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RELIABILITY INFORMATION TO SUPPORT DECISION MAKING FOR SHIP DESIGN

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ABSTRACT

Ship design in developing countries still face difficulties, leading to a large failure ratio. This paper proposed an exponential-related function adopted in an intuitionistic Fuzzy TOPSIS model for improving the understanding of failure and for building appropriate reliability knowledge to support decision making for ship design. The new method which is simple and straightforward have been successfully applied by virtue of numerical case studies for detecting failures, which in turn has provided information for building reliability knowledge to support decision making process. The method has been compared successfully with some similar computational approach in literature.

Keywords : *Exponential related (ER) function, Intuitionistic fuzzy weighted geometric (IFWG) operator, Intuitionistic Fuzzy TOPSIS*

1.0 INTRODUCTION

It is not only necessary now that contractors are able to effectively track, manage and understand the reliability improvement concerns during the earliest stages of their project. But also, they should be able to anticipate when the system will fail when finally, in operation [1], so as to remove them from use before they are put into life-threatening situations for the user or intended user. Having a dependable and accurate predictive estimate of when failures are expected in complex systems can allow for the healthy and efficient management of such system. According to Smith et al. [2] and Yang et al. [3], in improving the reliability and quality of components of new systems. The failure or potential failure information of the existing predecessor system should be analyzed and the information converted into appropriate design reliability knowledge for use in the new to-be-redesigned complex system. The identification of such failure information is most critical for achieving an improved product reliability and quality [4]. The understanding of the reliability concerns of existing complex systems can lead to an improved system [5, 6], performance predictability [7] and the opportunities for better product management [1].

This work is closely engaged in the design and implementation of the component with the highest influence on a mechanical related system's reliability and aim to provide a better understanding and management of the failure mechanisms in the system as well

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as in building appropriate reliability information and knowledge that be needed in the decision making process.

2.0 METHODOLOGY

In this section, the concept and definition of the exponential-related function and the corresponding Intuitionistic Fuzzy TOPSIS algorithm is presented.

2.1 Preliminary

Definition 1

Let $A = (\mu, v)$ be the intuitionistic fuzzy number. The new exponential-related function *ER* of the intuitionistic fuzzy number can be defined as;

$$ER(A) = e^{\left(\frac{1-\mu^2-v^2}{s}\right)}, \text{where } ER(A) \in [1/e, e] \tag{1}$$

2.2 Algorithm

The following paragraph will discuss algorithm of the exponential-related function adopted in an intuitionistic Fuzzy TOPSIS model (IF-TOPSISEF). Let consider a MCDM problem where a set of alternatives $A = \{A_1, A_2, A_3, \dots, A_m\}$, are assessed with respect to the criteria denoted by $C = \{C_1, C_2, C_3, \dots, C_m\}$. The characteristics of the alternative A_i with respect to a criteria C_j are defined first with linguistic variable and then converted to an IFS value $x_{ij} = (\mu_{ij}, v_{ij})$ $(i = 1,2, \dots, m, j = 1,2, \dots, n)$. The algorithm of the IF-TOPSIS_{EF} and the IFE method is given in following steps;

Step 1: Set up a group of Decision Makers (DMs) and aggregate their evaluations using IFWG operator [8]; Once the DMs has given their judgment using linguistic variables, the variables are expressed using the intuitionistic fuzzy number (IFNs) as shown in Table 1. The weight vector $\lambda = (\lambda_1, \lambda_2, \lambda_3, .., \lambda_l)^T$ is then used to aggregate all the DMs individual assessment matrices $D^k (k = 1,2,3, \dots, l)$ into the group assessment matrix (i.e. intuitionistic fuzzy decision matrix) $R_{mxn}(x_{ij})$;

$$IFWG\ (d_1 d_2 d_3, \dots, d_n) = \left(\prod_{i=1}^{n} (\mu_{ij})^{w_j}, 1 - \prod_{i=1}^{n} (1 - v_{ij})^{w_j}\right) \tag{2}$$

$$R_{mxn}(a_{ij}) = \begin{bmatrix} (\mu_{11}, v_{11}) & (\mu_{12}, v_{12}) & \cdots & (\mu_{1n}, v_{1n}) \\ (\mu_{21}, v_{21}) & (\mu_{22}, v_{22}) & \cdots & (\mu_{2n}, v_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ (\mu_{m1}, v_{m1}) & (\mu_{m2}, v_{m2}) & \cdots & (\mu_{mn}, v_{mn}) \end{bmatrix} \tag{3}$$

Table 1: Fuzzy numbers for approximating the linguistic variable

Linguistic terms	Intuitionistic fuzzy number
Very low (VL)	(0.20, 0.30)
Low (L)	(0.40, 0.50)
Good (G)	(0.50, 0.60)
High (H)	(0.70, 0.80)
Excellent (EX)	(0.90, 0.90)

Step 2: Using the intuitionistic fuzzy entropy (IFE) weight method to determine the criteria weight.

Definition 2 **[18]**
Let us consider an intuitionistic fuzzy set A in the universe of discourse $X = \{x_1, x_2, x_3, \dots, x_n\}$.The intuitionistic fuzzy set A can be transformed into a fuzzy set to structure an entropy measure of the intuitionistic fuzzy set by means of $\mu_{\bar{A}}(x_i) = (\mu_A(x_i) + 1 - v_A(x_i))/2$. Based on the definition of fuzzy information entropy, Liu & Ren [18] proposes the intuitionistic fuzzy entropy method for the computation of attribute weights when the weight information is completely unknown. By describing the entropy measures of the intuitionistic fuzzy set A as a trigonometric function;

$$E(A) = \frac{1}{n}\sum_{i=1}^{n} \text{Cot}\left(\frac{\pi}{4} + \frac{|\mu^2{}_A(x_i) - v^2{}_A(x_i)|}{4}\pi\right) \tag{4}$$

While the attribute weight is defined as;

$$\boldsymbol{\omega_j} = \frac{\mathbf{1} - \boldsymbol{H_j}}{\boldsymbol{n} - \sum_{j=0}^{n} \boldsymbol{H_j}} \tag{5}$$

where $\omega_j \in [0,1], \sum_{j=1}^{n}\omega_j = 1, H_j = \frac{1}{m}E(A_j)$ and $0 \leq H_j \leq 1$ for $(j = 1,2,3,\dots,n)$

Step 3: Convert the intuitionistic fuzzy decision matrix $R_{mxn}(x_{ij})$, using the exponential related function *ER* (i.e. equation (9)) to form the exponential related matrix $ERM_{mxn}\left(ER_{ij}\left(a_{ij}\right)\right)$ which represents the aggregated effect of the positive and negative evaluations in the performance ratings of the alternatives based on the intuitionistic fuzzy set (IFS) data;

$$ERM_{mxn}\left(E_{ij}\left(a_{ij}\right)\right) = ERM_{mxn}\left(E_{ij}\left(a_{ij}\right)\right) = \begin{bmatrix} ER_{11}(x_{11}) & ER_{12}(x_{12}) & \dots & ER_{1n}(x_{1n}) \\ ER_{22}(x_{22}) & ER_{22}(x_{22}) & \cdots & ER_{2n}(x_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ ER_{m1}(x_{m1}) & ER_{m2}(x_{m2}) & \cdots & ER_{mn}(x_{mn}) \end{bmatrix} \tag{6}$$

Step 4: Define the intuitionistic fuzzy positive ideal solution (IFPIS) $A^+ = (\mu_j, v_j)$ and the intuitionistic fuzzy negative ideal solution (IFNIS) $A^- = (\mu_j, v_j)$; *for the* exponential related function-based matrix;

$$A^+ = \{\langle C_j, [1,1]\rangle \mid C_j \in C\},\ A^- = \{\langle C_j, [0,0]\rangle \mid C_j \in C\},\ j = 1,2,3,\dots.,n. \tag{7}$$

Step 5: Compute the exponential related *ER* function-based separation measures in intuitionistic fuzzy environment $(d^+{}_i(A^+,\ A_i)$ and $(d^-{}_i(A^-,\ A_i)$ for each alternative for the IFPIS and IFNIS.

$$d^+{}_i(A^+,\ A_i) = \sqrt{\sum_{i=1}^{n}[w_j\ (1 - (\ ERM_{nxm}(a_{ij}))]^2} \tag{8}$$

$$d^-{}_i(A^-, A_i) = \sqrt{\sum_{i=1}^{n}[w_j\ (\ ERM_{nxm}(a_{ij}))]^2} \tag{9}$$

where w_j is the weight of the criteria.

Step 6: Compute the relative closeness coefficient, (CC_i), which is defined to rank all possible alternatives with respect to the positive ideal solution A^+. The general formula is given as;

$$CC_i = \frac{d^-{}_i(A^-,A_i)}{d^-{}_i(A^-,A_i) + d^+{}_i(A^+,A_i)}, \qquad (10)$$

where $CC_i\ (i = 1,2,..n)$ is the relative closeness coefficient of A_i with respect to the positive ideal solution A^+ and $0 \leq CC_i \leq 1$.

Step 7: Rank the alternatives in the descending order.

3.0 ILLUSTRATIVE EXAMPLE

In this section, the computational application of the proposed model is illustrated and use for detecting failures. It is complex Marine mechanical related systems by using a real-life case study, which is based on the evaluation of the most serious failure mode in a slewing gear of a marine crane vessel and for a hypothetical example to show the feasibility of the method. Where, the main goal is to provide the project designers with a simpler method for determining the component with the highest influence on the Marine mechanical related system's reliability and to provide a better understanding and management of the failure mechanisms thereby building appropriate reliability information and knowledge that be needed in decision making process.

3.1 Case Study

A Ship design and development related company, want to redesign the slewing gear of a proposed new marine crane vessel, and since reliability information is scare at the early phases of the design process. The failure information of an existing slewing gear is analyzed with the view to gaining appropriate design reliability knowledge and to understand the failure mechanisms of the gear, which is expected to be included in the management of the gear.

Three DMs associated with the following weighting vector $\lambda = (0.35, 0.30, 0.20)^T$ from the project management, government and from the contractor respectively were invited to evaluate the slewing gear after identifying six failure modes that is A_1, A_2, A_3, A_4, A_5, and A_6 were identify. Using the intuitionistic fuzzy decision matrices $d^k(k = 1,2,3)$ given by the six DMs, first in linguistic variables (see Table 2) which was later converted to intuitionistic fuzzy numbers (IFNs), we evaluate the six failure modes with respect to the criteria; Severity (*S*) which is the effect of failure on the slewing gear, Occurrence (*O*) which is the frequency of failure, and Detection (*D*) which is the probability of detecting the failure.

Table 2: DMs ratings using linguistic variables

C$_i$	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
		S			*O*			*D*	
A$_1$	G	VL	VL	H	G	L	G	H	H
A$_2$	H	H	H	EX	VL	L	G	EX	EX
A$_3$	EX	EX	EX	VL	H	H	G	H	H
A$_4$	G	H	G	H	G	G	EX	EX	EX
A$_5$	EX	EX	EX	H	L	H	H	L	G
A$_6$	H	G	G	EX	VL	G	VL	L	H

$$d^1 = \begin{bmatrix} (0.50,0.60) & (0.70,0.80) & (0.50,0.60) \\ (0.70,0.80) & (0.90,0.90) & (0.50,0.60) \\ (0.90,0.90) & (0.20,0.30]) & (0.50,0.60) \\ (0.50,0.60) & (0.70,0.80) & (0.90,0.90) \\ (0.90,0.90) & (0.70,0.80) & (0.70,0.80) \\ (0.70,0.80) & (0.90,0.90) & (0.20,0.30) \end{bmatrix}$$

$$d^2 = \begin{bmatrix} (0.20,0.30) & (0.50,0.60) & (0.70,0.80) \\ (0.70,0.80) & (0.20,0.30) & (0.90,0.90) \\ (0.90,0.90) & (0.70,0.80]) & (0.70,0.80) \\ (0.70,0.80) & (0.50,0.60) & (0.90,0.90) \\ (0.90,0.90) & (0.40,0.50) & (0.40,0.50) \\ (0.50,0.60) & (0.20,0.30) & (0.40,0.50) \end{bmatrix}$$

$$d^3 = \begin{bmatrix} (0.20,0.30) & (0.40,0.50) & (0.70,0.80) \\ (0.70,0.80) & (0.40,0.50) & (0.90,0.90) \\ (0.90,0.90) & (0.70,0.80]) & (0.70,0.80) \\ (0.50,0.60) & (0.50,0.60) & (0.90,0.90) \\ (0.90,0.90) & (0.70,0.80) & (0.50,0.60) \\ (0.50,0.60) & (0.50,0.60) & (0.70,0.80) \end{bmatrix}$$

By following the algorithm of the IF-TOPSIS$_{EF}$ as given in computational steps in section 2.1, we evaluate the six failure modes with respect to the criteria.

Steps 1&2: The DMs individual assessments of the six failure modes with respect to the criteria are aggregated using the IFWG operator, the final group assessment matrix which is the intuitionistic fuzzy decision matrix $R_{mxn}(x_{ij})$ is given in Table 3, while the weight of the criteria is calculated from the intuitionistic fuzzy decision matrix using the IFE method and the final weight values are given as

$w = \{0.223796, 0.484065, 0.252129\}$ respectively.

Table 3: Intuitionistic fuzzy decision matrix

	S	***O***	***D***
A_1	(0.35, 0.39)	(0.60, 0.62)	(0.66, 0.68)
A_2	(0.74, 0.75)	(0.50, 0.65)	(0.74, 0.77)
A_3	(0.91, 0.86)	(0.48, 0.61)	(0.66, 0.68)
A_4	(0.61, 0.63)	(0.62, 0.64)	(0.91, 0.86)
A_5	(0.91, 0.86)	(0.62, 0.66)	(0.58, 0.61)
A_6	(0.65, 0.64)	(0.52, 0.67)	(0.40, 0.48)

Step 3-5, using the exponential-related function, the intuitionistic fuzzy decision matrix $R_{4x3}(x_{ij})$ is converted to form the exponential related matrix $ERM_{4x3}\left(ER_{ij}\left(a_{ij}\right)\right)$ while the exponential related function-based separation measures $(d^{+}_{i}(A^{+}, A_i)$ and $(d^{-}_{i}(A^{-}, A_i)\ (i = 1,2,\ldots,6)$ is calculated using equation (14) and (15). In step 6-7, the relative closeness coefficient $CC_i, (i = 1,2,\ldots,6)$ to the ideal solution is calculated using equation (9), while the relative closeness coefficients are ranked in the descending order. The final result of the computation is shown in Table 4.

Table 4: The relative closeness coefficients of the four design concepts

	S	***O***	***D***	d^{+}_{i}	d^{-}_{i}	CC_i	**Rank**
A_1	1.27	1.09	1.04	0.08	0.65	0.8969	4
A_2	0.97	1.12	0.95	0.06	0.63	0.9152	2
A_3	0.83	1.15	1.04	0.08	0.64	0.8878	6
A_4	1.08	1.07	0.83	0.06	0.61	0.9129	3
A_5	0.83	1.06	1.10	0.05	0.61	0.9189	1
A_6	1.06	1.10	1.22	0.08	0.66	0.8968	5

Finally, from the ranking result of the failure modes in the slewing gear, one can conclude that the most critical failure modes that can easily influence the slewing gear as it relates to its reliability are the A_5 and the part which housed such failure mode should be considered more closely when redesigning the gear.

3.0 CONCLUSIONS

In determining the component with the highest influence on a mechanical related system's reliability and to provide a better understanding and management of the failure mechanisms in the system as well as to build an appropriate reliability information and knowledge that be needed in the decision making process. A new, simple and straight forward methods originally proposed in [9-13] have been integrated and applied in this study. The new method which is based on an IF-TOPSIS$_{EF}$ and IFE have been compared with the extended TOPSIS model proposed by [14], from the ranking result, we can conclude that the method is feasible and effective. The main advantages of the proposed new approach are that;

a) The implementation procedures of the proposed model and approach are easy and straightforward as compared to other Multi-criteria decision-making methods including the traditional TOPSIS approaches.
b) The proposed method can easily be used in determining the component with the highest influence on a mechanical related system's reliability and to provide a better understanding and management of the failure mechanisms in the system as well as in building appropriate reliability information and knowledge that be needed in the decision making process.

In the future, it is recommended to continue working on the application of the proposed method in other domain, specifically for problems with more criteria and alternatives.

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