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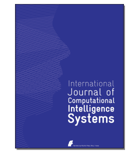

Research Article

An Intuitionistic Fuzzy Decision-Making for Developing Cause and Effect Criteria of Subcontractors Selection

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ABSTRACT

The decision-making trial and evaluation laboratory (DEMATEL) method has been applied to solve numerous multi-criteria decision-making (MCDM) problems where crisp numbers are utilized in defining linguistic evaluation. Previous literature suggests that the intuitionistic fuzzy DEMATEL (IF-DEMATEL) can offer a new decision-making method in solving MCDM problems where intuitionistic fuzzy sets (IFSs) are utilized in defining linguistic evaluation. This paper aims to develop a cause–effect diagram of subcontractor selection using a modified IF-DEMATEL method. In this paper, three modifications are made to the IF-DEMATEL method. Two memberships of IFSs, relative weights of experts, and a transformation equation are the elements introduced to the IF-DEMATEL. The linguistic variables that defined in IFSs are meant to capture wide arrays of uncertain and fuzzy information in solving MCDM problems. Furthermore, the modified IF-DEMATEL is applied it to a subcontractors' selection problem where groups of cause and effect criteria are segregated. A group of experts' opinions were sought to provide linguistic evaluations regarding the degree of influence between criteria in subcontractors' selection. The results show that four criteria are identified as cause criteria while six other criteria are identified as effect criteria. The results also suggest that the criteria "experience" is the main cause that influence the selection of subcontractors. The identification of cause and effect criteria would be a great significance for practical implementation of subcontractors' selection.

1. INTRODUCTION

The decision-making trial and evaluation laboratory (DEMATEL) method is one of the many multi-criteria decision-making (MCDM) methods that available in literature. The DEMATEL was initially developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 to study and resolve the complicated and intertwined problems [1,2]. Compared with other traditional MCDM techniques such as the analytic hierarchy process where criteria are independent, this method is one of the structural modeling techniques that can identify the interdependencies of system elements through causality graphs. The causal diagram uses digraphs rather than directionless graphs to portray the basic concept of contextual relationships and the strengths of influence among the elements [3]. This method has been applied in analyzing and developing the relationship of cause and effect among evaluation criteria [4]. In other words, the DEMATEL is used to derive inter-relationship among factors or criteria [5]. The DEMATEL is a comprehensive method for developing a basic model that contains causal connections between complex criteria. As to provide more evidence on the state-of-the-art of the DEMATEL, Si *et al.* [6], made a systematic review of the DEMATEL and its applications. In the DEMATEL, all criteria of the MCDM problems are partitioned into classifications, that is the cause and effect groups.

Despite all these advantages, the linguistic evaluation in DEMATEL suffers from several limitations. The DEMATEL is insufficient to provide a good decision tool in this age because most of the information are regularly exorbitant and huge. In addition, elicitation of experts' opinion could give evaluation in the situation where information is restricted or incomplete. In fact, the fuzziness in experts' opinions or insufficient knowledge about an issue could make the decision-making process more complicated [6,7]. In response to these limitations, the integration of fuzzy sets and DEMATEL (fuzzy DEMATEL) was proposed. The fuzzy DEMATEL basically works similar with the DEMATEL frameworks except for the linguistic used in evaluation. In the fuzzy DEMATEL, the seven-step computational procedures are embedded with fuzzy numbers where incomplete and vague information could be dealt with accordingly. The fuzzy DEMATEL has been used extensively in solving various decision problems [8–16]. Despite its success, previous literature suggests that intuitionistic fuzzy numbers (IFNs) are better options in dealing with incomplete and vague information in decision-making. These numbers are characterized by

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membership and nonmembership of intuitionistic fuzzy sets (IFS). Along a similar line, the fuzzy DEMATEL has been extended to the intuitionistic fuzzy DEMATEL (IF-DEMATEL) where single membership of fuzzy numbers is replaced by IFNs in defining linguistic variables. In particular, the linguistic variables used in IF-DEMATEL are defined using the concept of two or three numbers of IFNs.

There is a handful of newly published research papers discussing the IF-DEMATEL. Govindan *et al.* [17], for example, conducted a research in green supply chain management where IF-DEMATEL method was used to handle the importance and causal relationships between green supply management practices. A research of municipal solid waste management was conducted by Zulkifli and Abdullah [18] to visualize the most viable solid waste treatment using IF-DEMATEL. In a business study, Vafadarnikjoo *et al.* [19], applied IF-DEMATEL in prioritizing the selection criteria of bank branch locations. There was also a study of location selection of freight villages where IF-DEMATEL was integrated with two other decision-making methods for determining the most effective criteria [20]. Recently, IF-DEMATEL integrated with an elimination method to obtain the importance-weights of criteria in personnel selection [21]. Most of these related researches introduced IFS in DEMATEL using the 7-point linguistic scale from 0 to 6. This scale was written in IFSs with the inclusion of the third membership of hesitation degree. It seems that the authors used three numbers of IFSs where hesitation degree is written independently.

In contrast to the three numbers, this paper proposed a modified IF-DEMATEL where two numbers of IFNs are used as the third number of hesitation degree is already considered in the two numbers. In addition, the proposed IF-DEMATEL method also includes transformation equation proposed by [22] instead of expected value [23] for IFN values to crisp values. In the transformation equation, the deviations between membership and nonmembership numbers are predetermined to ensure true crisp value that can reflect the initial evaluation. Furthermore, the proposed IF-DEMATEL also considers the importance weight of experts. It was noticed that there are no weights of experts assumed in most of the DEMATEL based methods [24–27]. In response to this issue, this proposed method introduced relative weights of experts based on the three numbers of IFNs of five linguistic terms. Proportion equation proposed by [28] is adopted to the proposed IF-DEMATEL method. Differently from the fuzzy DEMATEL, this paper proposes an IF-DEMATEL method where dual memberships of IFS, relative weights of experts, and transformation equation are among the highlights. The proposed method is applied to unravel the multiple conflicting criteria of subcontractors' selection in which the cause and effect criteria of subcontractors' selection will be identified.

The contributions of this paper are threefold: (1) we propose to use relative weights of experts instead of considering equal weights among the experts. The proposed method introduces a proportion equation which makes the weights of experts more suitable for real-life application, (2) we propose to use a weighted averaging operator to find aggregated direct relation matrix where series of multiplications of assessment scales and relative weights of experts are involved, (3) we propose to introduce a transformation equation instead of typical averaged defuzzification method to transform two numbers of IFSs to single real numbers. These three contributions are embedded in the proposed IF-DEMATEL where the total relation matrix is used to obtain two groups of criteria. The rest of this paper is arranged as follows. Section 2 briefly reviews definitions of IFS, IFN, and its memberships. Section 3 presents the proposed method that is to be applied to a case study. In Section 4, detailed description of subcontractors' selection including its computational procedures and results are presented. Section 5 provides a brief conclusion.

2. PRELIMINARY

The IFS developed by [29] is a capable device for managing equivocalness. An extraordinary element of IFSs is that it is a degree of membership and a degree of nonmembership to every component. The IFS component is an expansion of [7] which just allocates one degree of membership to each element. In the past two decades, numerous authors have been acknowledged that the IFS theory is effectively used to connect various applications. IFSs have been applied to many areas such as medical diagnosis [30,31], decision-making problems [32,33], and pattern recognition [34,35]. The IFSs are one of the generalization of nonstandard fuzzy sets and are particularly useful in dealing with uncertainty [29].

Atanassov [29] has stated that let X be a fixed set, an IFS A in X is given as $A = \left\{\left(x, \mu_{A(x)}, \nu_{A(x)}\right), x \in X\right\}$ where $\mu_{A(x)} : X \to [0,1]$ and $\nu_{A(x)} : X \to [0,1]$ are membership function and nonmembership function, respectively, satisfying $0 \le \mu_{A(x)} + \nu_{A(x)} \le 1, \forall_x \in X$. The numbers $\mu_{A(x)}$ and $\nu_{A(x)}$ denote the degrees of membership and nonmembership, respectively, of the element x to A, for all $x \in X$.

In addition, $\pi_{A(x)} = 1 - \mu_{A(x)} - \nu_{A(x)}$ is called the hesitation degree of $x \in A$, representing the degree of indeterminacy or the degree of hesitancy of x to A. It is obvious that $0 \le \mu_{A(x)} \le 1, \forall x \in X$. If $\pi_{A(x)}$ is small, then the value of x is more certain; if $\pi_{A(x)}$ is greater, then knowledge about x is more uncertain. Obviously, when $\pi_{A(x)} = 1 - \nu_{A(x)}$ for all elements of the universe, then IFS is reduced to a traditional fuzzy set. Therefore, fuzzy sets can be considered as a special case of IFS.

For an IFS, the pair $\left(\mu_{A(x)}, \nu_{A(x)}\right)$ is called an IFN and each IFN can be simply denoted as $\alpha = (\mu_\alpha, \nu_\alpha)$ where $\mu_\alpha \in [0,1], \nu_\alpha \in [0,1]$ and $0 \le \mu_\alpha + \nu_\alpha \le 1$. For an IFN $\alpha = (\mu_\alpha, \nu_\alpha)$, if the value μ_α gets bigger and the value ν_α gets smaller, then the IFN $\alpha = (\mu_\alpha, \nu_\alpha)$ gets greater. Obviously, $\alpha^+ = (1,0)$ and $\alpha^- = (0,1)$ are the largest and the smallest IFNs, respectively. In addition, $S(\alpha) = \mu_\alpha - \nu_\alpha$ and $H(\alpha) = \mu_\alpha + \nu_\alpha$ are called the score and accuracy degrees of α, respectively.

3. PROPOSED IF DEMATEL

The DEMATEL is a classical method for solving criteria of MCDM problems. It can be used to visualize the relationship between criteria. The DEMATEL also can be used to separate all criteria into two groups which are known as cause and effect groups. As an extension of DEMATEL, the fuzzy DEMATEL was proposed by many researchers and applied to various fields [4,5,8,28,36]. With further extension of fuzzy DEMATEL, this section presents the IF-DEMATEL method in which the fuzzy DEMATEL is modified by introducing the IFS into the fuzzy DEMATEL. As a result of this fusion, the proposed IF-DEMATEL has several innovations. Firstly, instead of considering equal weights among the experts, this proposed method introduced relative weights of experts based on the three numbers of IFSs of five linguistic terms. Proportion equation proposed by [28] is adopted to the proposed method. Secondly, individual assessment of experts is aggregated using the concept of summation of weighted average. This is an averaging operator where relative weight of experts is multiplied with decision assessment. Finally, in this proposed method, we introduce a transformation equation instead of typical defuzzification method to transform two numbers of IFSs to single crisp numbers. These three innovations are embedded into the general framework of DEMATEL where total relation matrix is used to derive causal and effect groups of criteria. In this section, we present an improvement to the DEMATEL where the IFS is the prominent element in the proposed method. It is illustrated in Figure A1 (See Appendix).

Detailed computational procedures of the proposed method are presented as follows:

Step 1: Construct Direct Relation Matrix

Suppose an MCDM problem has n criteria $(c_1, c_2, c_3, \dots, c_n)$. Data are collected from kth experts. Expert's assessments are collected, and the data is arranged in a direct relation matrix. This matrix represents an assessment of interrelationship between criteria using the five linguistic rating scale of DEMATEL. With linguistic variable of influence, one criterion is compared with other criteria in terms of degree of influence. The assessments are written in memberships of IFSs. Table 1 shows five linguistic terms and its respective IFS.

The assessments are made to collect the first-hand data on the influence of one criterion as compared to other criteria of MCDM problem. The assessments collected from experts are arranged in form of matrix to construct initial matrix or direct relation matrix.

The direct relation matrix is arranged in the matrix A^k where elements in A^k are the influential rating one criterion with respect to other criteria.

$$A^k = \left[a_{ij}^k\right]_{n\times n} = \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \dots & c_n \end{array} \\ \begin{bmatrix} 0 & a_{12}^k & \dots & a_{1n}^k \\ a_{n1}^k & 0 & \dots & a_{2n}^k \\ \dots & \dots & \dots & \dots \\ a_{n1}^k & a_{n2}^k & \dots & 0 \end{bmatrix} \end{array} \quad (1)$$

where

$c_1, c_2, \dots, c_n$ are the criteria and

a_{ij}^k is the rating by kth expert in evaluation of inter-relationship between criteria.

Step 2: Priority Values of Experts

Each expert's opinion has a specific weight that must be accounted as they have varied in working experience and knowledge. So, the importance or weights of these experts are obtained by utilizing the IFS linguistic variable of importance. Table 2 presents the linguistic terms and its respective three memberships of IFS.

Assume that $\lambda_k = (\mu_k, v_k, \pi_k)$ is the memberships of IFS for relative importance weights of kth expert. The priority value of kth expert could be computed using Eq. (2).

$$\lambda = \frac{\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + v_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + v_k}\right)\right)} \quad (2)$$

where $\sum_{k=1}^{l} \lambda_k = 1$. In this paper, the hesitation degree is omitted.

Step 3: Construct Aggregated Weighted Direct Relation

Each individual expert assessment is aggregated in order to construct a collective intuitionistic fuzzy decision matrix. By using the intuitionistic fuzzy weighted averaging (IFWA) operator Eq. (3) [37], the aggregated intuitionistic fuzzy ratings x_{ij} represent the influence level of criterion i on j could be acquired. It is good to note that this step is indeed series of multiplications of assessment scales and weights of experts.

$$x_{ij} = \left(1 - \prod_{k=1}^{l}\left(1 - \mu_{ij}^k\right)^{\lambda_k}, \prod_{i=1}^{l}\left(v_{ij}^k\right)^{\lambda_k}\right), i, j \in \{1, 2.3, \dots, n\} \quad (3)$$

where

λ_k is the importance weight of kth expert

a_{ij}^k is is the corresponding of IFN of kth expert's opinion when comparing i to j.

Step 4: Construct Normalized Aggregated Weighted Direct Relation Matrix

In order to construct normalized direct relation matrix, summation of rows and summation of columns are computed first.

Table 1 Linguistic variable of influence and its intuitionistic fuzzy sets (IFSs) [8].

Linguistic variable	IFSs
No influence	(0.10, 0.90)
Low influence	(0.20, 0.65)
Fairly low influence	(0.30, 0.55)
Medium influence	(0.50, 0.50)
Fairly high influence	(0.65, 0.25)
High influence	(0.80, 0.05)
Absolutely high influence	(0.90, 0.10)

Table 2 Linguistic variable for experts' relative importance or weight [28].

Linguistic variable	IFSs
Very important	(0.9, 0.05, 0.05)
Important	(0.75, 0.20, 0.05)
Medium	(0.50, 0.50, 0.00)
Unimportant	(0.25, 0.70, 0.05)
Very unimportant	(0.10, 0.85, 0.05)

The maximum number from summation of rows and columns are identified. With these maximum numbers, is m calculated using Eq. (4).

$$m = \min\left(\frac{1}{\max \sum_{j=1}^{n} a_{ij}}, \frac{1}{\max \sum_{i=1}^{n} a_{ij}}\right), i, j \in \{1, 2.3, \ldots, n\} \quad (4)$$

The direct relation matrix in Table 2 is normalized by multiplying with m.

The normalized direct relation matrix of membership and non-membership is transformed into a crisp number p using transformation Eq. (5) [22].

$$p = \frac{(\mu - \nu + 1)}{2} \quad (5)$$

where

p is a crisp number

μ is the membership values in total relation matrix

ν is the nonmembership values in total relation matrix.

Step 5: Construct Total Relation Matrix [5]

In order to construct Total relation matrix T, summation of rows and summation of columns of normalized aggregated weighted direct relation matrix are computed first.

The maximum numbers from summation of rows and columns are used to construct total relation matrix.

$$T = X(I - X)^{-1} \quad (6)$$

where I is the identity matrix.

$$\text{and } X = m \times A \quad (7)$$

where m is defined in Eq. (4).

From the total relation matrix, we are able to find sum of columns and rows.

Step 6: Sum of Rows and Sum of Columns of Total Relation Matrix.

$$T = [t_y]_{n \times n} \quad i, j = 1, 2, \ldots, n$$

$$R = \left[\sum_{i=1}^{n} t_y\right]_{1 \times n} = [t_j]_{1 \times n}$$

$$D = \left[\sum_{j=1}^{n} t_y\right]_{n \times 1} = [t_i]_{n \times 1}$$

R = total of row m for matrix,

D= total of column n for matrix

Summation of rows and columns of the total relation matrix produced vectors D and R, respectively. $(R + D)$ is the horizontal axis vector named "Prominence" showed the importance of a criterion while $(R - D)$ which is the vertical axis called "Relation."

A criterion is considered as a member of the cause category if $(R - D)$ is positive, and in the case of its negative value, the criterion attributes it to the effect group. The $(R + D)$ and $(R - D)$ values are computed using MATLAB software.

Step 7: Construct the Causal Diagram

Hence, the causal diagram was depicted by mapping the data set of the $(R + D, R - D)$ which provides the discernment about the recognition of the entire system. Therefore, the causal diagram can visualize the complicated causal relationships between elements and provide valuable insights for decision-making.

Based on the coordinate positions of $(R + D)$ and $(R - D)$, attributes can be divided into the following 4 types:

i. $(R - D)$ is positive and $(R + D)$ is large:

   This indicates that the attributes are causes, which are also driving factors for solving problems.

ii. $(R - D)$ is positive and $(R + D)$ is small:

   This indicates that the attributes are independent and can influence only a few other attributes.

iii. $(R - D)$ is negative and $(R + D)$ is large:

   This indicates that the attributes are the core problems that must be solved. However, these are effect-type attributes, which cannot be directly improved.

iv. $(R - D)$ is negative and $(R + D)$ is small:

   This indicates that the attributes are independent and can be influenced by only a few other attributes.

Finally, the causal diagram is illustrated by mapping the data set $(R + D, R - D)$ onto two-dimensional planes. This mapping enables us to understand about the recognition of the entire system of criteria of decision-making problems. The entire system of criteria of subcontractors' selections is elucidated in the following section. Summarily, this proposed method has advantages in several ways. First is about the weights of experts. This paper proposed relative weights for experts using a proportion equation and this surely has an edge over the typical DEMATEL where weights of experts are assumed to be equal. The second advantage lies on the aggregation method used. In the proposed method, an aggregated membership and nonmembership of entries in direct relation matrix is simply obtained by summing the multiplication of individual judgment with relative weight of experts. This aggregation method is straightforward as compared to other aggregation operators where several parameters are involved. The third advantage of the proposed method is the use of transformation equation. To transform the membership and nonmembership of IFS to single real numbers, a simple average equation is applied. Instead of using three memberships, this equation is restricted to two memberships, thereby reduces the computational complexity.

4. A CASE STUDY OF SUBCONTRACTORS' SELECTION

Subcontractors usually help main contractor to overcome problems that related to the need for special expertise, limitation in finances, and shortage in resources. The main contractor is still in charge and should administer contracts to guarantee the project is executed and finished as pointed out in contract. Specialist subcontractor can be utilized, when the main contractor acquires products or administrations, which the main contractor doesn't deliver or can't deliver by his own company. Therefore selecting the deliverable subcontractors is critical in making sure the implementation of the project is completed within the stipulated times. In this paper, subcontractors selection problem is presented where a decision-making approach is employed. In fulfilling this objective, a group of five experts are invited to provide assessment via scales of linguistic variables. Detailed descriptions of experts and criteria are presented in the next subsection.

4.1. Experts, Criteria, and Linguistic Data Collection

Five experts attached to a construction company are invited to offer a linguistic assessment on criteria in selecting subcontractor. The experts consist of two project managers, two engineers, and one site supervisor of which, all these experts have more than three years experiences in construction industry. Experts are requested to provide degree of influence of a criterion with respect to other criteria using linguistic variables (see Table 1). The assessments are made to collect the first-hand data on the influence of one criterion as compared to other criteria in subcontractors' selection.

In study, the criteria affecting the selection of subcontractors are retrieved from the relevant literature in subcontractors' selection [38–44]. Criteria and their brief descriptions are depicted in Table 3.

These lists of criteria are the main subjects in this analysis where their importance and unidirectional cause–effect relationship are determined through series of computational procedures. Detailed computations and results are presented in the following subsection.

4.2. Computation and Results

Using the information gathered, the implementation of the proposed method is performed. Detailed computations and results are presented as follows.

Table 3 Criteria of subcontractors selection.

Criteria	Descriptions
Price (C_1)	Choosing subcontractors on a premise of most reduced cost regularly brings about cases for expansions of time, claims for extra charges, higher capital expenses of development and task, and a diminished quality in workmanship
Completing on Time (C_2)	It is normal to experience delays in development ventures. Deferral isn't generally caused by a cataclysmic occasion. Deferrals may make significant harm the proprietor. The date of finishing may change over the span of the agreement, The genuine finishing must be confirmed by the as of late concurred culmination date.
Experience (C_3)	The execution of the preliminary endeavor is considered by the legally binding laborer, subcontractor, and customer gathers as the most basic. While assessing who is welcome to exhibit a subcontract quote, the essential impermanent laborer will either consider the people who had past working associations or fuse subcontractors who have in advance viably completed made by various legally binding specialists of tantamount nature, scale, and capriciousness.
Financial Stability (C_4)	Compared with larger subcontractors, subcontractors trust that a superior money-related foundation is more imperative. In the construction industry, it is troublesome for little subcontractors to get budgetary help from banks. Without the necessary financial background, small subcontractors may not be eligible for a certain amount of engineering.
Compliance with Regulations (C_5)	Some subcontractors may themselves be a contractual worker of little development projects. In this manner, they ought to know about the significance of consistence with directions. They might not want to be denied from any offering openings, nor would they like to acquire a terrible notoriety and demolish their altruism.
Quality (C_6)	On the client/consultant side, they need to have quality facilities as well as for the duration of their life cycle keeping in mind the end goal to limit progressing upkeep costs, which is a typical marvel in construction subcontracting.
Performance History (C_7)	Linking contract continuation to contractor performance can serve as an incentive for performance excellence. Thorough review of past execution contributes important information to the department's decision-making regarding the exercise of options. Past performance assessment should include program and technical issues, cost control, business management, socio-economic programs, and other relevant contract obligations and requirements.
Safety Management (C_8)	Safety issues have increased vital importance throughout the construction industry. Numerous construction companies around the global are implementing safety, wellbeing, and environmental management framework to reduce injuries, eliminate illness, and to provide a safe work environment in their construction sites
Timely Payment to Labor (C_9)	Subcontractors are under the legally binding commitments to pay their worker on time.
Length of Time in Industry (C_{10})	Flexibility and cooperation when resolving delays is one of the criteria that need to be considered. They have to resolve the delay when there is a delay where the subcontractor and the main contractor face it. If the subcontractor is accustomed to time delays in the past projects. Years in the industry can affect the selection for subcontractors because they have to solve a lot of problems.

In this computation, priority values of experts are computed first using Eq. (2).

For example,

$$\text{Expert 1}: w_1 = 0.90 + 0.05\left(\frac{0.90}{0.90+0.05}\right) = 0.9474$$

$$\text{Expert 2}: w_2 = 0.75 + 0.20\left(\frac{0.75}{0.75+0.05}\right) = 0.9375$$

$$\text{Expert 3}: w_3 = 0.50 + 0.50\left(\frac{0.50}{0.50+0.00}\right) = 1.0000$$

$$\text{Expert 4}: w_4 = 0.25 + 0.70\left(\frac{0.25}{0.25+0.05}\right) = 0.8333$$

$$\text{Expert 5}: w_5 = 0.10 + 0.85\left(\frac{0.10}{0.10+0.05}\right) = 0.6667$$

Then, $\lambda_1 = \dfrac{0.9474}{4.3849} = 0.2161$

The priority values for four other experts are calculated similarly. Table 4 summarizes the priority values for experts.

These priority values of experts are then used in obtaining aggregated direct relation matrix. Direct relation matrices of expert's assessment are aggregated using Eq. (3).

For example, membership and nonmembership of a_{11} are computed as:

$$\begin{aligned} &1-\prod_{k=1}^{l}\left(1-\mu_j\right)^{\lambda_k} \\ &= 1-\left(\begin{array}{l}(1-0.00)\,\hat{}\,0.2161 * (1-0.00)\,\hat{}\,0.2138 * (1-0.00)\,\hat{} \\ 0.2281 * (1-0.00)\,\hat{}\,0.1900 * (1-0.00)\hat{}0.1520\end{array}\right) \\ &= 0.000 \end{aligned}$$

$$\begin{aligned} &\prod_{k=1}^{l}\left(v_j\right)^{\lambda_k} \\ &= 1\hat{}\,(0.2161) * 1\hat{}\,(0.2138) * 1\hat{}\,(0.2281) * 1\hat{}\,(0.1900) * 1\hat{}(0.1520) \\ &= 1.000 \end{aligned}$$

Similarly, membership and nonmembership for a_{21} are given as:

$$\begin{aligned} &1-\prod_{k=1}^{l}\left(1-\mu_j\right)^{\lambda_k} \\ &= 1-\left(\begin{array}{l}(1-0.1)\,\hat{}\,0.2161 * (1-0.5)\,\hat{}\,0.2138 * (1-0.5)\,\hat{}\,0.2281 * \\ (1-0.1)\,\hat{}\,0.1900 * (1-0.5)\hat{}0.1520\end{array}\right) \\ &= 0.3652 \end{aligned}$$

$$\begin{aligned} &\prod_{k=1}^{l}\left(v_j\right)^{\lambda_k} \\ &= 0.9\hat{}\,(0.2161) * 0.50\hat{}\,(0.2138) * 0.5\hat{}\,(0.2281) * 0.9\hat{}\,(0.1900) * \\ &\quad 0.5\hat{}(0.1520) \\ &= 0.6348 \end{aligned}$$

Similarly, other entries are calculated accordingly. The aggregated direct relation matrix is shown in Table 5.

Information in the aggregated direct relation matrix are given in IFNs. These numbers need to transform into a single value. Membership and nonmembership values are transformed into a single score (crisp value) using Eq. (5). Table 6 shows the aggregated crisp matrix.

In order to normalize the aggregated crisp matrix, summations of row and column of criteria are made. Table 7 shows these summations of criteria.

The maximum numbers from summation of row and column will be chosen, respectively, Eq. (4).

$$\begin{aligned} m &= \min\left(\tfrac{1}{6.7730}, \tfrac{1}{6.8254}\right) \\ &= \min(0.1476, 0.1465) \\ &= 0.1465 \end{aligned}$$

The direct relation matrix is then normalized by multiplying with 0.1465 Eq. (7). Table 8 presents the normalized direct relation matrix.

Using Eq. (6), we can obtain the total relation matrix. It is shown in Table 9.

Table 4 Priority values of experts.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Lambda, λ_k	0.2161	0.2138	0.2281	0.1900	0.1520

Table 5 Aggregated direct relation matrix.

Criteria	C_1	C_2	C_3	…	C_9	C_{10}
C_1	$\langle 0.0000, 1.0000 \rangle$	$\langle 0.3886, 0.6114 \rangle$	$\langle 0.4734, 0.4900 \rangle$	…	$\langle 0.3917, 0.5220 \rangle$	$\langle 0.4143, 0.5404 \rangle$
C_2	$\langle 0.3652, 0.6348 \rangle$	$\langle 0.0000, 0.0000 \rangle$	$\langle 0.6837, 0.1825 \rangle$	…	$\langle 0.2775, 0.6312 \rangle$	$\langle 0.6083, 0.2903 \rangle$
C_3	$\langle 0.7040, 0.2542 \rangle$	$\langle 0.8313, 0.0972 \rangle$	$\langle 0.0000, 0.0000 \rangle$	…	$\langle 0.2908, 0.6698 \rangle$	$\langle 0.7873, 0.1281 \rangle$
…	…	…	…	…	…	…
C_{10}	$\langle 0.5227, 0.3238 \rangle$	$\langle 0.7914, 0.1565 \rangle$	$\langle 0.7797, 0.1569 \rangle$	…	$\langle 0.3581, 0.4500 \rangle$	$\langle 0.0000, 0.0000 \rangle$

Table 6 Aggregated crisp matrix.

Criteria	C_1	C_2	C_3	C_4	C_5	…	C_8	C_9	C_{10}
C_1	0.5000	0.3886	0.4917	0.5636	0.2950	…	0.3443	0.4349	0.4369
C_2	0.3652	0.5000	0.7506	0.3804	0.3781	…	0.2733	0.3231	0.6590
C_3	0.7249	0.8670	0.5000	0.5543	0.6561	…	0.6410	0.3105	0.8296
C_4	0.6177	0.6953	0.2464	0.5000	0.4872	…	0.3427	0.8500	0.4764
C_5	0.1000	0.5960	0.3238	0.1297	0.5000	…	0.7775	0.4586	0.4519
C_6	0.8989	0.8672	0.7597	0.6754	0.4579	…	0.4357	0.2314	0.7026
C_7	0.8059	0.7641	0.8007	0.3641	0.5309	…	0.3818	0.3858	0.7115
C_8	0.5550	0.6950	0.2631	0.2573	0.8224	…	0.5000	0.1652	0.6286
C_9	0.3429	0.6347	0.3145	0.7714	0.4021	…	0.3407	0.5000	0.4601
C_{10}	0.5995	0.8175	0.8114	0.4995	0.3703	…	0.3613	0.4540	0.5000

Table 7 Summation of row and column.

Criteria	Summation of row	Summation of column
C_1	4.8128	5.5101
C_2	5.0850	6.8254
C_3	6.7730	5.2619
C_4	5.2839	4.6955
C_5	4.3742	4.9000
C_6	6.3383	6.4485
C_7	6.0495	6.3506
C_8	5.3256	4.3983
C_9	4.5046	4.1135
C_{10}	5.8137	5.8567
Maximum	6.7730	6.8254

Table 8 Normalized direct relation matrix.

Criteria	C_1	C_2	C_3	C_4	C_5	…	C_8	C_9	C_{10}
C_1	0.0733	0.0569	0.0720	0.0826	0.0432	…	0.0504	0.0637	0.0640
C_2	0.0535	0.0733	0.1100	0.0557	0.0554	…	0.0400	0.0473	0.0965
C_3	0.1062	0.1270	0.0733	0.0812	0.0961	…	0.0939	0.0455	0.1215
C_4	0.0905	0.1019	0.0361	0.0733	0.0714	…	0.0502	0.1245	0.0698
C_5	0.0147	0.0873	0.0474	0.0190	0.0733	…	0.1139	0.0672	0.0662
C_6	0.1317	0.1271	0.1113	0.0990	0.0671	…	0.0638	0.0339	0.1029
C_7	0.1181	0.1119	0.1173	0.0533	0.0778	…	0.0559	0.0565	0.1042
C_8	0.0813	0.1018	0.0385	0.0377	0.1205	…	0.0733	0.0242	0.0921
C_9	0.0502	0.0930	0.0461	0.1130	0.0589	…	0.0499	0.0733	0.0674
C_{10}	0.0878	0.1198	0.1189	0.0732	0.0543	…	0.0529	0.0665	0.0733

Causal diagram is obtained by calculating the summations of row and summation of column of the total relation matrix. The summations of row (R) summations of column (D), ($R + D$) and ($R - D$) of total relation matrix are shown in Table 10.

The values of $R+D$ and $R-D$ are mapped onto Cartesian coordinate to construct the causal diagram. It is shown in Figure 1.

Based on the information from the causal diagram (see Figure 1), the criteria are divided into two groups by x-axis. The cause criteria are Experience, Safety Management, Financial Stability, and Timely Payment to Labor as the ($R - D$) is positive. On the other hand, the effect criteria are Length of Time in Industry, Quality, Performance History, Compliance with Regulations, Price, and Completing on Time. This result also indicates that "Experience" is the most important criteria in subcontractors selection owing to the largest value of ($R - D$).

5. COMPARATIVE ANALYSIS

It can be seen that the criteria of subcontractors' selection are segregated into two groups using the proposed IF-DEMATEL. However, these results are confined to the research frameworks and the evaluation model used. It is hypothesized that the results would no longer stable or unchanged if other computational method is used. Therefore, this section provides a comparative analysis in

Table 9 Total relation matrix.

Criteria	C_1	C_2	C_3	C_4	C_5	…	C_8	C_9	C_{10}
C_1	0.3812	0.4258	0.3719	0.3375	0.3013	…	0.2817	0.2806	0.3841
C_2	0.3856	0.4722	0.4367	0.3285	0.3336	…	0.2906	0.2780	0.4432
C_3	0.5322	0.6403	0.4953	0.4312	0.4568	…	0.4180	0.3452	0.5684
C_4	0.4083	0.4881	0.3506	0.3438	0.3416	…	0.2934	0.3550	0.4048
C_5	0.2852	0.4179	0.3157	0.2413	0.3085	…	0.3237	0.2556	0.3540
C_6	0.5325	0.6079	0.5068	0.4292	0.4051	…	0.3674	0.3181	0.5231
C_7	0.5012	0.5734	0.4965	0.3716	0.4009	…	0.3482	0.3254	0.5068
C_8	0.4106	0.5012	0.3684	0.3068	0.4019	…	0.3282	0.2563	0.4401
C_9	0.3238	0.4258	0.3148	0.3428	0.2927	…	0.2591	0.2740	0.3556
C_{10}	0.4585	0.5651	0.4842	0.3798	0.3670	…	0.3333	0.3272	0.4627

Table 10 Summations of row and column.

Criteria	Summation of row (R)	Summation of column (D)	R + D	$R - D$
C_1	3.6606	4.2192	7.8798	−0.5586
C_2	3.9370	5.1176	9.0546	−1.1806
C_3	5.1139	4.1409	9.2548	0.9731
C_4	3.8731	3.5125	7.3856	0.3606
C_5	3.2799	3.6095	6.8894	−0.3296
C_6	4.8040	4.8823	9.6864	−0.0783
C_7	4.5971	4.8271	9.4242	−0.2300
C_8	3.9867	3.2435	7.2302	0.7432
C_9	3.3266	3.0154	6.3419	0.3112
C_{10}	4.4321	4.4430	8.8750	−0.0109

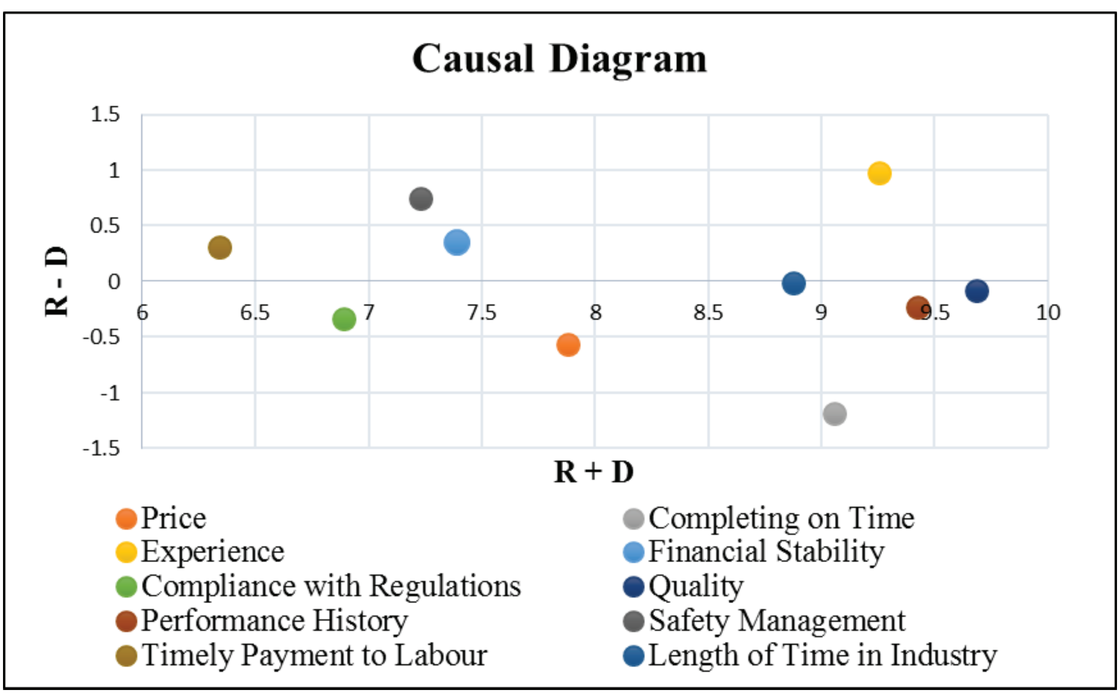

Figure 1 Causal diagram.

which the result obtained using the proposed method is compared to other methods. Specifically, the DEMATEL method [2] is used to compute real numbers input data and the results are compared to the results obtained using the proposed method. This comparative analysis is made from two perspectives. The first perspective is to investigate the criteria that belong to cause group and effect group.

Table 11 Comparative results of criteria using two different methods.

Methods	Cause criteria	Effect criteria
Proposed IF-DEMATEL	• Experience (C_3) • Safety Management (C_8) • Financial Stability (C_4) • Timely Payment to Labor (C_9)	• Length of Time in Industry (C_{10}) • Quality (C_6) • Performance History (C_7) • Compliance with Regulations (C_5) • Price (C_1) • Completing on Time (C_2)
DEMATEL	• Experience (C_3) • Quality (C_6) • Compliance with Regulations (C_5) • Safety Management (C_8) • Length of Time in Industry (C_{10})	• Financial Stability (C_4) • Performance History (C_7) • Timely Payment to Labor (C_9) • Price (C_1) • Completing on Time (C_2)

Table 12 Comparative results of degree of importance using two different methods.

Method	Degree of importance
Proposed IF-DEMATEL	$C_3 > C_8 > C_4 > C_9 > C_{10} > C_6 > C_7 > C_5 > C_1 > C_2$
DEMATEL	$C_3 > C_6 > C_5 > C_8 > C_{10} > C_4 > C_7 > C_9 > C_1 > C_2$

Note: ">" denotes "more important than."

Table 11 presents the comparative results obtained from the use of two DEMATEL-based methods.

As shown in Table 11, some criteria are shared under the same group despite different methods used. For example, the criteria "Experience" and "Safety Management" are shared under the same cause criteria group. In contrast, the result is totally different for the criterion "Financial Stability." This criterion is placed under cause group and effect group of the IF-DEMATEL and the DEMATEL, respectively. This difference could be attributed to the type of numbers employed in each method. Real numbers are employed in linguistic scales of DEMATEL. On the other hand, IFNs are employed in the proposed IF-DEMATEL.

This section also compares the results from the perspective of degree of importance. Using the proposed IF-DEMATEL and the DEMATEL, the importance of ten criteria can be prioritized by seeing to the values of (*R*-*C*). Table 12 shows the comparative results of 'degree of importance' of criteria.

Comparing the two results, it can be seen that the most important criterion and the least important criterion obtained using the DEMATEL method and IFS-DEMATEL method are consistent. However, the degree of importance of other criteria between the two methods are a bit inconsistent. It is understandable that the inconsistent results are due the different linguistic variables used. In DEMATEL method, the linguistic variables that are defined in real numbers are used. In contrast, the linguistic variables that are defined in dual memberships of IFSs are used in the proposed IFS-DEMATEL. It is believed that the IF-DEMATEL has an edge in dealing with a complex decision problem owing to the fact that IFSs are dealt with membership and nonmembership judgments. The proposed method in this study also contributes to the changes in the algorithm of the DEMATEL thereby would slightly affect the degree of importance.

Evidently the two methods suggest that the criterion "Experience" (C_3) is the most important criterion in subcontractors selection. It is also good to mention that the two methods also agree that the criterion "Completing on Time" (C_2) is the least important criterion. However, the remaining eight criteria show a slight inconsistency in their position of preference. These results are compared with the work of Ng *et al.* [43]. It is found that the results are slightly inconsistent where the criteria "financial strength" and "adequacy of experiences" are the two most important criteria in their research. With a statistical approach, Doloi [44] identified the criteria "technical expertise," "past success," "time in business," "work methods," and "working capital" are also important pre-qualification criteria in subcontractors selection.

6. CONCLUSION

The DEMATEL and fuzzy DEMATEL have been used extensively to solve various multi-criteria decision-making. By means of an extension of these two decision-making methods, IF-DEMATEL was introduced as to deal with wider range of vague and uncertain information. In group multi-criteria decision-making approaches, the weights of experts and aggregation operator are among the features that need particular attention. In this paper, several innovations to the IF-DEMATEL have been proposed. As to avoid the assumption of equal weights among experts, this paper proposed relative weights for experts using a proportion equation. To aggregate the evaluation made by experts, an averaging operator is used in the proposed method. Apart from these two innovations, this paper also proposed the use of a transformation equation as a technique to convert IFN to crisp numbers. This innovated IF-DEMATEL is then implemented to a case study of subcontractors' selection. The most interesting finding was about the two categories of criteria in subcontractors' selection. The ten most important criteria for scrutinizing subcontractors were identified and these criteria were assessed by five experts. The ultimate result of this research is segregating the criteria of subcontractors' selection into the cause and effect criteria. It is found that Experience, Safety Management, Financial Stability, and Timely Payment to Labor are the criteria in the cause group, while Length of Time in Industry, Quality, Performance History, Compliance with Regulations, Price, and Completing on Time are the criteria in the effect group. In a nutshell, the criteria "Experience" is identified as the main cause that affects the selection of subcontractors. It is shown that the proposed IF-DEMATEL method is a valuable instrument to decide the key success factors in subcontractors' selection. This finding has an important outlook of this study. The identification of two groups of criteria is not only significant to subcontractors' selection, but more importantly, this study has shown the superiority of the proposed method is suggesting the most important and the least important criteria. Nonetheless, the proposed mentioned method suffers from some limitations. The current study was limited by a group of experts where their evaluations are subjected to their experience and perceptions. The current study has only examined ten criteria in which these criteria are not exhaustive and could be added in future research. Considerably more work will need to be done to determine the correlation between criteria and also multi-person decision analysis among experts. A further study with more focus on DEMATEL and the new sets such as Fermatean fuzzy [45] and hesitant multi-fuzzy soft set [46] are therefore suggested.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHORS' CONTRIBUTION

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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REFERENCES

[1] A. Gabus, E. Fontela, World Problems, an Invitation to Further Thought within the Framework of DEMATEL, Battelle Geneva Research Center, Geneva, Switzerland, 1972. https://www.scienceopen.com/document?vid=f6e5887c-7f0c-4303-8379-58fe891eeb03

[2] E. Fontela, A. Gabus, The DEMATEL Observer, DEMATEL 1976 Report, Battelle Geneva Research Center, Geneva, Switzerland, 1976.

[3] M.L. Tseng, Y.H. Lin, Application of fuzzy DEMATEL to develop a cause and effect model of municipal solid waste management in Metro Manila, Environ. Monit. Assess. 158 (2009), 519.

[4] L. Abdullah, N. Rahim, The use of fuzzy DEMATEL for urban sustainable development, in: C. Kahraman, S. Cebi, S. Cevik Onar, B. Oztaysi, A. Tolga, I. Sari (Eds.), Intelligent and Fuzzy Techniques in Big Data Analytics and Decision Making (INFUS 2019), Advances in Intelligent Systems and Computing, vol. 1029, Springer, Cham, Switzerland, 2020, pp. 722–729.

[5] K.P. Lin, M.L. Tseng, P.F. Pai, Sustainable supply chain management using approximate fuzzy DEMATEL method, Resour. Conserv. Recy. 128 (2018), 134–142.

[6] S.L. Si, X.Y. You, H.C. Liu, P. Zhang, DEMATEL technique: a systematic review of the state-of-the-art literature on methodologies and applications, Math. Probl. Eng. 2018 (2018), 1–33.

[7] L.A. Zadeh, Fuzzy sets, Inf. Control. 8 (1965), 338–353.

[8] G. Büyüközkan, G. Fethullah, Application of a new combined intuitionistic fuzzy MCDM approach based on axiomatic design methodology for the supplier selection problem, Appl. Soft Comput. 52 (2017), 1222–1238.

[9] R. Kozik, Using a fuzzy DEMATEL method for analyzing the factors influencing subcontractors' selection, AIP Conf. Proc. 1738 (2016), 200006.

[10] S.K. Patil, R. Kant, A hybrid approach based on fuzzy DEMATEL and FMCDM to predict success of knowledge management adoption in supply chain, Appl. Soft Comput. 18 (2014), 126–135.

[11] S. Luthra, K. Govindan, R.K. Kharb, S.K. Mangla, Evaluating the enablers in solar power developments in the current scenario using fuzzy DEMATEL, Renew. Sust. Energy Rev. 63 (2016), 379–397.

[12] L. Abdullah, N. Zulkifli, A new DEMATEL method based on interval type-2 fuzzy sets for developing a causal relationship of knowledge management criteria, Neural Comput. Appl. 31 (2019), 4095–4111.

[13] S. Ljubojević, D. Pamučar, D. Jovanović, V. Vešović, Outsourcing transport service: a fuzzy multi-criteria methodology for provider selection based on comparison of the real and ideal parameters of providers, Oper. Res. 19 (2019), 399–433.

[14] F. Acuña-Carvajal, L. Pinto-Tarazona, H. López-Ospina, R. Barros-Castro, L. Quezada, K. Palacio, An integrated method to plan, structure and validate a business strategy using fuzzy DEMATEL and the balanced scorecard, Expert Syst. Appl. 122 (2019), 351–368.

[15] L. Abdullah, C.M. Goh, N. Zamri, M. Othman, Application of interval valued intuitionistic fuzzy DEMATEL for flood management, J. Intell. Fuzzy Syst. 38 (2020), 873–881.

[16] L. Najib, A.T. Ab Ghani, L. Abdullah, M.F. Ahmad, An application of coastal erosion decision problem using interval type-2 fuzzy DEMATEL method, J. Sustain. Sci. Manag. 12 (2017), 204–217. https://jssm.umt.edu.my/wp-content/uploads/sites/51/2017/12/23-web.pdf

[17] K. Govindan, R. Khodaverdi, A. Vafadarnikjoo, Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain, Expert Syst. Appl. 42 (2015), 7207–7220.

[18] N. Zulkifli, L. Abdullah, Intuitionistic fuzzy DEMATEL for municipal solid waste treatment technologies, Int. J. Eng. Technol. 7 (2018), 710–712.

[19] A. Vafadarnikjoo, M. Mobin, S.M.A.K. Firouzabadi, An intuitionistic fuzzy based-DEMATEL to rank risks of construction projects, in Proceedings of the International Conference on Industrial Engineering and Operations Management, Detroit, MI, USA, 2016, pp. 1366–1377. http://ieomsociety.org/ieomdetroit/pdfs/362.pdf

[20] A. Karaşan, C. Kahraman, A novel intuitionistic fuzzy DEMATEL – ANP – TOPSIS integrated methodology for freight village location selection, J. Intell. Fuzzy Syst. 36 (2019), 1335–1352.

[21] H.S. Kilic, A.E. Demirci, D. Delen, An integrated decision analysis methodology based on IF-DEMATEL and IF-ELECTRE for personnel selection, Decis. Support Syst. 137 (2020), 113360.

[22] A. Varghese, S. Kuriakose, Centroid of an intuitionistic fuzzy number, Notes Intuitionistic Fuzzy Sets. 18 (2012), 19–24. http://ifigenia.org/images/1/1b/NIFS-18-1-19-24.pdf

[23] P. Grzegrorzewski, The hamming distance between intuitionistic fuzzy sets, in Proceedings of the 10th IFSA World Congress, Istanbul, Turkey, 2003, pp. 35–38.

[24] L. Abdullah, P. Goh, Decision making method based on Pythagorean fuzzy sets and its application to solid waste management, Complex Intell. Syst. 5 (2019), 185–198.

[25] L. Abdullah, R. Ramli, H.O. Bakodah, M. Othman, Developing a causal relationship among factors of e-commerce: a decision making approach, J. KSU-Comput. Inf. Sci. 32 (2020), 1194–1201.

[26] R. Kaya, B. Yet, Building Bayesian networks based on DEMATEL for multiple criteria decision problems: a supplier selection case study, Expert Syst. Appl. 134 (2019), 234–248.

[27] S. Bakir, S. Khan, K. Ahsan, S. Rahman, Exploring the critical determinants of environmentally oriented public procurement using the DEMATEL method, J. Environ. Manag. 225 (2018), 325–335.

[28] F.E. Boran, S. Genç, M. Kurt, D. Akay, A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method, Expert Syst. Appl. 36 (2009), 11363–11368.

[29] K.T. Atanassov, Intuitionistic fuzzy sets, Fuzzy Sets Syst. 20 (1986), 87–96.

[30] M. Kirişci, Comparison of medical decision-making with intuitionistic fuzzy parametrized fuzzy soft set and Riesz summability, New Math. Nat. Comput. 15 (2019), 351–359.

[31] J. Dhivya, B. Sridevi, A novel similarity measure between intuitionistic fuzzy sets based on the mid points of transformed triangular fuzzy numbers with applications to pattern recognition and medical diagnosis, Appl. Math. 34 (2019), 229–252.

[32] H.P. Chen, G.Q. Xu, Group decision making with incomplete intuitionistic fuzzy preference relations based on additive consistency, Comput. Ind. Eng. 135 (2019), 560–567.

[33] H. Garg, G. Kaur, TOPSIS based on nonlinear-programming methodology for solving decision-making problems under cubic intuitionistic fuzzy set environment, Comput. Appl. Math. 38 (2019), 114.

[34] Q. Jiang, X. Jin, S.J. Lee, S. Yao, A new similarity/distance measure between intuitionistic fuzzy sets based on the transformed isosceles triangles and its applications to pattern recognition, Expert Syst. Appl. 116 (2019), 439–453.

[35] R. Joshi, S. Kumar, Exponential Jensen intuitionistic fuzzy divergence measure with applications in medical investigation and pattern recognition, Soft Comput. 23 (2019), 8995–9008.

[36] L. Abdullah, N. Zulkifli, H. Liao, E, Herrera-Viedma, A. Al-Barakati, An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management, Eng. Appl. Artif. Intell. 82 (2019), 207–215.

[37] A. Cox, M. Townsend, Strategic Procurement in Construction: Towards Better Practice in the Management of Construction Supply Chains, Thomas Telford Publishing, London E14 4JD, 1998.

[38] H. Huang, E.M. Trauth, Cultural influences and globally distributed information systems development: experiences from Chinese IT professionals, in Proceedings of the 2007 ACM SIGMIS CPR Conference on Computer Personnel Research: The Global Information Technology Workforce, St. Louis, MO, USA, 2007, pp. 36–45.

[39] S. Ang, S.A. Slaughter, Work outcomes and job design for contract *versus* permanent information systems professionals on software development teams, Mis Q. 25 (2001), 321–350.

[40] K. Karim, M. Marosszeky, S. Davis, Managing subcontractor supply chain for quality in construction, Eng. Constr. Archit. Manag. 13 (2006), 27–42.

[41] G. Arslan, S. Kivrak, M.T. Birgonul, I. Dikmen, Improving subcontractor selection process in construction projects: web-based sub-contractor evaluation system (WEBSES), Autom. Constr. 17 (2008), 480–488.

[42] R.M. Choudhry, D. Fang, S.M. Ahmed, Safety management in construction: best practices in Hong Kong, J. Prof. Iss. Eng. Educ. Pract. 134 (2008), 20–32.

[43] T.S. Ng, M. Skitmore, W.F. Chung, Ten basic factors to identify suitable subcontractors for construction projects, in Proceedings of the CIB TG 23 International Conference on Professionalism in Construction: Culture of High Performance, Hong Kong, 2003, pp. 1–8. https://www.irbnet.de/daten/iconda/CIB9174.pdf

[44] H. Doloi, Analysis of pre-qualification criteria in contractor selection and their impacts on project success. Constr. Manag. Econ. 27 (2009), 1245–1263.

[45] T. Senapati, R. Yager, Fermatean fuzzy weighted averaging/geometric operators and its application in multi-criteria decision-making methods, Eng. Appl. Artif. Intell. 85 (2019), 112–121.

[46] A. Dey, T. Senapati, M. Pal, G. Chen, A novel approach to hesitant multi-fuzzy soft set based decision-making, AIMS Math. 5 (2020), 1985–2008.

APPENDIX

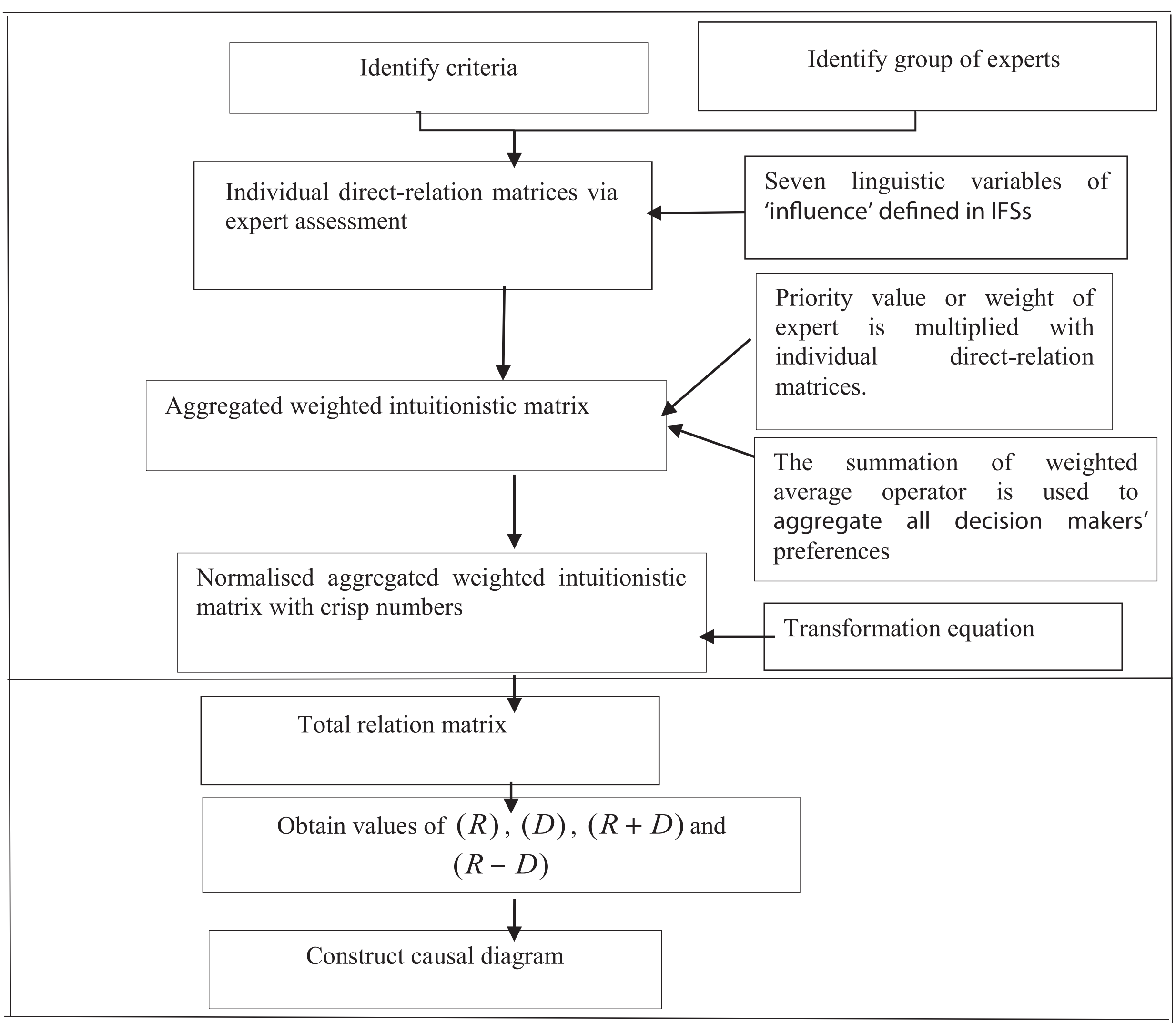

Figure A1 Flowchart of the proposed method.