

Cengiz Kahraman*, Başar Öztayşi and Sezi Çevik Onar

An Integrated Intuitionistic Fuzzy AHP and TOPSIS Approach to Evaluation of Outsource Manufacturers

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Abstract: Outsourcing is the action of contracting a specific task, function, or process to an external company instead of using an organisation's resources. The history of outsourcing goes back to the 1980s when it was used for cost reduction in non-core business operations. Over time, outsourcing has moved to more strategic areas and has become an important factor in business performance. The selection of the best alternative among alternative outsource manufacturers is a multi-criteria decision-making problem. In this study, the fuzzy set theory is used to capture the uncertainty embedded into the decision problem. In this paper, an interval-valued intuitionistic fuzzy Analytic Hierarchy Process and Technique for Order of Preference by Similarity to Ideal Solution-based methodology is proposed, and an application is provided for the evaluation of outsource manufacturers.

Keywords: Outsourcing, interval-valued intuitionistic fuzzy sets, multi-criteria decision-making, outsource manufacturer, TOPSIS.

1 Introduction

Outsourcing is defined as the action of contracting a specific task, function, or process to an external company instead of doing it with an organisation's own resources. In the 1980s, outsourcing was used for cost reduction in non-core business operations. It became more popular in the 1990s, when organisations started to outsource the functions that they did not have enough expertise on. It became a key strategic factor that allows companies to focus only on their core competencies and benefit from the expertise of other companies [18]. As a result, by the 2000s, outsourcing became a norm, and as a result of advances in information technology (IT), companies found the chance of successfully outsourcing more of their operations. Hätönen and Eriksson [19] grouped the history of outsourcing into three, and stated that it has moved from “traditional” in the 1980s to “strategic” in the 1990s and “transformational” in the 2000s. As a part of the transformation, the term “business process outsourcing” has become a popular business practice, in which the organisation delegates one or more business processes to an external provider [14].

By outsourcing, companies can focus on their core competencies, such as manufacturing, design, or consulting, and thus, utilise its sources only to those competencies [3]. From the perspective of a company, outsourcing can be divided into two decision levels. At the first level, the company must decide which functions or process to outsource. In other terms, the company should decide whether to outsource a process or not. At the second, the company evaluates the alternatives and selects a proper company to outsource. While the first problem is more involved with strategic planning and economic analysis, the former one is a multi-criteria decision making (MCDM) problem.

***Corresponding author: Cengiz Kahraman**, Department of Industrial Engineering, Istanbul Technical University, 34367 Macka, Istanbul, Turkey, e-mail: kahramanc@itu.edu.tr

Başar Öztayşi and Sezi Çevik Onar: Department of Industrial Engineering, Istanbul Technical University, 34367 Macka, Istanbul, Turkey

MCDM deals with problems where there are discrete alternatives and more than one perspectives for evaluation. MCDM techniques may include decision makers' subjective evaluations and objective measurement values into the decision-making process. Although in classical approaches, subjective evaluations are also presented with crisp values, fuzzy set theory [67] provides tools and operations to represent uncertainty and imprecision in decision making in a better way. Thus, classical MCDM approaches have been extended to integrate fuzzy sets into the decision-making process [22], such as information systems selection [40], transportation investments selection [27], technology selection [5], location selection [24], urban planning [42], and energy selection [44]. As a result of advances, the classical fuzzy set approach is extended to improve the representation of uncertainty and imprecision in modelling and solving problems. These extensions, such as hesitant fuzzy sets [55], intuitionistic fuzzy sets [2], type-2 fuzzy sets [68], interval-valued fuzzy sets [68], and fuzzy multi-sets [65] have also been used in MCDM problems.

In this study, a decision-making model for evaluating the outsourcing alternative is developed based on intuitionistic fuzzy sets, as the expert evaluations of outsourcing alternatives involve uncertainty and vagueness. The decision model integrates Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) techniques with intuitionistic fuzzy sets. AHP is used for determining the weights of the criteria, and TOPSIS is used for comparing the alternatives. In this paper, a numerical case study containing seven criteria and three alternatives is also provided.

The originality of the paper comes from the proposed decision model and application of the model in the manufacturing outsourcing problem. This paper is the first paper on multi-expert outsource manufacturer selection by integrating the methods of intuitionistic fuzzy AHP and intuitionistic fuzzy TOPSIS. This compact linguistic evaluation methodology based on intuitionistic fuzzy sets enables decision makers to reflect their hesitations in decision processes. Besides, the superiority of AHP in determining the criteria weights and the superiority of TOPSIS in handling huge decision matrices simultaneously exist in the proposed methodology. The rest of the paper is organised as follows. Section 2 gives a brief literature review on outsourcing. Section 3 introduces the evaluation criteria of outsourcing manufacturers. Section 4 presents the intuitionistic fuzzy sets and their preliminaries. Section 5 gives the proposed intuitionistic fuzzy MCDM model. Section 6 includes an application of the proposed intuitionistic fuzzy model. Section 7 concludes the paper and gives further suggestions.

2 Literature Survey on Outsourcing

The literature on outsourcing can be classified into three parts. In the first group, studies that focus on the effects of outsourcing on a company or economy are included. In the second group, analyses regarding outsourcing decisions of the companies are examined. The third group involves studies that focus on selecting the best alternative for a specific outsourcing decision.

In one of the initial studies, McCarthy and Anagnostou [35] focused on the effects of outsourcing on an organisation using input-output methodology. Yamashita [66] examined the effects of foreign outsourcing decision on wage inequality in US manufacturing companies, and showed that imports from developing countries increase the inequality while imports from developed countries do not show the same impact. Galdon-Sanchez et al. [13] investigated the relationship between the increase in outsourcing and its effect on the market share. The authors collected data from Spanish manufacturing plants on peripheral services, and their results showed that focusing on core manufacturing activities provides positive results.

The second group of studies focuses on the outsourcing decision of companies. In one of the initial studies, Tayles and Drury [53] provided a process for outsourcing decisions and presented a case study for the strategic sourcing model they proposed. In another study, Momme [37] analysed the process of outsourcing manufacturing, proposed a model to identify the production system elements and internal support functions, and suggested a framework that links the phases of the entire outsourcing process to strategic planning. Choi [7] also examined outsourcing decisions for production companies under certainty and uncertainty conditions. The results revealed that if the expected outsourcing cost is equal to the known in-house cost of a

process, outsourcing is not feasible for risk-averse firms. Besides, a risk-averse firm chooses partial outsourcing, though outsourcing has a cost disadvantage. Rapp [46] focused on the outsourcing decision problem and defined the factors associated with determining if a company should outsource its sales force or not. In this manner, the author proposed a novel analysis that can be used in this decision. Bayrak [4] proposed a methodology to support decision makers in evaluating the factors and give a better IT outsourcing decision. Martinez-Noya and Garcia-Canal [34] focused on the outsourcing decision of research and development services. The authors defined organisational and environmental factors affecting outsourcing and offshoring decisions, and investigated the effects of these factors on outsourcing decisions. Nosoochi and Nookabadi [38] proposed a stochastic outsource planning model for integration demand and cost uncertainties.

The third group focuses on the process of selecting the appropriate outsourcing company. Various methods are used to select outsourcing companies, such as AHP, Analytic Network Process (ANP), TOPSIS, Iterative Multi-criteria Decision Making (TODIM), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Strengths-Weaknesses-Opportunities-Threads (SWOT) analysis, Decision-Making Trial and Evaluation Laboratory (DEMATEL), Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE), and grey relation. In one of the most recent papers, Modak et al. [36] focused on the outsourcing problem of a coal mining organisation and proposed a decision process based on a balanced scorecard and fuzzy AHP. The balanced scorecard is used to determine the strategic elements of decision making, and fuzzy AHP is applied to determine the relative importance weight of criteria and the alternatives. Wang et al. [58] used a likelihood-based TODIM approach based on multi-hesitant fuzzy linguistic information to evaluate logistics outsourcing providers. Using the proposed method, decision problems in which decision makers show bounded rationality, hesitance, and repetitiveness can be better handled. Tavana et al. [52] proposed a decision model for outsourcing reverse logistics. The proposed model first uses SWOT analysis to define and classify the criteria and then uses intuitionistic fuzzy AHP to determine the importance weights. Later, fuzzy preference programming is used to produce local weights, which are used to rank the alternatives. Kahraman et al. [23] proposed a novel approach using hesitant linguistic term sets for supplier selection problem. Prakash and Barua [45] focused on the outsourcing decision on third-party reverse logistics services. In their decision model, the authors used AHP for the evaluation and ranking of selection criteria and the VIKOR method for the final selection of reverse logistics partners.

Uygun et al. [56] focused on the outsourcing decision for a telecommunication company. In the proposed model, first DEMATEL is used to determine the criteria and dependencies among them. Later, fuzzy ANP is used to obtain the final priorities of the alternatives. Karsak and Dursun [25] used quality function deployment, 2-tuple linguistic representation approach for supplier evaluation and selection problem. Senvar et al. [49] proposed a decision model for multi-attribute supplier selection using fuzzy PROMETHEE technique. Li and Wan [28] extended the outsourcing decisions and modelled the problem as a fuzzy multi-criteria group decision-making problem with incomplete weight information. The authors used fuzzy linear programming to determine the weights of the criteria, and fuzzy goal programming to obtain the relative closeness degrees of the alternative to ideal solutions. This closeness coefficient is later used to rank the alternatives. Oztaysi and Isik [41] proposed a supplier evaluation approach using a fuzzy clustering technique. Tjader et al. [54] focused on determining an IT outsourcing strategy. The authors developed the decision model based on a balanced scorecard approach and ANP method. Using the ANP method, the decision model takes into account the dependency among the main criteria defined by the balanced scorecard.

Hsu et al. [20] proposed a hybrid decision model for selection of outsourcing companies, combining the DEMATEL, ANP, and grey relation methods. Kaya [26] focused on the outsourcing decision for the management of wastes of electrical and electronic equipment by using a fuzzy MCDM approach. The author proposed a group decision-making approach using fuzzy AHP to evaluate and select the appropriate outsourcing firm. Liou et al. [32] proposed a new hybrid MCDM model for outsourcing decision, which addresses the dependencies among the various criteria. In the proposed method, the relations-structure among the criteria is determined using the DEMATEL method. The authors later utilised fuzzy preference programming and the ANP to select the best alternative among outsourcing providers. Chen et al. [6] focused on the outsourcing IT problem and presented a decision model using fuzzy PROMETHEE to evaluate four potential suppliers using seven criteria and four

decision-makers. Lin et al. [30] proposed a new hybrid MCDM technique to cope with the complex and interactive vendor evaluation and selection problem. The authors used ANP in their study, as the decision model they proposed involved criteria with inner dependencies and ANP can handle these dependencies.

Liou and Chuang [31] proposed a new hybrid MCDM model for outsourcing decision in cooperating the DEMATEL, ANP, and VIKOR methods. The decision model assumes that there exists a dependency among criteria. The model utilises DEMATEL to build a relations-structure among criteria, ANP to determine the relative weights of each criterion, and VIKOR to prioritise the alternatives. Chen et al. [6] focused on strategic outsourcing of information technologies. The authors proposed a decision model using the fuzzy VIKOR method and a systematic process for developing the best alternative and compromise solution under each of the selection criteria. Önüt et al. [39] focused on supplier selection for outsourcing. The author proposed a decision model that contains both tangible and intangible criteria. The proposed model uses fuzzy ANP for determining the weights of the criteria and TOPSIS for selecting the best alternative. Wadhwa and Ravindran [57] modelled the vendor selection problem in outsourcing as a multi-objective optimisation problem. The objective function was designed to minimise price, lead time, and rejected products at the same time. The authors showed the results of various methods including weighted objective, goal programming, and compromise programming.

Araz et al. [1] proposed a model for the evaluation and management of the outsourcer. The proposed method first evaluates the alternative using the PROMETHEE method and then fuzzy goal programming is used to select the most suitable alternative and determines the quantities to be ordered. Işıklar et al. [21] focused on third-party logistics and proposed an intelligent decision support system for logistics outsourcing decisions. The proposed approach integrates case-based reasoning, rule-based reasoning, and compromise programming techniques in a fuzzy environment. Shyur and Shih [50] also proposed a hybrid model for supporting the vendor selection process for new task situations. In the proposed model, first criteria are determined and prioritised using the ANP technique, and then TOPSIS is adopted to rank competing products regarding their overall performances. Choy et al. [8] proposed a decision support system for outsourcing operations using case-based reasoning and neural networks. The proposed decision support system continuously tracks and benchmarks the performance of suppliers and help decision makers in selecting the best alternative.

In the literature, outsourcing provider selection has been widely investigated by many authors. Especially, the selection of logistics providers is one of the most well-known problems in the literature [12, 15, 17, 47, 48, 51]. Yet, a limited number of studies focused on the selection of outsourcing manufacturing providers. This comprehensive problem has special characteristics when it is compared to other outsourcing provider selection problems. Choy et al. [8] utilised case-based reasoning and neural network for selecting suppliers during the process of new product development. Choy et al. [9] developed a case-based reasoning decision support system for evaluating the performance of suppliers in the new product development process. Gray et al. [16] evaluated the impact of manufacturer's cost and quality priorities in outsource manufacturing decisions. Ciravenga et al. [10] defined the advantages and risks associated with outsourcing manufacturing in the automotive industry. Although there are several studies in outsource manufacturing providers, a comprehensive study for evaluating outsource manufacturing provider companies is essential both for practitioners and academicians.

The proposed integrated methodology presents an intuitionistic fuzzy AHP where the weights of the criteria are determined and an intuitionistic fuzzy TOPSIS where the intuitionistic fuzzy decision matrix is weighted by the weights obtained from AHP. To the best of authors' knowledge, there is not such an integrated intuitionistic fuzzy methodology applied to the outsource manufacturer selection problem. The methodology can also aggregate the evaluations of more than one expert.

3 Outsource Manufacturer Selection Criteria

Outsourcing manufacturer selection is crucial; it is very critical for the main company to identify and recognise effective selection criteria. There are various uncertainties and risks in the evaluation of alternatives

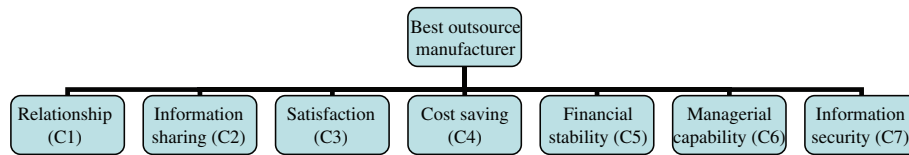


Figure 1: Evaluation Criteria.

regarding compatibility and feasibility. Thus, in this study, linguistic evaluations that can capture this uncertainty are utilised. Outsourcing manufacturer selection criteria are determined to involve both objective and subjective criteria in the decision process. As a result of an extended literature survey, the potential criteria are evaluated by the decision makers to form the final criteria set. Finally, there are seven criteria proposed for evaluating the alternative companies (Figure 1).

The explanations of the criteria in Figure 1 are as follows.

- Relationship (C1): Relationships among the parties are very important for the selection of the best alternative. This criterion involves shared risks and rewards, ensuring cooperation between the main company and the outsourcing company [31]. In a prior study, Dwyer et al. [11] investigated the seller-buyer relationship development process and proposed five stages: awareness, exploration, expansion, commitment, and dissolution. This criterion shows the strength and quality of the relationship between the main company and the outsourcing alternatives.
- Information sharing (C2): Integration and collaborative working environments have become very important to the success of supply chains. Thus, besides the manufacturing activity integration of information systems, the capability of information sharing has become a very important factor for the selection. As a result, the information sharing criterion is added to the decision model to represent the compatibility of information sharing systems of the outsourcing company.
- Satisfaction (C3): Satisfaction is one of the most important factors for customer repurchasing decision [29]. In our decision problem, satisfaction refers to both satisfaction of the buyer company and satisfaction of the end user. It can be difficult to collect quantitative satisfaction data about each alternative, so expert evaluations using linguistic terms are very useful for maintaining satisfaction scores.
- Cost saving (C4): The main idea of outsourcing is to let another company accomplish a specific task in a higher quality and with lower costs due to economies of scale. This criterion refers to the economic outcome of the alternative outsourcing activity.
- Financial stability and flexibility (C5): Sustainability of the partnership relationship is very important for mid-term and long-term plans. Thus, this criterion is added to the model to show the financial stability of the outsourcing company and the flexibility in billing and payment conditions.
- Managerial capability (C6): As the outsourcing decision is vital for the main company, the capability and willingness of managers to provide outsourcing services is an important criterion. Higher managerial capability refers to a better and more sustainable partnership.
- Information security (C7): Mutual trust-based information sharing between the main and the outsourcing company is necessary for both the continuance of the agreement and also for the security of confidential information.

4 Intuitionistic Fuzzy Sets

Atanassov's [2] intuitionistic fuzzy sets take into account the membership value as well as the non-membership value for describing any x in X , such that the sum of membership and non-membership is ≤ 1 . In the following, we define the basic definitions of intuitionistic fuzzy sets.

Definition 1: Let $X \neq \emptyset$ be a given set. An intuitionistic fuzzy set in X is an object A given by

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x), \nu_{\tilde{A}}(x)); x \in X\}, \quad (1)$$

where $\mu_{\tilde{A}}(x):X \rightarrow [0, 1]$ and $\nu_{\tilde{A}}(x):X \rightarrow [0, 1]$ satisfy the condition $0 \leq \mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) \leq 1$, for every $x \in X$.

Let $D \subseteq [0, 1]$ be the set of all closed subintervals of the interval and X be a universe of discourse. An interval-valued intuitionistic fuzzy set (IVIFS) in $\tilde{A}$ over X is an object having the form [2]

$$\tilde{A} = \{ \langle x, \mu_{\tilde{A}}(x), \nu_{\tilde{A}}(x) \rangle | x \in X \}, \quad (2)$$

where $\mu_{\tilde{A}} \rightarrow D \subseteq [0, 1]$, $\nu_{\tilde{A}}(x) \rightarrow D \subseteq [0, 1]$, with the condition $0 \leq \sup \mu_{\tilde{A}}(x) + \sup \nu_{\tilde{A}}(x) \leq 1$, $\forall x \in X$.

The intervals $\mu_{\tilde{A}}(x)$ and $\nu_{\tilde{A}}(x)$ denote the membership function and the non-membership function of the element x to the set $\tilde{A}$, respectively. Thus, each $x \in X$, $\mu_{\tilde{A}}(x)$, and $\nu_{\tilde{A}}(x)$ are closed intervals, and their starting and ending points are denoted by $\mu_{\tilde{A}}^-(x)$, $\mu_{\tilde{A}}^+(x)$, $\nu_{\tilde{A}}^-(x)$, and $\nu_{\tilde{A}}^+(x)$, respectively. IVIFS $\tilde{A}$ is then denoted by

$$\tilde{A} = \{ \langle x, [\mu_{\tilde{A}}^-(x), \mu_{\tilde{A}}^+(x)], [\nu_{\tilde{A}}^-(x), \nu_{\tilde{A}}^+(x)] \rangle | x \in X \}, \quad (3)$$

where $0 \leq \mu_{\tilde{A}}^+(x) + \nu_{\tilde{A}}^+(x) \leq 1$, $\mu_{\tilde{A}}^-(x) \geq 0$, $\nu_{\tilde{A}}^-(x) \geq 0$.

For each element x , we can compute the unknown degree (hesitancy degree) of an IVIFS of $x \in X$ in $\tilde{A}$ defined as follows:

$$\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \nu_{\tilde{A}}(x) = ([1 - \mu_{\tilde{A}}^+(x) - \nu_{\tilde{A}}^+(x)], [1 - \mu_{\tilde{A}}^-(x) - \nu_{\tilde{A}}^-(x)]). \quad (4)$$

For convenience, let $\mu_{\tilde{A}}(x) = [\mu_{\tilde{A}}^-(x), \mu_{\tilde{A}}^+(x)] = [\mu_{\tilde{A}}^-, \mu_{\tilde{A}}^+]$, $\nu_{\tilde{A}}(x) = [\nu_{\tilde{A}}^-(x), \nu_{\tilde{A}}^+(x)] = [\nu_{\tilde{A}}^-, \nu_{\tilde{A}}^+]$, so $\tilde{A} = ([\mu_{\tilde{A}}^-, \mu_{\tilde{A}}^+], [\nu_{\tilde{A}}^-, \nu_{\tilde{A}}^+])$.

Some arithmetic operations with interval-valued intuitionistic fuzzy numbers (IVIFNs) and $\lambda \geq 0$ are given in the following.

Let $\tilde{A} = ([\mu_{\tilde{A}}^-, \mu_{\tilde{A}}^+], [\nu_{\tilde{A}}^-, \nu_{\tilde{A}}^+])$ and $\tilde{B} = ([\mu_{\tilde{B}}^-, \mu_{\tilde{B}}^+], [\nu_{\tilde{B}}^-, \nu_{\tilde{B}}^+])$ be two IVIFNs. Then,

$$\tilde{A} \oplus \tilde{B} = ([\mu_{\tilde{A}}^- + \mu_{\tilde{B}}^- - \mu_{\tilde{A}}^- \mu_{\tilde{B}}^-, \mu_{\tilde{A}}^+ + \mu_{\tilde{B}}^+ - \mu_{\tilde{A}}^+ \mu_{\tilde{B}}^+], [\nu_{\tilde{A}}^- \nu_{\tilde{B}}^-, \nu_{\tilde{A}}^+ \nu_{\tilde{B}}^+]), \quad (5)$$

$$\tilde{A} \otimes \tilde{B} = ([\mu_{\tilde{A}}^- \mu_{\tilde{B}}^-, \mu_{\tilde{A}}^+ \mu_{\tilde{B}}^+], [\nu_{\tilde{A}}^- + \nu_{\tilde{B}}^- - \nu_{\tilde{A}}^- \nu_{\tilde{B}}^-, \nu_{\tilde{A}}^+ + \nu_{\tilde{B}}^+ - \nu_{\tilde{A}}^+ \nu_{\tilde{B}}^+]). \quad (6)$$

Definition 2: Let $\tilde{\alpha} = ([a, b], [c, d])$ be an IVIFN. The following score function is proposed for defuzzifying $\tilde{\alpha}$ [43]:

$$I(\tilde{\alpha}) = \frac{a + b + (1 - c) + (1 - d) + a \times b - \sqrt{(1 - c) \times (1 - d)}}{4}. \quad (7)$$

In Eq. (7), the terms $(1 - c)$ and $(1 - d)$ convert non-membership degrees to membership degrees, while the term $\sqrt{(1 - c) \times (1 - d)}$ decreases the defuzzified value.

Definition 3: Let $\tilde{A}$ be an IVIFN. The score function of $\tilde{A}$ can be given by Eq. (8) [64]:

$$S(\tilde{A}) = \frac{\mu_{\tilde{A}}^- + \mu_{\tilde{A}}^+ - \nu_{\tilde{A}}^- - \nu_{\tilde{A}}^+}{2}. \quad (8)$$

Let $\tilde{A}$ be an IVIFN. The accuracy function $H(\tilde{A})$ of $\tilde{A}$ can be formulated by Eq. (9) [64]:

$$H(\tilde{A}) = \frac{\mu_{\tilde{A}}^- + \mu_{\tilde{A}}^+ + \nu_{\tilde{A}}^- + \nu_{\tilde{A}}^+}{2}. \quad (9)$$

Definition 4: Let $\tilde{\alpha}_j = ([a_j, b_j], [c_j, d_j])$ ($j = 1, 2, \dots, n$) be a collection of IVIFNs and let the interval-valued intuitionistic fuzzy weighted averaging (IIFWA) operator $Q^n \rightarrow Q$, if

$$\text{IIFWA}_w(\tilde{\alpha}_1, \tilde{\alpha}_2, \dots, \tilde{\alpha}_n) = w_1 \tilde{\alpha}_1 \oplus w_2 \tilde{\alpha}_2 \oplus \dots \oplus w_n \tilde{\alpha}_n, \quad (10)$$

where Q is the set of all IVIFNs, $w = (w_1, w_2, \dots, w_n)$ is the weight vector of the IVIFNs $\tilde{\alpha}_j$ ($j = 1, 2, \dots, n$), and $w_j > 0$, $\sum_{j=1}^n w_j = 1$. The IIFWA operator can be further transformed into the following form:

$$\text{IIFWA}_w(\tilde{\alpha}_1, \tilde{\alpha}_2, \dots, \tilde{\alpha}_n) = \left[\left[1 - \left(\prod_{i=1}^n (1 - a_i) \right)^{w_i}, 1 - \left(\prod_{i=1}^n (1 - b_i) \right)^{w_i} \right], \left[\left(\prod_{i=1}^n c_i \right)^{w_i}, \left(\prod_{i=1}^n d_i \right)^{w_i} \right] \right]. \quad (11)$$

Especially if $w = (1/n, 1/n, \dots, 1/n)$, then the IIFWA operator reduces to an interval-valued intuitionistic fuzzy averaging operator, where

$$\text{IIFA}(\tilde{\alpha}_1, \tilde{\alpha}_2, \dots, \tilde{\alpha}_n) = \frac{1}{n}(\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 \oplus \dots \oplus \tilde{\alpha}_n) = \left[\left[1 - \left(\prod_{i=1}^n (1 - a_i) \right)^{1/n}, 1 - \left(\prod_{i=1}^n (1 - b_i) \right)^{1/n} \right], \left[\left(\prod_{i=1}^n c_i \right)^{1/n}, \left(\prod_{i=1}^n d_i \right)^{1/n} \right] \right]. \quad (12)$$

5 Proposed Method

In this paper, we propose an approach for MCDM problems with an interval-valued intuitionistic AHP and IVIF-TOPSIS method. The methodology is composed of two phases. The first phase consists of eight steps and ends by obtaining the criteria weights. The second phase also consists of eight steps and ends by ranking the alternatives based on criteria weights obtained in the first phase and expert judgments. In the following, we present the steps of our proposed method.

Step 1. Linguistic pairwise comparison matrices are formed according to the decision model, and decision makers fill the matrices using the linguistic scale given in Table 1.

Step 2. The linguistic pairwise matrices are converted to their corresponding IVIFSs using the scale given in Table 1 to obtain intuitionistic pairwise comparison matrices and an aggregated pairwise comparison matrix ($\tilde{R}_g$):

$$\tilde{R}_g = \begin{bmatrix} ([\mu_{g_{11}}^-, \mu_{g_{11}}^+], [v_{g_{11}}^-, v_{g_{11}}^+]) & \cdots & ([\mu_{g_{1n}}^-, \mu_{g_{1n}}^+], [v_{g_{1n}}^-, v_{g_{1n}}^+]) \\ \vdots & \ddots & \vdots \\ ([\mu_{g_{n1}}^-, \mu_{g_{n1}}^+], [v_{g_{n1}}^-, v_{g_{n1}}^+]) & \cdots & ([\mu_{g_{nn}}^-, \mu_{g_{nn}}^+], [v_{g_{nn}}^-, v_{g_{nn}}^+]) \end{bmatrix}.$$

Step 3. Score judgement matrices ($\tilde{S}$) are formed using the scoring function given in Eq. (8):

$$\tilde{S} = \begin{bmatrix} [\mu_{g_{11}}^- - v_{g_{11}}^+, \mu_{g_{11}}^+ - v_{g_{11}}^-] & \cdots & [\mu_{g_{1n}}^- - v_{g_{1n}}^+, \mu_{g_{1n}}^+ - v_{g_{1n}}^-] \\ \vdots & \ddots & \vdots \\ [\mu_{g_{n1}}^- - v_{g_{n1}}^+, \mu_{g_{n1}}^+ - v_{g_{n1}}^-] & \cdots & [\mu_{g_{nn}}^- - v_{g_{nn}}^+, \mu_{g_{nn}}^+ - v_{g_{nn}}^-] \end{bmatrix}.$$

Table 1: Linguistic Scale and its Corresponding IVIFS.

Linguistic terms	Membership and non-membership values
Absolutely low (AL)	$([0.10, 0.25], [0.65, 0.75])$
Very low (VL)	$([0.15, 0.30], [0.60, 0.70])$
Low (L)	$([0.20, 0.35], [0.55, 0.65])$
Medium low (ML)	$([0.25, 0.4], [0.50, 0.60])$
Approximately equal (AE)	$([0.45, 0.55], [0.30, 0.45])$
Medium high (MH)	$([0.50, 0.60], [0.25, 0.40])$
High (H)	$([0.55, 0.65], [0.20, 0.35])$
Very high (VH)	$([0.60, 0.70], [0.15, 0.30])$
Absolutely high (AH)	$([0.65, 0.75], [0.10, 0.25])$
Exactly equal (EE)	$([0.5, 0.5], [0.5, 0.5])$

Step 4. Interval exponential matrices ($\tilde{A}$) are calculated as given in Eq. (13):

$$\begin{aligned}\tilde{A} &= \begin{bmatrix} [e^{(\mu_{s_{11}}^- - v_{s_{11}}^+)}, e^{(\mu_{s_{11}}^+ - v_{s_{11}}^-)}] & \dots & [e^{(\mu_{s_{1j}}^- - v_{s_{1j}}^+)}, e^{(\mu_{s_{1j}}^+ - v_{s_{1j}}^-)}] \\ \vdots & \ddots & \vdots \\ [e^{(\mu_{s_{n1}}^- - v_{s_{n1}}^+)}, e^{(\mu_{s_{n1}}^+ - v_{s_{n1}}^-)}] & \dots & [e^{(\mu_{s_{nm}}^- - v_{s_{nm}}^+)}, e^{(\mu_{s_{nm}}^+ - v_{s_{nm}}^-)}] \end{bmatrix} \\ &= \begin{bmatrix} [\tilde{a}_{11}^-, \tilde{a}_{11}^+] & \dots & [\tilde{a}_{1n}^-, \tilde{a}_{1n}^+] \\ \vdots & \ddots & \vdots \\ [\tilde{a}_{n1}^-, \tilde{a}_{n1}^+] & \dots & [\tilde{a}_{nn}^-, \tilde{a}_{nn}^+] \end{bmatrix}.\end{aligned}\quad (13)$$

Step 5. Priority vectors of the interval exponential matrices are calculated using Eq. (14):

$$\tilde{w}_i = \left[\frac{\sum_{j=1}^n \tilde{a}_{ij}^-}{\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij}^+}, \frac{\sum_{j=1}^n \tilde{a}_{ij}^+}{\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij}^-} \right] = [w_i^-, w_i^+], i = 1, \dots, n. \quad (14)$$

Step 6. Possibility degree matrices are obtained using Eqs. (15) and (16):

$$P(\tilde{w}_i > \tilde{w}_j) = p_{ij} = \frac{\max(0, w_i^+ - w_j^-) - \max(0, w_i^- - w_j^+)}{(w_i^+ - w_i^-) + (w_j^+ - w_j^-)}, \quad (15)$$

$$P(\tilde{w}_j > \tilde{w}_i) = p_{ji} = \frac{\max(0, w_j^+ - w_i^-) - \max(0, w_j^- - w_i^+)}{(w_i^+ - w_i^-) + (w_j^+ - w_j^-)}. \quad (16)$$

Step 7. Possibility degrees are prioritised using Eq. (17):

$$w_i = \frac{\sum_{j=1}^n p_{ij} - 1}{n} + 0.5. \quad (17)$$

Step 8. The weights are normalised as given in Eq. (18):

$$w_i^T = \frac{w_i}{\sum_{i=1}^n w_i}. \quad (18)$$

Steps 1–8 are repeated to obtain the weight of each main criterion and the weights of its sub-criteria. Then, phase 2 starts with Step 9 by collecting experts' evaluations and ends by prioritising the alternatives.

Step 9. The experts evaluate the alternatives using the linguistic scale given in Table 1.

Step 10. The linguistic evaluations are converted to IVIFS to obtain the decision matrices ($\tilde{D}_k$ for each decision maker:

$$\tilde{D}_k = \begin{matrix} & \begin{matrix} A_1 & A_2 & \dots & A_m \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} ([\mu_{11k}^-, \mu_{11k}^+], [v_{11k}^-, v_{11k}^+]) & ([\mu_{12k}^-, \mu_{12k}^+], [v_{12k}^-, v_{12k}^+]) & \dots & ([\mu_{1mk}^-, \mu_{1mk}^+], [v_{1mk}^-, v_{1mk}^+]) \\ ([\mu_{21k}^-, \mu_{21k}^+], [v_{21k}^-, v_{21k}^+]) & ([\mu_{22k}^-, \mu_{22k}^+], [v_{22k}^-, v_{22k}^+]) & \dots & ([\mu_{2mk}^-, \mu_{2mk}^+], [v_{2mk}^-, v_{2mk}^+]) \\ \vdots & \vdots & \ddots & \vdots \\ ([\mu_{n1k}^-, \mu_{n1k}^+], [v_{n1k}^-, v_{n1k}^+]) & ([\mu_{n2k}^-, \mu_{n2k}^+], [v_{n2k}^-, v_{n2k}^+]) & \dots & ([\mu_{nmk}^-, \mu_{nmk}^+], [v_{nmk}^-, v_{nmk}^+]) \end{bmatrix} \end{matrix}.$$

Step 11. Positive ideal solution (PIS) and negative ideal solution (NIS) are obtained for each decision maker by using score and accuracy functions:

$$\widetilde{\text{NIS}}_k = (([\mu_{1-k}^-, \mu_{1-k}^+], [v_{1-k}^-, v_{1-k}^+]), ([\mu_{2-k}^-, \mu_{2-k}^+], [v_{2-k}^-, v_{2-k}^+]), \dots, ([\mu_{n-k}^-, \mu_{n-k}^+], [v_{n-k}^-, v_{n-k}^+])), \quad (19)$$

$$\widetilde{\text{PIS}}_k = (([\mu_{1^k}^-, \mu_{1^k}^+], [v_{1^k}^-, v_{1^k}^+]), ([\mu_{2^k}^-, \mu_{2^k}^+], [v_{2^k}^-, v_{2^k}^+]), \dots, ([\mu_{n^k}^-, \mu_{n^k}^+], [v_{n^k}^-, v_{n^k}^+])). \quad (20)$$

Step 12. The separation measure between the alternatives and PIS (D_j^{*k}) are calculated for each expert:

$$D_j^{*k} = \sqrt{\frac{1}{2} \sum_{i=1}^n w_i^T \left\{ (\mu_{ijk}^- - \mu_{i^k}^-)^2 + (\mu_{ijk}^+ - \mu_{i^k}^+)^2 + (v_{ijk}^- - v_{i^k}^-)^2 + (v_{ijk}^+ - v_{i^k}^+)^2 + (\pi_{ijk}^l - \pi_{i^k}^l)^2 + (\pi_{ijk}^u - \pi_{i^k}^u)^2 \right\}}. \quad (21)$$

Step 13. Calculate the separation measure between the j^{th} alternative and NIS (D_j^{-k}) for each expert:

$$D_j^{-k} = \sqrt{\frac{1}{2} \sum_{i=1}^n w_i^T \left\{ (\mu_{ijk}^- - \mu_{i^k}^-)^2 + (\mu_{ijk}^+ - \mu_{i^k}^+)^2 + (v_{ijk}^- - v_{i^k}^-)^2 + (v_{ijk}^+ - v_{i^k}^+)^2 + (\pi_{ijk}^l - \pi_{i^k}^l)^2 + (\pi_{ijk}^u - \pi_{i^k}^u)^2 \right\}}. \quad (22)$$

Step 14. Separation measures for the experts are aggregated using Eq. (23):

$$D_j^* = \sum_{k=1}^K (\lambda_k D_j^{*k}), \quad (23)$$

where λ_k is the weight of decision maker k .

Step 15. The closeness coefficient of each alternative is obtained by using Eq. (24):

$$U_j = \frac{D_j^-}{D_j^- + D_j^*}, \quad j = 1, 2, \dots, m. \quad (24)$$

Step 16. The alternatives are ranked according to the closeness coefficient values.

6 Real-World Application

In this section, the proposed method is applied to a real case study. In this case study, a global textile firm plans to outsource some of its production activities to local firms. After a literature review and experts' comments, a set of seven criteria given in Section 3 is determined. The textile firm evaluates three alternative outsourcing companies (A1, A2, and A3) for outsourcing.

First, the weights of the criteria are determined by pairwise comparisons. For this aim, the decision makers fill the pairwise comparison matrix given in Table 2.

The aggregated pairwise comparison matrix is given in Table 3. The aggregated value for C1–C2 is [(0.18, 0.33), (0.57, 0.67)]. This value is calculated as follows: in Table 2, the corresponding linguistic evaluations are VL, L, and L. The IVIF values associated with these terms are [(0.15, 0.3), (0.6, 0.7)], [(0.2, 0.35), (0.55, 0.65)], [(0.2, 0.35), (0.55, 0.65)]. The parameters of the resulting value are calculated using Eq. (12).

$$1 - (\sqrt[3]{(1-0.15) \times (1-0.2) \times (1-0.2)}) = 0.18$$

$$1 - (\sqrt[3]{(1-0.3) \times (1-0.35) \times (1-0.35)}) = 0.33$$

$$\sqrt[3]{(0.6) \times (0.55) \times (0.55)} = 0.57$$

$$\sqrt[3]{(0.7) \times (0.65) \times (0.65)} = 0.67.$$

The interval exponential matrices ($\tilde{A}$) are formed as given in Table 4. In the table, the interval exponential value for C1–C2 is [0.62, 0.79]. This value is calculated using Eq. (13) as $[e^{(0.18-0.67)}, e^{(0.33-0.57)}]$.

The possibility degree matrix is formed using Eqs. (15) and (16). In Table 5, 0.523 is calculated as

$$\frac{(0.50 + 0 + 0.33 + 0 + 0 + 0.08 + 0.20) - 1}{7} + 0.5 = 0.523.$$

Table 2: Pairwise Comparisons of the Criteria.

	Expert 1							Expert 2							Expert 3						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
C1	EE	VL	ML	AL	AL	L	ML	EE	L	ML	AL	AL	L	L	EE	L	L	VL	AL	L	ML
C2		EE	H	ML	H	MH	H		EE	MH	L	H	MH	H		EE	MH	L	H	MH	MH
C3			EE	VL	L	ML	ML			EE	VL	VL	L	L			EE	AL	ML	ML	L
C4				EE	MH	H	H				EE	MH	MH	MH				EE	H	H	H
C5					EE	MH	H					EE	E	H					EE	H	VH
C6						EE	MH						EE	MH						EE	MH
C7							EE							EE							EE

Table 3: Aggregated Pairwise Comparison Matrix.

	C1	C2	C3	C4
C1	[(0.5, 0.5), (0.5, 0.5)]	[(0.18, 0.33), (0.57, 0.67)]	[(0.23, 0.38), (0.52, 0.62)]	[(0.12, 0.27), (0.63, 0.73)]
C2	[(0.57, 0.67), (0.18, 0.33)]	[(0.5, 0.5), (0.5, 0.5)]	[(0.52, 0.62), (0.23, 0.38)]	[(0.22, 0.37), (0.53, 0.63)]
C3	[(0.52, 0.62), (0.23, 0.38)]	[(0.23, 0.38), (0.52, 0.62)]	[(0.5, 0.5), (0.5, 0.5)]	[(0.15, 0.28), (0.62, 0.72)]
C4	[(0.63, 0.73), (0.11, 0.27)]	[(0.53, 0.63), (0.22, 0.37)]	[(0.62, 0.72), (0.13, 0.28)]	[(0.5, 0.5), (0.5, 0.5)]
C5	[(0.65, 0.75), (0.1, 0.25)]	[(0.2, 0.35), (0.55, 0.65)]	[(0.55, 0.65), (0.2, 0.35)]	[(0.23, 0.38), (0.52, 0.62)]
C6	[(0.55, 0.65), (0.2, 0.35)]	[(0.25, 0.4), (0.5, 0.6)]	[(0.52, 0.62), (0.23, 0.38)]	[(0.22, 0.37), (0.53, 0.63)]
C7	[(0.52, 0.62), (0.23, 0.38)]	[(0.22, 0.37), (0.53, 0.63)]	[(0.53, 0.63), (0.22, 0.37)]	[(0.22, 0.37), (0.53, 0.63)]
	C5	C6	C7	
C1	[(0.5, 0.5), (0.5, 0.5)]	[(0.18, 0.33), (0.57, 0.67)]	[(0.23, 0.38), (0.52, 0.62)]	
C2	[(0.57, 0.67), (0.18, 0.33)]	[(0.5, 0.5), (0.5, 0.5)]	[(0.52, 0.62), (0.23, 0.38)]	
C3	[(0.52, 0.62), (0.23, 0.38)]	[(0.23, 0.38), (0.52, 0.62)]	[(0.5, 0.5), (0.5, 0.5)]	
C4	[(0.63, 0.73), (0.11, 0.27)]	[(0.53, 0.63), (0.22, 0.37)]	[(0.62, 0.72), (0.13, 0.28)]	
C5	[(0.65, 0.75), (0.1, 0.25)]	[(0.2, 0.35), (0.55, 0.65)]	[(0.55, 0.65), (0.2, 0.35)]	
C6	[(0.55, 0.65), (0.2, 0.35)]	[(0.25, 0.4), (0.5, 0.6)]	[(0.52, 0.62), (0.23, 0.38)]	
C7	[(0.52, 0.62), (0.23, 0.38)]	[(0.22, 0.37), (0.53, 0.63)]	[(0.53, 0.63), (0.22, 0.37)]	

Table 4: Interval Exponential Matrix.

	C1	C2	C3	C4	C5	C6	C7
C1	[1, 1]	[0.62, 0.79]	[0.68, 0.88]	[0.54, 0.69]	[0.52, 0.67]	[0.64, 0.82]	[0.68, 0.87]
C2	[1.26, 1.63]	[1, 1]	[1.14, 1.47]	[0.66, 0.85]	[1.22, 1.57]	[1.11, 1.42]	[1.18, 1.52]
C3	[1.14, 1.47]	[0.68, 0.88]	[1, 1]	[0.57, 0.72]	[0.64, 0.82]	[0.68, 0.88]	[0.66, 0.85]
C4	[1.45, 1.86]	[1.18, 1.52]	[1.4, 1.8]	[1, 1]	[1.14, 1.47]	[1.18, 1.52]	[1.18, 1.52]
C5	[1.49, 1.92]	[0.64, 0.82]	[1.23, 1.58]	[0.68, 0.88]	[1, 1]	[1.11, 1.43]	[1.26, 1.62]
C6	[1.22, 1.57]	[0.7, 0.9]	[1.14, 1.47]	[0.66, 0.85]	[0.78, 1]	[1, 1]	[1.11, 1.42]
C7	[1.14, 1.47]	[0.66, 0.85]	[1.18, 1.52]	[0.66, 0.85]	[0.62, 0.79]	[0.7, 0.9]	[1, 1]

Table 5: Possibility Degree Matrix and Normalised Weights.

	C1	C2	C3	C4	C5	C6	C7	Prioritization	Normalised weights
C1	0.50	0.00	0.33	0.00	0.00	0.08	0.20	0.523	0.075
C2	1.00	0.50	0.91	0.36	0.53	0.66	0.78	1.248	0.178
C3	0.67	0.09	0.50	0.00	0.11	0.25	0.37	0.699	0.100
C4	1.00	0.64	1.00	0.50	0.67	0.80	0.92	1.405	0.201
C5	1.00	0.47	0.89	0.33	0.50	0.64	0.76	1.217	0.174
C6	0.92	0.34	0.75	0.20	0.36	0.50	0.62	1.04	0.15
C7	0.80	0.22	0.63	0.08	0.24	0.38	0.50	0.868	0.124

The normalised weight of C1, 0.075, is calculated as

$$\frac{0.523}{(0.523 + 1.248 + 0.699 + 1.405 + 1.217 + 1.04 + 0.868)} = 0.075.$$

Following the steps of the proposed method, the weights of the criteria are determined as 0.075, 0.178, 0.100, 0.201, 0.174, 0.15, and 0.124, respectively.

Next, the decision makers evaluate the alternatives using linguistic terms. The evaluations of the alternative with respect to different alternatives are represented in Table 6.

For C1 evaluation of Expert 1, the associated fuzzy numbers are $[(0.5, 0.6), (0.25, 0.4)]$, $[(0.55, 0.65), (0.2, 0.35)]$, and $[(0.6, 0.7), (0.15, 0.3)]$. The score functions of these values are 0.45, 0.65, and 0.85, respectively. Thus, the NIS is $[(0.5, 0.6), (0.25, 0.4)]$ and the PIS is $[(0.6, 0.7), (0.15, 0.3)]$. Table 7 presents the calculated distances from the ideal solution for Expert 1 by using Eqs. (21) and (22) and the weights calculated in Step 8.

The operations are repeated for Expert 2 and Expert 3, and the separation values are obtained as given in Table 7.

The results of the proposed method are given in Table 8. Then, by using Eq. (23), the aggregated separation values are obtained. Finally, using Eq. (24), the closeness coefficient of each alternative is calculated. The aggregated separation values and closeness coefficients are given in Table 8.

As the alternative with the highest closeness coefficient is the best alternative, alternative 3 should be selected. The order of the alternatives is as follows: $A3 > A1 > A2$.

Now, we will compare our results with the fuzzy simple additive weighting (SAW) method. The fuzzy score based on the SAW method is calculated by Eq. (25):

$$s_j = \sum_{k=1}^K \sum_{i=1}^n w_i \times \text{def}(\tilde{\alpha}_{ijk}), \quad (25)$$

Table 6: Alternative Evaluations.

	Expert 1			Expert 2			Expert 3		
	A1	A2	A3	A1	A2	A3	A1	A2	A3
C1	MH	H	VH	MH	MH	H	H	VH	AH
C2	ML	VL	ML	ML	ML	ML	L	L	VL
C3	H	MH	H	MH	MH	VH	VH	H	H
C4	ML	VL	ML	ML	ML	VL	ML	VL	L
C5	H	MH	H	H	VH	H	H	H	MH
C6	L	ML	L	L	VL	ML	VL	ML	ML
C7	MH	MH	H	VH	AH	VH	AH	VH	VH

Table 7: Distance from Ideal Solutions Separation Measures for Expert 1.

	Distances from NIS			Distances from PIS		
	A1	A2	A3	A1	A2	A3
C1	0	0.01	0.04	0.04	0.01	0
C2	0.04	0	0.04	0	0.04	0
C3	0.01	0	0.01	0	0.01	0
C4	0.04	0	0.04	0	0.04	0
C5	0.01	0	0.01	0	0.01	0
C6	0	0.01	0	0.01	0	0.01
C7	0	0	0.01	0.01	0.01	0
D_j^1	0.095	0.033	0.105	0.053	0.100	0.027

Table 8: Results of Evaluations.

	A1	A2	A3
Exp1			
D+	0.053	0.100	0.027
D−	0.095	0.033	0.105
Exp2			
D+	0.068	0.073	0.074
D−	0.069	0.074	0.073
Exp3			
D+	0.067	0.074	0.062
D−	0.083	0.071	0.074
Aggregated			
D+	0.063	0.082	0.055
D−	0.082	0.060	0.084
U	0.567	0.420	0.606

Table 9: Defuzzification of Linguistic Scale.

Linguistic term	Defuzzified value
AL	0.1698
VL	0.2121
L	0.2558
ML	0.3007
AE	0.4693
MH	0.5198
H	0.5716
VH	0.6247
AH	0.6790

where s_j is the score of the j^{th} alternative ($j=1, \dots, J$), w_i represents the weight of the i^{th} criterion, and $\text{def}(\alpha_{ijk})$ represents the defuzzified value of the linguistic term assigned to alternative j with respect to criterion i by expert k .

We first defuzzify the linguistic scale in Table 1 as in Table 9.

Substituting the defuzzified values into the decision matrix given in Table 3, we obtain Table 10.

Applying Eq. (25), we obtain the score 0.423221 for alternative 1 (A1), 0.410613 for alternative 2 (A2), and 0.42506 for alternative 3 (A3). The ranking of the alternatives is consistent with our proposed method. However, our method does not require any defuzzification, which causes loss of information.

7 Conclusions

Outsourcing manufacturing may be advantageous in several areas. Some of them are lower labour costs, access to an outsourcing resource to quickly schedule prototyping and other production-related functions without reallocating internal resources, supplementing existing in-house manufacturing efforts and making it easier to meet the new demands, and outsourcing a company's production with greater efficiency. Selection of the best outsourcing manufacturer is a challenging problem with several conflicting criteria. Most of these criteria are intangible and can be properly evaluated by linguistic terms. The proposed IVIF AHP and TOPSIS methodology could successfully select the best outsourcing manufacturer. The integration of these two most popular MCDM methods produces an excellent evaluation methodology under fuzziness. The hesitancy of decision makers could be handled by the intuitionistic fuzzy sets by both calculating the criteria

Table 10: Defuzzified Decision Matrix.

	Expert 1		
	A1	A2	A3
C1	0.5198	0.5716	0.6247
C2	0.3007	0.2121	0.3007
C3	0.5716	0.5198	0.5716
C4	0.3007	0.2121	0.3007
C5	0.5716	0.5198	0.5716
C6	0.2558	0.3007	0.2558
C7	0.5198	0.5198	0.5716
	Expert 2		
	A1	A2	A3
C1	0.5198	0.5198	0.5716
C2	0.3007	0.3007	0.3007
C3	0.5198	0.5198	0.6247
C4	0.3007	0.3007	0.2121
C5	0.5716	0.6247	0.5716
C6	0.2558	0.2121	0.3007
C7	0.6247	0.6790	0.6247
	Expert 3		
	A1	A2	A3
C1	0.5716	0.6247	0.6790
C2	0.2558	0.2558	0.2121
C3	0.6247	0.5716	0.5716
C4	0.3007	0.2121	0.2558
C5	0.5716	0.5716	0.5198
C6	0.2121	0.3007	0.3007
C7	0.6790	0.6247	0.6247

weights by pairwise comparison matrices and prioritising the alternative outsource manufacturers using the TOPSIS method.

For further research, we suggest other extensions of fuzzy sets, such as hesitant fuzzy sets [59, 62, 63], 2-tuple linguistic methods [33, 61], type-2 fuzzy sets, neutrosophic sets, fuzzy cross-entropy [60], or Pythagorean fuzzy sets to be used for the same problem. The obtained results can be compared with our results. Alternatively, instead of IVIF numbers, triangular intuitionistic fuzzy numbers, or trapezoidal intuitionistic fuzzy numbers can be used in the proposed methodology.

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