

The aggregated intuitionistic fuzzy weights $(w_j)$of criteria calculated by

$$w_j = IFWA\left(w_j^1, w_j^2, \dots. w_j^l\right) = (1 - \prod_{k=1}^{l} (1 - \mu_j^k)^{\lambda_k}, \prod_{i=1}^{n} (\mu_{\alpha_i})^{w_i})$$

where $w_j = (\mu_j, v_j),\ j = 1,2,3, \dots. n$

The normalized weighs of criteria $w_j = (\mu_j, v_j)$, can be obtained by

$$\overline{w}_j = \frac{\mu_j + \pi_j\left(\frac{\mu_j}{\mu_j + v_j}\right)}{\sum_{j=1}^{n}\left(\mu_j + \pi_j\left(\frac{\mu_j}{\mu_j + v_j}\right)\right)}, j = 1,2,3, \dots., n$$

Step 3: Calculate relative weight w_{jr} of attribute C_j to the reference attribute C_r,

i.e., $w_{jr} = \frac{w_j}{w_r};\ \ j;\ r\ \in N$; where $w_r = \max\{w_j : j \in N\}$.

Step 4: Calculate the dominance degree of alternative A_i over alternative $A_k$concerning attribute C_j, $\Phi(A_i, A_k) =$

$$\begin{cases} \sqrt{(y_{ij} - y_{kj}) w_{jr} / \left(\sum_{j=1}^{n} w_{jr}\right)}, & (y_{ij} - y_{kj}) > 0, \\ 0, & (y_{ij} - y_{kj}) = 0, \\ -\frac{1}{\theta}\sqrt{\left((y_{kj} - y_{ij})\right)\left(\sum_{j=1}^{n} w_{jr}\right)/w_{jr}}\ , & (y_{ij} - y_{kj}) < 0, \end{cases}$$

where θ is the attenuation factor of the losses. $y_{ij} - y_{kj}$, denotes the gain of alternative A_i over alternative A_k concerning attribute C_j if $y_{ij} - y_{kj} > 0$ and the loss if $y_{ij} - y_{kj} < 0$.

Step 5: Calculate the overall dominance degree of alternative A_i over alternative A_k, i.e.,

$$\delta(A_i, A_k) = \sum_{j=1}^{n} \Phi_j(A_i, A_k)\ i, k\ \epsilon M$$

Step 6: Calculate the overall value of alternative Ai, i.e.,

$$\xi(A_i) = \frac{\sum_{k=1}^{m} \delta(A_i, A_k) - \min_{i \in M} \sum_{k=1}^{m} \delta(A_i, A_k)}{\max_{i \in M} \sum_{k=1}^{m} \delta(A_i, A_k) - \min_{i \in M} \sum_{k=1}^{m} \delta(A_i, A_k)}, (i \in M)$$

Step 7: Rank all the alternatives and select the most desirable one(s) according to the overall values of alternatives. The greater $\xi(A_i)$ is, the better alternative $A_i$will be.

4. NUMERICAL EXAMPLE

This section applies the proposed algorithm to solve a parting curve selection and evaluation problem to demonstrate the feasibility and applicability of proposed approach. Suppose that designer desires to select an efficient parting curve for optimal mold design process. In the selection A_1, A_2, A_3, A_4 and A_5 are five feasible parting curves of molded part and D_1, D_2, D_3 and D_4 are four designers employed to evaluate the five parting curves based on five criteria: undercuts C_1 , flatness C_2, projected area C_3 , dimensional stability C_4 and draw C_5.

Suppose that evaluation ratings of parting curves A_1, A_2, A_3, A_4 and A_5 under each criteria C_1, C_2, C_3, C_4 and C_5 are presented by linguistic terms shown in Table III and related Intuitionistic fuzzy numbers are shown in Table I.

Also, suppose that linguistic weighing set and related intuitionistic fuzzy numbers are employed to assess the importance of all criteria shown in Table IV and related ratings numbers are shown in Table II.

Table I. Linguistic Terms for Rating Alternatives

Linguistic Terms	IFNs
Extremely Poor (EP)	(0.00, 0.90)
Very Poor (VP)	(0.10, 0.85)
Poor(P)	(0.25, 0.60)
Moderately Poor (MP)	(0.40, 0.50)
Fair(F)	(0.50, 0.45)
Moderately Good (MG)	(0.60, 0.30)
Good(G)	(0.75, 0.10)
Very Good (VG)	(0.90, 0.05)
Extremely Good (EG)	(1.00, 0.00)

Table II. Linguistic Terms for Rating Criteria

Linguistic Terms	IFNs
Very Low (VL)	(0.15, 0.75)
Low (L)	(0.35, 0.50)
Medium (M)	(0.50, 0.45)
High (H)	(0.75, 0.10)
Very High (VH)	(0.85, 0.10)

Table III. Assessed Information on the Five Criteria

Criteria	Decision Makers	Supplier alternatives				
		A_1	A_2	A_3	A_4	A_5
C_1	DM_1	F	F	MG	MG	F
	DM_2	MG	MG	F	F	MG
	DM_3	F	MG	MG	MG	MG
	DM_4	MG	MG	MG	F	F
C_2	DM_1	F	F	MG	F	F
	DM_2	G	MP	F	F	G
	DM_3	MG	F	MG	MG	MG
	DM_4	G	MG	G	F	F
C_3	DM_1	G	F	F	MG	MG
	DM_2	F	MG	F	G	MG
	DM_3	MG	MG	MP	MG	G
	DM_4	F	G	MG	VG	VG
C_4	DM_1	MG	VG	F	MP	G
	DM_2	F	VG	VG	MP	G
	DM_3	MG	G	G	MG	MG
	DM_4	G	G	VG	F	MG
C_5	DM_1	F	MG	VG	MG	F
	DM_2	G	MG	VG	MG	F
	DM_3	MG	G	VG	MG	MG
	DM_4	F	MG	G	F	MG

Table IV. Importance Weights of Criteria

Criteria	Decision Makers			
	DM_1	DM_2	DM_3	DM_4
C_1	H	M	VH	H
C_2	VH	H	H	VH
C_3	M	H	M	H
C_4	VH	VH	H	VH
C_5	M	M	H	M

After converting the linguistic evaluation into IFNs by using Table I, the aggregated intuitionistic fuzzy ratings of alternatives and criteria are calculated based on IFWA operator and result shown in Table V.

Table V: Normalized Intuitionistic Fuzzy Differences for Five Alternatives and Normalized Weights of Criteria

	C_1	C_2	C_3	C_4	C_5
Weights	0.208	0.218	0.189	0.219	0.166
A_1	0.720	0.000	0.730	0.528	0.809
A_2	0.000	1.000	0.438	0.057	0.584
A_3	0.100	0.214	1.000	0.000	0.000
A_4	1.000	0.980	0.043	1.000	1.000
A_5	0.860	0.537	0.000	0.598	0.877

Table VI: The Over All Dominance Degree $\delta(A_i)$ of Alternative A_i

$\delta(A_1)$	$\delta(A_2)$	$\delta(A_3)$	$\delta(A_4)$	$\delta(A_5)$
-2.119	-5.273	-8.386	2.742	-1.734

Finally, the overall value of alternative A_i, i.e., $\xi(A_i)$ is calculated and ranking and selection of the most desirable one(s) is done according to the overall values of alternatives. The greater $\xi(A_i)$ is, the better alternative A_i will be. The result is shown in Table VII.

Table VII: The Overall Value $\xi(A_i)$ of Alternative A_i

$\xi(A_1)$	$\xi(A_2)$	$\xi(A_3)$	$\xi(A_4)$	$\xi(A_5)$
0.563174	0.279745	0	1	0.59777

Therefore, the ranking order of five parting curves is $A_4 > A_5 > A_1 > A_2 > A_3$.

So, the best parting curve is A_4 according to decision makers.

5. COMPARISION AND DISCUSSION

This section compares the proposed approach with another fuzzy MCDM approach to demonstrate its applicability. We consider the numerical example taken by Quang et al [1] in which we take the same alternatives, criteria and decision makers. Here the method uses extension of fuzzy MCDM which uses new maximizing and minimizing set ranking approach to determine the ranking of alternatives.

Using MATLAB for calculation and applying the steps of algorithm proposed by the above paper, the final fuzzy evaluation values of each alternative is given in Table VIII.

Table VIII. The Final Fuzzy Evaluation Values of Each Alternative

	A_i	C_i	B_i	D_i	Q_i	Y_i	Z_i
A_1	0.026	0.014	0.125	-0.168	0.165	0.347	0.451
A_2	0.022	0.016	0.135	-0.174	0.247	0.451	0.531
A_3	0.023	0.018	0.154	-0.161	0.199	0.354	0.419
A_4	0.024	0.017	0.146	-0.164	0.251	0.498	0.576
A_5	0.028	0.013	0.139	-0.179	0.178	0.157	0.389

Therefore, the ranking order of five parting curves is $A_4 > A_1 > A_3 > A_2 > A_5$.

So, the best parting curve is A_4 according to decision makers.

The final comparison of the two methods is shown in Table IX.

Table IX. Comparison of Ranking of the Two Methods

Methods applied for ranking	Ranking order of the parting curves.
Quang et al fuzzy extension method [1]	$A_4 > A_1 > A_3 > A_2 > A_5$
Proposed Intuitionistic fuzzy –TODIM method	$A_4 > A_5 > A_1 > A_2 > A_3$

6. CONCLUSION AND FUTURE SCOPE

This study presents an effective strategy-aligned intuitionistic fuzzy TODIM approach suitable for solving the parting curve design selection problem under a Intuitionistic fuzzy environment. The proposed hybrid IF-TODIM MCDM approach in molded design for parting curve can also be programmed for efficient execution. The practicability of the above method is shown in the above algorithm.

The main novel points and merits of the proposed system are in fivefold:

First, the proposed approach can adequately handle the inherent uncertainty and imprecision of human decision-making. The conventional TODIM combined with Intuitionistic fuzzy has been extended to the domain of parting curve design selection.

Second, the proposed system can rate both qualitative and quantitative criteria and effectively select suitable design mold in system.

Third, because the proposed system utilizes simplified ranking intuitionist fuzzy numbers and IFWA operator rather than the other fuzzy ranking methods, its computation is much faster.

Fourth, the proposed system allows MADM problems to accommodate linguistic terms represented as fuzzy numbers.

The proposed system facilitates the creation of a more realistic decision procedure. Consequently, the novel architecture of IF-TODIM method can be applied to other management decision-making problems, such as personnel selection, Facility location selection and project assessment and in pattern recognition and image processing.

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