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An Integrated Circular Intuitionistic Fuzzy MCDM Framework with Radius Operators for Same-Day Delivery Service Selection

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Abstract

The rapid expansion of e-commerce has increased the demand for rapid, reliable, and efficient logistics services, particularly same-day delivery (SDD). Selecting SDD service providers is a multi-criteria decision-making (MCDM) problem because it involves multiple evaluation criteria and linguistic judgments under uncertainty. This study develops a decision-making framework based on circular intuitionistic fuzzy sets (CIFS) for SDD service selection and evaluates the effect of different CIFS radius operators on ranking outcomes. The proposed methodology is implemented in a case study of SDD service selection in Malang, involving 30 qualified respondents who had used all evaluated SDD alternatives, four criteria, and three alternatives. Respondent evaluations are aggregated and analyzed using three radius operators: maximum Euclidean distance, radius algebraic product, and radius algebraic sum. A sensitivity analysis is also conducted over the full range of the parameter λ. The results show that, within this case study, the radius algebraic product operator provides the most stable ranking, consistently producing $AL_3 \succ AL_2 \succ AL_1$. These findings indicate that the choice of CIFS radius operator significantly affects decision stability and sensitivity to radius-based dispersion.

Keywords: Circular Intuitionistic Fuzzy Set; Logistics Service Selection; Multi-Criteria Decision Making; Radius Operator; Same-Day Delivery.

1. Introduction

In recent years, the demand for logistics services, particularly *same-day delivery* (SDD), has continued to increase in line with the growth of *e-commerce*, the rising volume of last-mile delivery orders, intensifying service competition, and customer expectations for fast, timely, and reliable delivery [1–3]. The selection of SDD logistics service providers constitutes a strategic decision, as it directly affects service quality, operational costs, order fulfillment rates, and customer satisfaction [4]. Since this decision involves multiple interrelated criteria, a decision support approach based on Multi-Criteria Decision Making (MCDM) is considered appropriate to facilitate a rational, measurable, and accountable selection process [5].

However, MCDM-based decision-making in the context of SDD service selection is often challenged by uncertainty and ambiguity. This arises because the evaluation of alternatives typically relies on decision-maker judgments that are qualitative, subjective, and expressed in linguistic terms, and are not always supported by complete or sufficient data [6–8]. To address such conditions, fuzzy set theory was introduced as a framework for modeling uncertainty [9]. A further development is the *Intuitionistic Fuzzy Sets* (IFS), which incorporate the degree of membership (DM), degree of non-membership (DNM), and degree of hesitation, thereby

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providing a more expressive representation of uncertain evaluation contexts [10]. Nevertheless, in certain group decision-making scenarios, this representation remains insufficient to explicitly capture the dispersion of decision-maker assessments [11, 12]. To overcome this limitation, *Circular Intuitionistic Fuzzy Sets* (CIFS) were proposed by incorporating a radius parameter that forms a circular region around the DM-DNM center and characterizes the dispersion of decision-maker assessments [11].

Several previous studies have demonstrated that CIFS can be integrated with MCDM procedures to generate alternative rankings across various decision-making problems [13, 14]. Furthermore, CIFS has been combined with methods such as AHP, VIKOR, and ELECTRE, highlighting its potential as an analytical tool for handling uncertainty in multi-criteria decision-making [15, 16]. Among these studies, Cakir and Tas (2023) [13] provide a significant methodological contribution through the development of a CIFS-MCDM framework for evaluating and ranking alternatives. These developments demonstrate that CIFS–MCDM extends IFS-based decision-making by incorporating a radius parameter to more comprehensively represent uncertainty and decision-maker-assessment dispersion [17, 18].

In the initial development and most applications of CIFS–MCDM, the radius formulation generally follows the conventional maximum Euclidean distance (ME) operator [13, 14, 19]. Although simple and widely used, this maximum-based formulation has limited exploration of the algebraic properties of CIFS radius operations. To extend the ME-based radius formulation, Pratama et al. [18] introduced two alternative binary radius operators, namely Radius Algebraic Product (RAP) and Radius Algebraic Sum (RAS). However, RAP and RAS are originally defined as binary operators, whereas multi-decision-maker CIFS–MCDM requires the aggregation of distance values from multiple decision makers. Therefore, the n-ary extensions of RAP and RAS, along with their integration into CIFS–MCDM procedures for multi-decision-maker assessment, remain insufficiently examined in existing studies [18].

Based on this gap, this study develops an extended CIFS–MCDM framework for SDD service selection by combining the CIFS-MCDM procedure of Çakır and Taş [13] with the RAP and RAS radius operators of Pratama et al. [18]. In this framework, the adopted CIFS–MCDM procedure serves as the baseline for criteria weighting and alternative ranking, whereas RAP and RAS are incorporated as alternative radius operations to ME after being formulated in n-ary forms for multi-decision-maker assessments. The framework is then used to examine how different radius definitions affect criteria weights, alternative rankings, ranking stability, and sensitivity.

This study makes four main contributions: integrating RAP and RAS into the CIFS–MCDM framework, extending the radius formulations of RAP and RAS into n-ary forms for multi-decision-maker assessment, systematically comparing ME, RAP, and RAS through sensitivity analysis, and applying the integrated framework to SDD logistics service selection in Malang, Indonesia.

2. Methods

This study develops an integrated CIFS–MCDM framework by adopting the CIFS–MCDM procedure of Çakır and Taş [13] for criteria weighting and alternative ranking and integrating it with three radius operators, namely ME, RAP, and RAS. The RAP and RAS operators are adopted from Pratama et al. [18] and extended into n-ary forms for multi-decision-maker assessments. The IFWA and IFWG operators are used to aggregate intuitionistic fuzzy assessments, whereas the CIFS radius is determined from the Euclidean distances between individual assessments and the aggregated center. These distance values are then processed using the ME, RAP, and RAS operators. This integration aims to examine the effects of different radius formulations on criteria weights, alternative rankings, ranking stability, and decision sensitivity.

The method is applied to SDD service provider selection in Malang, Indonesia. The evaluation criteria are determined through a literature review and adjusted to local operational conditions [20]. Data are collected through questionnaires from respondents who meet the eligibility criteria, namely being at least 18 years old, domiciled in Malang, having used all evaluated service alternatives (AL1, AL2, and AL3) within the last six months, and understanding the characteristics of the services being assessed. The linguistic assessments are converted into intuitionistic fuzzy numbers and represented in CIFS through DM, DNM, and a radius that captures the dispersion of assessments around the aggregated center.

2.1. Intuitionistic Fuzzy Set and Circular Intuitionistic Fuzzy Set

Fuzzy set theory, introduced in [9], provides a foundation for modeling uncertainty. Atanassov extended this concept through IFS by incorporating DM, DNM, and hesitation degree [10]. CIFS extends IFS by representing each element as $(\mu, \nu; r)$, where the DM–DNM pair is equipped with a radius. The radius forms a circular region around the center and enables CIFS to capture value dispersion more comprehensively [11].

Definition 1 (IFS [10])**.** Let X be a universe of discourse. An intuitionistic fuzzy set A in X is defined as follows:

$$A = \{(x, \mu_A(x), \nu_A(x)) : x \in X\}$$

where $\mu_A : X \to [0,1]$ and $\nu_A : X \to [0,1]$ are functions satisfying

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1, \quad \forall x \in X.$$

The value $\mu_A(x)$ is called the degree of membership and $\nu_A(x)$ is called the degree of non-membership of element x, hereafter denoted as DM and DNM, respectively. For each $x \in X$, the degree of hesitation is defined as:

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$$

For each $x \in X$, the intuitionistic fuzzy number (IFN) $\tilde{a}(x)$ is defined as follows:

$$\tilde{a}(x) = (\mu_A(x), \nu_A(x))$$

Definition 2 (CIFS [11])**.** Let E be a universe of discourse and let $C \subseteq E$. For a parameter $r \in [0, \sqrt{2}]$, a CIFS C_r is defined as

$$C_r = \{\, (x,\, u_C(x),\, v_C(x);\, r) \;\big|\; x \in E \,\}.$$

where

$$u_C,\, v_C : E \to [0,1], \qquad \pi_C : E \to [0,1],$$

subject to

$$0 \leq u_C(x) + v_C(x) \leq 1, \qquad \pi_C(x) = 1 - u_C(x) - v_C(x), \quad \forall\, x \in E.$$

Here, $u_C(x)$ denotes the DM, $v_C(x)$ denotes the DNM, and $\pi_C(x)$ denotes the degree of hesitation for all $x \in E$.

2.2. Aggregation operators in CIFS

Aggregation operators in CIFS are used to combine several IFNs into a single representative value by employing the weights of each criterion [13]. The IFWA operator applies an arithmetic weighted averaging approach, whereas the IFWG operator applies a geometric approach that is more sensitive to extreme values [13]. The resulting aggregated values are subsequently used as the centers of the CIFS for each alternative [13].

Definition 3 (IFWA [21]). Let $\{(p_{i1}, q_{i1}), (p_{i2}, q_{i2}), \ldots, (p_{in}, q_{in})\}$ be a set of IFNs. The intuitionistic fuzzy weighted averaging (IFWA) operator is defined as follows:

$$\bar{C}_i = IFWA_{W_i}((p_{i1}, q_{i1}), (p_{i2}, q_{i2}), \ldots, (p_{in}, q_{in})) = \left(1 - \prod_{j=1}^{n}(1 - p_{ij})^{w_{ij}}, \prod_{j=1}^{n} q_{ij}^{w_{ij}}\right) \quad (1)$$

where $W_i = \{w_{i1}, \ldots, w_{in}\}$ is the weight vector, with $w_{ij} \in [0, 1]$ and $\sum_{j=1}^{n} w_{ij} = 1$.

Definition 4 (IFWG [21]). Let $\{(p_{i1}, q_{i1}), (p_{i2}, q_{i2}), \ldots, (p_{in}, q_{in})\}$ be a set of IFNs. The intuitionistic fuzzy weighted geometric (IFWG) operator is defined as follows:

$$\tilde{C}_i = \left(\prod_{j=1}^{n} p_{ij}^{w_{ij}}, 1 - \prod_{j=1}^{n}(1 - q_{ij})^{w_{ij}}\right) \quad (2)$$

where $W_i = \{w_{i1}, \ldots, w_{in}\}$ is the weight vector, with $w_{ij} \in [0, 1]$ and $\sum_{j=1}^{n} w_{ij} = 1$.

2.3. Euclidean Distance and Radius Operators in CIFS

The Euclidean distance in CIFS is used to measure the distance between each IFN pair and the set center in the DM–DNM space. These distance values serve as the basis for radius construction, which represents the dispersion of values with respect to the center. The conventional ME operator defines the radius as the maximum Euclidean distance, thereby reflecting the outermost boundary of the value distribution.

By comparison, RAP and RAS are binary radius operators that combine two radius values through algebraic operations. The RAP operator uses a scaled multiplicative form, whereas the RAS operator uses an adjusted additive form.

Definition 5 (Euclidean Distance [13]). Let C_i be a CIFS with center $c_i = (p_{c,i}, q_{c,i}) \in [0, 1]^2$, and let $\{(p_{ij}, q_{ij})\}_{j=1}^{k}$ be the corresponding pairs of IFSs. For each $j = 1, \ldots, k$, the Euclidean distance from the center c_i to the pair (p_{ij}, q_{ij}) is defined as follows:

$$\ell_{ij} = d_E(c_i, (p_{ij}, q_{ij})) = \sqrt{(p_{c,i} - p_{ij})^2 + (q_{c,i} - q_{ij})^2}. \quad (3)$$

Definition 6 (ME [11]). The radius r_{ME_i} of C_i is defined as follows:

$$r_{ME_i} = \max_{1 \le j \le k} \sqrt{\left(u_c(C_i) - p_{ij}\right)^2 + \left(v_c(C_i) - q_{ij}\right)^2}, \quad (4)$$

where $c_i = (u_c(C_i), v_c(C_i)) \in [0, 1]^2$ is the center of C_i, (p_{ij}, q_{ij}) is an IFN pair, and k is the number of pairs in C_i. This radius represents the degree of value dispersion with respect to the center in the (DM, DNM) space.

Definition 7 (RAP [18]). Let $\psi \in [1, \sqrt{2}]$. For each $a, b \in [0, \psi]$, with $a = \ell_{ij}$ and $b = \ell_{it}$, the RAP operator $\mathcal{T}^* : [0, \psi] \times [0, \psi] \to [0, \psi]$ is defined as follows:

$$\mathcal{T}^*(a, b) = \frac{ab}{\psi}.$$

Definition 8 (RAS [18]). Let $\psi \in [1, \sqrt{2}]$. For each $a, b \in [0, \psi]$, with $a = \ell_{ij}$ and $b = \ell_{it}$, the RAS operator $\mathcal{S}^* : [0, \psi] \times [0, \psi] \to [0, \psi]$ is defined as follows:

$$\mathcal{S}^*(a, b) = a + b - \frac{ab}{\psi}. \tag{5}$$

2.4. Score Function, Accuracy, and Ranking Rules in CIFS

The score function is used to evaluate the assessment level of a CIFS by using the DM, DNM, and radius [13]. The parameter λ regulates the decision-making attitude, namely pessimistic, neutral, or optimistic [13].

The accuracy function is used as an additional comparison when the score values are equal, by indicating the degree of information certainty [22]. The ranking rules are then applied by first comparing the score values, and if they are equal, continuing with the accuracy values to determine the order of alternatives [13].

Definition 9 (Score and Accuracy Functions of CIFS [23]). For $c = (u_c, v_c; r_c)$ and $\lambda \in [0, 1]$, the score function and accuracy function of CIFS are defined as follows:

$$S_{C\text{-}IFS}(c) = u_c - v_c + \frac{\sqrt{2}\, r_c(2\lambda - 1)}{3}, \qquad S_{C\text{-}IFS}(c) \in [-1, 1], \tag{6}$$

$$H_{C\text{-}IFS}(c) = u_c + v_c, \qquad H_{C\text{-}IFS}(c) \in [0, 1],$$

where $\lambda = 0$ is pessimistic, $\lambda = 1$ is optimistic, and $\lambda = 0.5$ is neutral.

Definition 10 (Ranking Rules [13]). Let $c_1 = (u_{c_1}, v_{c_1}; r)$ and $c_2 = (u_{c_2}, v_{c_2}; r)$ be two CIFSs. The ranking rules in CIFS are defined as follows:

- If $S_{C\text{-}IFS}(c_1) > S_{C\text{-}IFS}(c_2)$, then $c_1 \succ c_2$.
- If $S_{C\text{-}IFS}(c_1) = S_{C\text{-}IFS}(c_2)$ and $H_{C\text{-}IFS}(c_1) > H_{C\text{-}IFS}(c_2)$, then $c_1 \succ c_2$.
- If $S_{C\text{-}IFS}(c_1) = S_{C\text{-}IFS}(c_2)$ and $H_{C\text{-}IFS}(c_1) = H_{C\text{-}IFS}(c_2)$, then $c_1 = c_2$.

2.5. CIFS–MCDM Framework with Radius Operators

The steps for selecting SDD service providers are developed through the integration of the CIFS–MCDM method developed by Çakır and Taş[24] and the RAP and RAS radius operators introduced by Pratama et al[18]. Selected components from these two approaches are synthesized and adapted to produce an extended CIFS–MCDM framework with three radius operators, namely ME, RAP, and RAS. The proposed method consists of two main stages: criteria weight determination and alternative ranking. Before presenting these stages, the main matrix notation used in the proposed CIFS–MCDM framework is summarized in Table 1.

Table 1: Matrix notation used in the proposed CIFS–MCDM framework

Notation	Description
$[PK]$	Criteria assessment matrix
$[PK_{\text{agg}}]$	Aggregated criteria assessment matrix
$[PK]^{(j)}$	Alternative assessment matrix for AL_j
$[PK_{\text{IFWA}}]$	Alternative decision matrix aggregated using IFWA
$[PK_{\text{IFWG}}]$	Alternative decision matrix aggregated using IFWG
$[\widetilde{PK}_{\text{agg}}]$	Weighted aggregated alternative assessment matrix

2.6. Criteria Weight Determination

1. Construction of the intuitionistic fuzzy decision matrix ($[\boldsymbol{PK}]_{n\times k}$). The first step is to determine the case study, the set of criteria, and the set of decision makers. The set of criteria is expressed as $K = \{K_1, K_2, \dots, K_n\}$, where n denotes the number of criteria. The set of decision makers is expressed as $PK = \{PK_1, PK_2, \dots, PK_k\}$, where k denotes the number of decision makers.

The decision makers' linguistic assessments for each criterion are converted into IFNs using the scale in Table 2 to form an intuitionistic fuzzy decision matrix. Each term in $\mathcal{L} = \{AL, STB, KB, ML, C, MH, B, SB, AH\}$ is represented by an IFN (μ, ν), where $0 \le \mu + \nu \le 1$.

Table 2: Linguistic scale for IFN [13]

Linguistic Term	Code	IFN (μ, ν)
Absolutely Low	AL	(0.10, 0.90)
Very Low	STB	(0.20, 0.75)
Low	KB	(0.30, 0.65)
Medium Low	ML	(0.40, 0.55)
Fair	C	(0.50, 0.45)
Medium High	MH	(0.60, 0.35)
High	B	(0.70, 0.25)
Very High	SB	(0.80, 0.15)
Absolutely High	AH	(0.90, 0.10)

The linguistic mapping is defined as $\Phi : \mathcal{L} \to [0,1] \times [0,1]$. For a linguistic assessment $L_\ell^{(i)} \in \mathcal{L}$, it is defined that

$$c_\ell^{(i)} = \Phi(L_\ell^{(i)}) = (\mu_\ell^{(i)}, \nu_\ell^{(i)}), \qquad 0 \le \mu_\ell^{(i)} + \nu_\ell^{(i)} \le 1.$$

The hesitation margin is determined by the predefined linguistic scale and is not directly elicited from each individual decision maker. Therefore, the CIFS radius is interpreted as a measure of group-level dispersion among decision-maker assessments around the aggregated center, rather than as intrinsic hesitation of individual decision makers.

Based on this mapping, the assessments of each decision-maker for each criterion are arranged into a matrix called the intuitionistic fuzzy decision matrix, denoted by $[PK]_{n\times k}$, as follows:

$$[PK]_{n\times k} = \left[c_\ell^{(i)}\right]_{n\times k} = \begin{bmatrix} c_1^{(1)} & c_1^{(2)} & \cdots & c_1^{(k)} \\ c_2^{(1)} & c_2^{(2)} & \cdots & c_2^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ c_n^{(1)} & c_n^{(2)} & \cdots & c_n^{(k)} \end{bmatrix} = \begin{bmatrix} (\mu_1^{(1)}, \nu_1^{(1)}) & (\mu_1^{(2)}, \nu_1^{(2)}) & \cdots & (\mu_1^{(k)}, \nu_1^{(k)}) \\ (\mu_2^{(1)}, \nu_2^{(1)}) & (\mu_2^{(2)}, \nu_2^{(2)}) & \cdots & (\mu_2^{(k)}, \nu_2^{(k)}) \\ \vdots & \vdots & \ddots & \vdots \\ (\mu_n^{(1)}, \nu_n^{(1)}) & (\mu_n^{(2)}, \nu_n^{(2)}) & \cdots & (\mu_n^{(k)}, \nu_n^{(k)}) \end{bmatrix}.$$

Here, $\ell = 1, \dots, n$ denotes the criteria, and $i = 1, \dots, k$ denotes the decision makers. The rows of $[PK]_{n\times k}$ represent the criteria, while the columns represent the decision makers. This matrix is used in the next step to obtain the aggregated intuitionistic fuzzy matrix.

2. Aggregation of the intuitionistic fuzzy decision matrix ($[\mathbf{PK}_{\text{Agg}}]_{n\times 1}$). In this step, the decision-maker weights are first defined as

$$W_D = \{w_{D_1}, w_{D_2}, \dots, w_{D_k}\}, \qquad w_{D_i} \ge 0, \qquad \sum_{i=1}^{k} w_{D_i} = 1.$$

In this study, all decision makers are assumed to have equal importance. Since 30 decision makers are involved, equal weights are assigned as

$$w_{D_i} = \frac{1}{30}, \qquad i = 1, 2, \dots, 30.$$

The intuitionistic fuzzy decision matrix $[\mathbf{PK}]_{n\times k}$ obtained from Step 1 is then aggregated across the decision makers using the IFWA operator in Eq. (1). The aggregation is performed for each criterion K_ℓ, so that each row of $[\mathbf{PK}]_{n\times k}$ produces one aggregated IFN

$$\bar{c}_\ell = (\bar{\mu}_\ell, \bar{\nu}_\ell), \qquad \ell = 1, 2, \ldots, n.$$

Thus, the aggregated intuitionistic fuzzy decision matrix, denoted by $[\mathbf{PK}_{\text{Agg}}]_{n\times 1}$, is obtained as

$$[\mathbf{PK}_{\text{Agg}}]_{n\times 1} = [\bar{c}_\ell]_{n\times 1} = \begin{bmatrix} \bar{c}_1 \\ \bar{c}_2 \\ \vdots \\ \bar{c}_n \end{bmatrix}.$$

3. Determination of the CIFS radius. From Step 2, the matrix $[PK]_{n\times k}$ is obtained:

$$\bar{\mathbf{c}} = (\bar{c}_1, \ldots, \bar{c}_n)^\top, \qquad \bar{c}_\ell = (\bar{\mu}_\ell, \bar{\nu}_\ell), \quad \ell = 1, \ldots, n.$$

For each criterion K_ℓ, compute the Euclidean distance between the assessment of the i-th decision-maker and the center $\bar{c}_\ell$ using Eq. (3), as follows:

$$r_\ell^{(i)} \; := \; E\big((\mu_\ell^{(i)}, \nu_\ell^{(i)}), (\bar{\mu}_\ell, \bar{\nu}_\ell)\big) \; = \; \sqrt{\left(\mu_\ell^{(i)} - \bar{\mu}_\ell\right)^2 + \left(\nu_\ell^{(i)} - \bar{\nu}_\ell\right)^2}, \quad i = 1, \ldots, k,$$

with the bound $0 \le r_\ell^{(i)} \le \sqrt{2}$. The radius values are determined using Eq. (4) for ME and the n-ary formulations of RAP and RAS in Eq. (8) and Eq.(9), respectively, resulting in the values r_{ME}, r_{RAP}, and r_{RAS}. These n-ary formulations are presented later as the theoretical results of this study. For the multi-decision-maker case, the Euclidean distances $r_\ell^{(i)}$, $i = 1, \ldots, k$, obtained from all decision makers for each criterion K_ℓ, are aggregated to obtain the radius values. Since RAP and RAS are binary operators, these distances are combined recursively using their n-ary extensions. In this study, $k = 30$; hence, r_{RAP} and r_{RAS} are computed by recursively aggregating the 30 Euclidean distance values $r_\ell^{(1)}, r_\ell^{(2)}, \ldots, r_\ell^{(30)}$ for each criterion.

4. Computing the criteria weights. Compute the final criteria weights using the corresponding value of r with the following formula:

$$w_{C_i} = \frac{u_i - v_i + \sqrt{2}r + 1}{4}, \tag{7}$$

The criteria-weighting formula follows the CIFS-MCDM procedure proposed by Çakır and Taş (2023) [13]. In this formula, the membership and non-membership degrees represent positive and negative contributions to each criterion evaluation, while the radius component incorporates dispersion information in the CIFS structure. The obtained initial weights are then normalized to produce the final criteria weights.

5. Normalization of criteria weights. Normalize the criteria weights in order to obtain valid normalized weights, namely W_{ME}, W_{RAP}, and W_{RAS}.

2.7. Alternative Ranking Based on Criteria Weights

1. Construction of the intuitionistic fuzzy evaluation matrix of alternatives $[PK]_{k\times n}$. The normalized criteria weights W_{ME}, W_{RAP}, and W_{RAS} obtained in the previous stage are used in the alternative ranking process. In this study, there are three alternatives denoted by $AL = \{AL_1, AL_2, AL_3\}$. Furthermore, an intuitionistic fuzzy evaluation matrix is constructed from the decision makers' assessments for each alternative with respect to each criterion, denoted as

$$[PK] = [\tilde{d}_{ij}]_{k\times n},$$

where $\tilde{d}_{ij}$ denotes the intuitionistic fuzzy value of alternative AL_i with respect to criterion K_j.

2. Aggregation of the intuitionistic fuzzy evaluation matrix for alternatives. The aggregated intuitionistic fuzzy decision matrix is calculated using Eq. (1) and Eq. (2). This aggregated matrix is denoted by

$$[PK_{\text{agg}}] = [\tilde{d}_{ij}^{\text{agg}}]_{m\times n},$$

where $\tilde{d}_{ij}^{\text{agg}}$ denotes the aggregated value of alternative A_i with respect to criterion K_j.

3. Computing the aggregated decision matrix $[\widetilde{PK}_{\text{agg}}]_{m\times 1}$. Based on the criteria weights W_{ME}, W_{RAP}, and W_{RAS}, the aggregated decision matrix of alternatives is computed through the aggregation operators in Eq. (1) and Eq. (2), and is denoted as

$$[\widetilde{PK}_{\text{agg}}] = [\tilde{d}_i]_{m\times 1},$$

where m denotes the number of alternatives and $\tilde{d}_i$ denotes the aggregated decision value for the i-th alternative.

4. Determination of the radius values. Determine the radius length of each aggregated decision $[\widetilde{PK}_{\text{agg}}]$ using Eqs. (4), (8), and (9), and then update the decision matrix into the CIFS form.

5. Determination of the parameter value. Determine the parameter value $\lambda \in [0,1]$ to represent the decision-maker's preference, whether optimistic, neutral, or pessimistic.

6. Computing the alternative score values. Compute the score value of each alternative using Eq. (6).

7. Determination of the alternative ranking order. Arrange the alternatives based on the ranking rules defined in Definition 10.

8. Conducting sensitivity analysis. Conduct sensitivity analysis by varying the decision-maker attitude parameter λ over the interval $[0,1]$, where $\lambda = 0$ represents the fully pessimistic condition and $\lambda = 1$ represents the fully optimistic condition.

9. Comparing the ranking results. Compare the ranking results under the ME, RAP, and RAS radii based on the sensitivity analysis results.

3. Results and Discussion

This section presents the theoretical and computational results of the proposed CIFS–MCDM framework. The theoretical results consist of the n-ary extensions of the RAP and RAS radius operators, which are required for multi-decision-maker assessments. The computational results present the implementation of the framework for SDD logistics service selection in Malang, including aggregation, criteria weighting, alternative ranking, and sensitivity analysis.

3.1. Theoretical Results: n-ary Extensions of RAP and RAS Radius Operators

Since the RAP and RAS operators are originally defined in binary form in Definitions 7 and 8, their application to multi-decision-maker assessments requires extensions to n-ary forms. These extensions constitute the theoretical results of this study and are formulated in the following theorems, namely Theorem 1 and Theorem 2.

Theorem 1 (n-ary extension of the RAP radius operator)**.** *Let* $\psi > 0$ *and* $T^*(x,y) := \dfrac{xy}{\psi}$

on $[0, \psi]$*. For every* $n \geq 1$ *and* $(a_1, \ldots, a_n) \in [0, \psi]^n$*, define*

$$T_1^*(a_1) := a_1, \qquad T_n^*(a_1, \ldots, a_n) := T^*(T_{n-1}^*(a_1, \ldots, a_{n-1}), a_n).$$

Then

$$T_n^*(a_1, \ldots, a_n) = \frac{\prod_{i=1}^n a_i}{\psi^{n-1}}. \tag{8}$$

Proof. For $n = 2$, based on Definition 7, we obtain

$$T_2^*(a_1, a_2) = T^*(a_1, a_2) = \frac{a_1 a_2}{\psi}.$$

This form is consistent with

$$T_2^*(a_1, a_2) = \frac{\prod_{i=1}^2 a_i}{\psi^{2-1}}.$$

Assume that the statement holds for $n = k$, with $k \geq 2$, namely

$$T_k^*(a_1, \ldots, a_k) = \frac{\prod_{i=1}^k a_i}{\psi^{k-1}}.$$

It will be shown that the statement also holds for $n = k + 1$. Based on the recursive definition, we obtain

$$T_{k+1}^*(a_1, \ldots, a_{k+1}) = T^*\left(T_k^*(a_1, \ldots, a_k), a_{k+1}\right).$$

Then, by Definition 7,

$$\begin{aligned} T_{k+1}^*(a_1, \ldots, a_{k+1}) &= \frac{T_k^*(a_1, \ldots, a_k) a_{k+1}}{\psi} = \frac{\left(\frac{\prod_{i=1}^k a_i}{\psi^{k-1}}\right) a_{k+1}}{\psi} = \frac{\left(\prod_{i=1}^k a_i\right) a_{k+1}}{\psi^k} \\ &= \frac{\prod_{i=1}^{k+1} a_i}{\psi^k} = \frac{\prod_{i=1}^{k+1} a_i}{\psi^{(k+1)-1}}. \end{aligned}$$

Thus, the statement holds for $n = k + 1$. By mathematical induction, we obtain

$$T_n^*(a_1, \ldots, a_n) = \frac{\prod_{i=1}^n a_i}{\psi^{n-1}}.$$

□

Theorem 2 (*n*-ary RAS radius operator)**.** *If* $\psi > 0$ *and* $S^*(x, y) := x + y - \frac{xy}{\psi}$ *on* $[0, \psi]$*, then for every* $n \geq 1$ *and* $(a_1, \ldots, a_n) \in [0, \psi]^n$*, with*

$$S_1^*(a_1) := a_1, \qquad S_n^*(a_1, \ldots, a_n) := S^*(S_{n-1}^*(a_1, \ldots, a_{n-1}), a_n),$$

the following holds:

$$S_n^*(a_1, \ldots, a_n) = \psi\left(1 - \prod_{i=1}^n \left(1 - \frac{a_i}{\psi}\right)\right) \in [0, \psi]. \tag{9}$$

Proof. For $n = 2$, based on Definition 8, we obtain

$$S_2^*(a_1, a_2) = S^*(a_1, a_2) = a_1 + a_2 - \frac{a_1 a_2}{\psi}. \tag{10}$$

Eq. (10) can be written as $S_2^*(a_1, a_2) = \psi\left(1 - \prod_{i=1}^{2}\left(1 - \frac{a_i}{\psi}\right)\right)$.
Assume that the statement holds for $n = k$, with $k \geq 2$,
namely $S_k^*(a_1, \ldots, a_k) = \psi\left(1 - \prod_{i=1}^{k}\left(1 - \frac{a_i}{\psi}\right)\right)$. It will be shown that the statement also holds for $n = k + 1$. Based on the recursive definition,

$$S_{k+1}^*(a_1, \ldots, a_k, a_{k+1}) = S^*\left(S_k^*(a_1, \ldots, a_k), a_{k+1}\right).$$

Thus,

$$S_{k+1}^* = S_k^* + a_{k+1} - \frac{S_k^* a_{k+1}}{\psi}.$$

Let

$$P_k = \prod_{i=1}^{k}\left(1 - \frac{a_i}{\psi}\right).$$

Based on the induction hypothesis, we have

$$S_k^* = \psi(1 - P_k).$$

Substituting this form into S_{k+1}^* gives

$$\begin{aligned} S_{k+1}^* &= \psi(1 - P_k) + a_{k+1} - \frac{\psi(1 - P_k)a_{k+1}}{\psi} = \psi(1 - P_k) + P_k a_{k+1} \\ &= \psi - P_k(\psi - a_{k+1}) = \psi\left(1 - P_k\left(1 - \frac{a_{k+1}}{\psi}\right)\right). \end{aligned}$$

Since

$$P_k\left(1 - \frac{a_{k+1}}{\psi}\right) = \prod_{i=1}^{k+1}\left(1 - \frac{a_i}{\psi}\right),$$

we obtain

$$S_{k+1}^*(a_1, \ldots, a_k, a_{k+1}) = \psi\left(1 - \prod_{i=1}^{k+1}\left(1 - \frac{a_i}{\psi}\right)\right).$$

Thus, the statement holds for $n = k + 1$. By mathematical induction, we obtain

$$S_n^*(a_1, \ldots, a_n) = \psi\left(1 - \prod_{i=1}^{n}\left(1 - \frac{a_i}{\psi}\right)\right).$$ □

In the implementation of this study, $\psi = \sqrt{2}$ is used as the largest admissible upper bound because the Euclidean distance in the (μ, ν)-space satisfies $0 \leq r \leq \sqrt{2}$. Thus, all distance values used as inputs of the RAP and RAS operators remain within the required domain $[0, \psi]$.

3.2. Computational Results

In this study, the selection of SDD service providers in Malang was conducted using the criteria presented in Table 3. These criteria were determined based on a literature review on SDD, e-commerce logistics, and express delivery services, and were further adapted to the local operational conditions in Malang [25, 26]. The alternatives consisted of three SDD service providers operating in Malang, denoted as AL_1, AL_2, and AL_3. These alternatives were evaluated by 30 qualified respondents who were domiciled in Malang, had used all evaluated SDD service alternatives within the last six months, and understood the service characteristics being assessed. All evaluations were processed using the CIFS-MCDM framework with the assistance of Microsoft Excel to obtain the criteria weights and the final ranking of alternatives.

Table 3: Evaluation criteria for SDD services and their operational definitions

Main Criteria	Definition
Delivery Speed	The ability of the SDD service to fulfill orders quickly and on time, as reflected in the average waiting time, maximum waiting time, and *service rate* [27–29].
Service Cost	The amount of cost borne by customers when using the SDD service, including delivery charges and price affordability [30, 31].
Tracking Convenience	The ease of monitoring order status and location during the delivery process [32, 33].
Customer Satisfaction	The overall customer evaluation of the quality of the SDD service [34, 35].

3.2.1. Criteria Weight Determination

Step 1. Construction of the intuitionistic fuzzy decision matrix $[PK]_{n\times k}$. Table 4 presents the linguistic assessments of 30 qualified respondents on four criteria, which are then converted into intuitionistic fuzzy numbers and represented as the decision matrix $[PK]_{4\times 30}$ in Table 5.

Table 4: Respondent assessments of the criteria

	PK1	PK2	PK3	PK4	PK5	PK6	PK7	PK8	PK9	PK10	PK11	PK12	PK13	PK14	PK15
K1	B	SB	B	SB	SB	SB	SB	SB	SB	B	SB	B	C	C	SB
K2	SB	SB	SB	SB	SB	B	SB	SB	SB	SB	B	B	B	KB	B
K3	SB	B	SB	SB	C	B	C	SB	B	SB	B	SB	C	C	SB
K4	B	B	C	B	C	SB	SB	SB	SB	B	B	SB	B	KB	B
	PK16	**PK17**	**PK18**	**PK19**	**PK20**	**PK21**	**PK22**	**PK23**	**PK24**	**PK25**	**PK26**	**PK27**	**PK28**	**PK29**	**PK30**
K1	B	B	C	C	B	B	B	C	B	SB	SB	B	SB	SB	C
K2	C	STB	KB	KB	B	B	C	B	B	SB	SB	SB	SB	SB	C
K3	SB	B	KB	SB	B	B	B	SB	C	B	C	SB	B	SB	C
K4	B	SB	STB	SB	SB	SB	C	C	C	B	B	SB	B	SB	KB

Table 5: Transformation of respondent linguistic assessments into IFNs for the criteria

	PK1	PK2	PK3	$\cdots$	PK28	PK29	PK30
K1	$(0.7, 0.25)$	$(0.8, 0.15)$	$(0.7, 0.25)$	$\cdots$	$(0.8, 0.15)$	$(0.8, 0.15)$	$(0.5, 0.45)$
K2	$(0.8, 0.15)$	$(0.8, 0.15)$	$(0.8, 0.15)$	$\cdots$	$(0.8, 0.15)$	$(0.8, 0.15)$	$(0.5, 0.45)$
K3	$(0.8, 0.15)$	$(0.7, 0.25)$	$(0.8, 0.15)$	$\cdots$	$(0.7, 0.25)$	$(0.8, 0.15)$	$(0.5, 0.45)$
K4	$(0.7, 0.25)$	$(0.7, 0.25)$	$(0.5, 0.45)$	$\cdots$	$(0.7, 0.25)$	$(0.8, 0.15)$	$(0.3, 0.65)$

Step 2. Aggregation of the intuitionistic fuzzy decision matrix $[PK_{Agg}]_{n\times 1}$. The aggregated intuitionistic fuzzy decision matrix $[PK_{Agg}]_{n\times 1}$ is computed using Eq. (1), with the following results:

$$[PK_{\text{agg}}] = \begin{bmatrix} K_1 & (0.72123,\ 0.22538) \\ K_2 & (0.70611,\ 0.23845) \\ K_3 & (0.70436,\ 0.24136) \\ K_4 & (0.69217,\ 0.25280) \end{bmatrix}.$$

These values are subsequently used as the CIFS centers for determining the radius in Step 3.

Step 3. Computation of the Euclidean distance and construction of the CIFS radius. For each IFS value in Table 5, the Euclidean distance to the corresponding aggregated criterion center is computed. These distances are then combined using the three radius operators in Eqs. (4), (8), and (9)

$$\left[PK^{\mathrm{ME}}_{\mathrm{agg}}\right] = \begin{bmatrix} K_1 & (0.72123, 0.22538, 0.31527) \\ K_2 & (0.70611, 0.23845, 0.71961) \\ K_3 & (0.70436, 0.24136, 0.57489) \\ K_4 & (0.69217, 0.25280, 0.69960) \end{bmatrix}$$

$$\left[PK^{\mathrm{RAP}}_{\mathrm{agg}}\right] = \begin{bmatrix} K_1 & (0.72123, 0.22538, 5.58535 \times 10^{-37}) \\ K_2 & (0.70611, 0.23845, 6.06039 \times 10^{-37}) \\ K_3 & (0.70436, 0.24136, 9.30574 \times 10^{-40}) \\ K_4 & (0.69217, 0.25280, 1.56783 \times 10^{-40}) \end{bmatrix}$$

$$\left[PK^{\mathrm{RAS}}_{\mathrm{agg}}\right] = \begin{bmatrix} K_1 & (0.72123, 0.22538, 1.32925) \\ K_2 & (0.70611, 0.23845, 1.39708) \\ K_3 & (0.70436, 0.24136, 1.36644) \\ K_4 & (0.69217, 0.25280, 1.38979) \end{bmatrix}$$

Step 4. Computing the criteria weights. Based on the CIFS values obtained in Step 3, the weight of each criterion is computed using Equation (7). This step produces a weight vector for each radius operator.

Step 5. Normalization of the criteria weights. The criteria weights obtained in Step 4 are then normalized, yielding the criteria weight vectors represented in Table 6 below.

Table 6: Normalized criteria weights

Criteria	W_{ME}	W_{RAP}	W_{RAS}
K1	0.21263	0.25501	0.24786
K2	0.27216	0.25020	0.25283
K3	0.24924	0.24941	0.24931
K4	0.26597	0.24538	0.25000

3.2.2. Alternative Ranking

This stage aims to obtain the ranking order of the three SDD service alternatives, namely AL_1, AL_2, and AL_3, based on the criteria weights obtained in Stage 3.2.1.

Step 1. Construction of the intuitionistic fuzzy decision matrices for alternatives $\left([PK]^{(j)}_{30\times4}\right)$. Table 7 presents the linguistic assessment matrices of 30 qualified respondents for each alternative across four criteria. These assessments are subsequently converted using Table 2 to form the intuitionistic fuzzy decision matrices shown in Table 8. Here, $[PK]^{(j)}_{30\times4}$ denotes the decision matrix for alternative AL_j, $j = 1, 2, 3$.

Step 2: Aggregation of the intuitionistic fuzzy decision matrix ($[PK]_{3\times4}$). The aggregation of the intuitionistic fuzzy decision matrix is computed using Eqs. (1) and (2), resulting in

$$[PK_{\mathrm{IFWA}}]_{3\times4} = \begin{bmatrix} & K_1 & K_2 & K_3 & K_4 \\ AL_1 & (0.61413, 0.32835) & (0.64904, 0.29624) & (0.63280, 0.30819) & (0.60735, 0.33386) \\ AL_2 & (0.60771, 0.33712) & (0.65160, 0.29193) & (0.65264, 0.28981) & (0.68047, 0.26228) \\ AL_3 & (0.66842, 0.27532) & (0.64915, 0.29343) & (0.65813, 0.28559) & (0.62197, 0.32115) \end{bmatrix}$$

Table 7: Respondent assessments of SDD service alternatives based on four criteria

Group 1						Group 2						Group 3					
Resp.	Alt.	K1	K2	K3	K4	Resp.	Alt.	K1	K2	K3	K4	Resp.	Alt.	K1	K2	K3	K4
PK1	AL1	C	B	C	C	PK11	AL1	C	B	SB	B	PK21	AL1	KB	SB	STB	KB
PK1	AL2	B	SB	B	SB	PK11	AL2	B	B	SB	B	PK21	AL2	C	KB	C	KB
PK1	AL3	SB	B	SB	C	PK11	AL3	B	B	SB	B	PK21	AL3	KB	STB	STB	KB
PK2	AL1	C	B	B	STB	PK12	AL1	SB	B	SB	B	PK22	AL1	KB	C	KB	STB
PK2	AL2	KB	SB	KB	SB	PK12	AL2	B	SB	SB	SB	PK22	AL2	B	B	B	SB
PK2	AL3	SB	KB	C	B	PK12	AL3	C	B	B	C	PK22	AL3	B	SB	B	SB
PK3	AL1	C	SB	C	B	PK13	AL1	B	C	B	SB	PK23	AL1	STB	KB	KB	STB
PK3	AL2	B	B	B	SB	PK13	AL2	SB	SB	SB	SB	PK23	AL2	STB	C	STB	STB
PK3	AL3	SB	SB	C	B	PK13	AL3	B	B	B	SB	PK23	AL3	STB	KB	KB	C
PK4	AL1	C	C	SB	STB	PK14	AL1	SB	C	SB	SB	PK24	AL1	KB	C	STB	STB
PK4	AL2	KB	B	C	C	PK14	AL2	B	B	B	SB	PK24	AL2	C	SB	STB	SB
PK4	AL3	SB	KB	B	B	PK14	AL3	B	B	B	B	PK24	AL3	B	SB	C	B
PK5	AL1	C	B	KB	C	PK15	AL1	KB	KB	STB	KB	PK25	AL1	SB	C	C	SB
PK5	AL2	B	SB	B	B	PK15	AL2	KB	KB	STB	C	PK25	AL2	B	C	SB	SB
PK5	AL3	SB	C	SB	KB	PK15	AL3	KB	C	KB	C	PK25	AL3	B	B	SB	KB
PK6	AL1	SB	B	SB	SB	PK16	AL1	C	KB	C	KB	PK26	AL1	B	B	SB	STB
PK6	AL2	SB	B	SB	SB	PK16	AL2	STB	STB	STB	STB	PK26	AL2	SB	C	SB	KB
PK6	AL3	B	SB	B	SB	PK16	AL3	B	C	KB	C	PK26	AL3	C	SB	C	B
PK7	AL1	SB	C	SB	B	PK17	AL1	C	B	C	B	PK27	AL1	B	SB	C	C
PK7	AL2	B	SB	C	C	PK17	AL2	KB	B	C	B	PK27	AL2	B	B	C	SB
PK7	AL3	B	KB	B	SB	PK17	AL3	KB	SB	C	B	PK27	AL3	SB	KB	SB	STB
PK8	AL1	B	B	C	SB	PK18	AL1	STB	C	KB	KB	PK28	AL1	B	B	SB	B
PK8	AL2	C	KB	C	B	PK18	AL2	KB	KB	C	KB	PK28	AL2	C	SB	C	SB
PK8	AL3	SB	B	B	C	PK18	AL3	STB	STB	C	STB	PK28	AL3	SB	SB	STB	KB
PK9	AL1	B	C	C	B	PK19	AL1	KB	SB	SB	B	PK29	AL1	SB	SB	SB	SB
PK9	AL2	C	STB	SB	C	PK19	AL2	B	KB	SB	C	PK29	AL2	B	B	SB	SB
PK9	AL3	B	C	SB	C	PK19	AL3	C	SB	B	KB	PK29	AL3	SB	SB	SB	SB
PK10	AL1	SB	B	SB	SB	PK20	AL1	SB	SB	SB	SB	PK30	AL1	C	B	C	C
PK10	AL2	C	B	SB	C	PK20	AL2	B	B	SB	SB	PK30	AL2	B	B	B	B
PK10	AL3	C	B	SB	SB	PK20	AL3	SB	SB	SB	SB	PK30	AL3	C	C	B	B

Table 8: Transformation of respondent linguistic assessments of alternatives into IFNs

Resp.	Alternative	K1	K2	K3	K4
PK1	AL1	$(0.5, 0.45)$	$(0.7, 0.25)$	$(0.5, 0.45)$	$(0.5, 0.45)$
PK1	AL2	$(0.7, 0.25)$	$(0.8, 0.15)$	$(0.7, 0.25)$	$(0.8, 0.15)$
PK1	AL3	$(0.8, 0.15)$	$(0.7, 0.25)$	$(0.8, 0.15)$	$(0.5, 0.45)$
		⋮			
PK30	AL1	$(0.5, 0.45)$	$(0.7, 0.25)$	$(0.5, 0.45)$	$(0.5, 0.45)$
PK30	AL2	$(0.7, 0.25)$	$(0.7, 0.25)$	$(0.7, 0.25)$	$(0.7, 0.25)$
PK30	AL3	$(0.5, 0.45)$	$(0.5, 0.45)$	$(0.7, 0.25)$	$(0.7, 0.25)$

$$[PK_{\text{IFWG}}]_{3\times 4} = \begin{bmatrix} & K_1 & K_2 & K_3 & K_4 \\ AL_1 & (0.52375,\ 0.42167) & (0.59712,\ 0.35073) & (0.52600,\ 0.41850) & (0.48217,\ 0.46044) \\ AL_2 & (0.52975,\ 0.41577) & (0.56021,\ 0.38466) & (0.55282,\ 0.39127) & (0.58866,\ 0.35645) \\ AL_3 & (0.58480,\ 0.36053) & (0.55268,\ 0.39221) & (0.57571,\ 0.36974) & (0.53325,\ 0.41205) \end{bmatrix}$$

Step 3: Computing the aggregated decision matrix $\left[\widetilde{PK}_{\text{agg}}\right]_{3\times 1}$**.** The computation of the aggregated decision matrix for the alternatives is carried out by using the criteria weights obtained from Stage 3.2.1 and Eqs. (1) and (2). The results are presented as follows.

$$\left[\widetilde{PK}^{\text{ME}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62686, 0.31568) \\ AL_2 & (0.65109, 0.29202) \\ AL_3 & (0.64867, 0.29452) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{ME}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53153, 0.41328) \\ AL_2 & (0.55908, 0.38577) \\ AL_3 & (0.55972, 0.38547) \end{bmatrix}$$

$$\left[\widetilde{PK}^{\text{RAP}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62622, 0.31628) \\ AL_2 & (0.64870, 0.29445) \\ AL_3 & (0.65005, 0.29318) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{RAP}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53091, 0.41394) \\ AL_2 & (0.55719, 0.38768) \\ AL_3 & (0.56148, 0.38372) \end{bmatrix}$$

$$\left[\widetilde{PK}^{\text{RAS}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62628, 0.31622) \\ AL_2 & (0.64914, 0.29401) \\ AL_3 & (0.64978, 0.29344) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{RAS}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53089, 0.41395) \\ AL_2 & (0.55754, 0.38733) \\ AL_3 & (0.56116, 0.38404) \end{bmatrix}$$

Step 4: Determining the radius values. The radius values are determined based on the aggregated decision matrices, which serve as the CIFS centers, by using Eqs. (4), (8), and (9). The computed radius values are presented as follows.

$$\left[\widetilde{PK}^{\text{ME}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62686, 0.31568; 0.02949) \\ AL_2 & (0.65109, 0.29202; 0.06257) \\ AL_3 & (0.64867, 0.29452; 0.03771) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{ME}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53153, 0.41328; 0.09063) \\ AL_2 & (0.55908, 0.38577; 0.04196) \\ AL_3 & (0.55972, 0.38547; 0.03751) \end{bmatrix}$$

$$\left[\widetilde{PK}^{\text{RAP}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62622, 0.31628; 4.93\times 10^{-8}) \\ AL_2 & (0.64870, 0.29445; 2.21\times 10^{-8}) \\ AL_3 & (0.65005, 0.29318; 3.72\times 10^{-9}) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{RAP}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53091, 0.41394; 1.54\times 10^{-7}) \\ AL_2 & (0.55719, 0.38768; 1.49\times 10^{-8}) \\ AL_3 & (0.56148, 0.38372; 1.13\times 10^{-7}) \end{bmatrix}$$

$$\left[\widetilde{PK}^{\text{RAS}}_{\text{agg,IFWA}}\right] = \begin{bmatrix} AL_1 & (0.62628, 0.31622; 0.08191) \\ AL_2 & (0.64914, 0.29401; 0.11054) \\ AL_3 & (0.64978, 0.29344; 0.07607) \end{bmatrix} \qquad \left[\widetilde{PK}^{\text{RAS}}_{\text{agg,IFWG}}\right] = \begin{bmatrix} AL_1 & (0.53089, 0.41395; 0.16981) \\ AL_2 & (0.55754, 0.38733; 0.09170) \\ AL_3 & (0.56116, 0.38404; 0.10232) \end{bmatrix}$$

Step 5: Computing the score values. The score value of each alternative is computed using Eq.(6) and ranked based on Definition 10. The ranking results for $\lambda \in [0,1]$ are presented in Table 9 and Table 10.

Table 9 shows that under IFWA aggregation, the RAP operator produces the most stable ranking order, namely $AL_3 \succ AL_2 \succ AL_1$ for all values of λ. In contrast, the ME and RAS operators exhibit ranking changes as λ increases. For ME, the best alternative shifts from AL_3 to AL_2 starting at $\lambda = 0.5$, whereas for RAS this change occurs starting at $\lambda = 0.6$. Thus, RAP is the most stable, while ME and RAS are more sensitive to variations in λ.

Table 10 shows that under IFWG aggregation, the stability pattern of RAP is maintained, namely $AL_3 \succ AL_2 \succ AL_1$ for all values of λ. However, the ME and RAS operators exhibit higher sensitivity than under IFWA. For the ME operator, the best alternative changes from AL_3 to AL_2, and then to AL_1 at high values of λ. For the RAS operator, AL_2 is the best alternative at $\lambda = 0.1$ and $\lambda = 0.2$, AL_3 becomes dominant for the middle range of λ, and AL_1 becomes the best alternative at $\lambda = 0.9$ and $\lambda = 1.0$. These results indicate that under IFWG aggregation, the influence of the radius on the score function is stronger, so changes in λ more readily affect changes in the ranking order of the alternatives.

3.3. Discussion

The results show that the radius operators directly affect both criteria weights and alternative rankings. The ME operator assigns the highest weight to service cost ($K_2 = 0.27216$), whereas the RAP operator assigns the highest weight to delivery speed ($K_1 = 0.25501$), although the resulting weights are nearly balanced. Similarly, the RAS operator produces a nearly balanced weight

Table 9: Score values and alternative ranking results under IFWA aggregation for each radius operator and variation in λ.

Operator	λ	$S(AL_1)$	$S(AL_2)$	$S(AL_3)$	Ranking order
ME	0.1	0.092606	0.096091	**0.103828**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.2	0.095386	0.101991	**0.107383**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.3	0.098167	0.107890	**0.110938**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.4	0.100947	0.113790	**0.114493**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.5	0.103728	**0.119689**	0.118048	$AL_2 \succ AL_3 \succ AL_1$
ME	0.6	0.106508	**0.125589**	0.121603	$AL_2 \succ AL_3 \succ AL_1$
ME	0.7	0.109288	**0.131488**	0.125158	$AL_2 \succ AL_3 \succ AL_1$
ME	0.8	0.112069	**0.137388**	0.128713	$AL_2 \succ AL_3 \succ AL_1$
ME	0.9	0.114849	**0.143287**	0.132268	$AL_2 \succ AL_3 \succ AL_1$
ME	1.0	0.117630	**0.149187**	0.135823	$AL_2 \succ AL_3 \succ AL_1$
RAP	0.1	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.2	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.3	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.4	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.5	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.6	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.7	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.8	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.9	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAP	1.0	0.103313	0.118083	**0.118955**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.1	0.072462	0.076693	**0.090095**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.2	0.080185	0.087114	**0.097267**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.3	0.087908	0.097536	**0.104438**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.4	0.095630	0.107957	**0.111610**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.5	0.103353	0.118378	**0.118782**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.6	0.111076	**0.128800**	0.125953	$AL_2 \succ AL_3 \succ AL_1$
RAS	0.7	0.118799	**0.139221**	0.133125	$AL_2 \succ AL_3 \succ AL_1$
RAS	0.8	0.126522	**0.149643**	0.140296	$AL_2 \succ AL_3 \succ AL_1$
RAS	0.9	0.134245	**0.160064**	0.147468	$AL_2 \succ AL_3 \succ AL_1$
RAS	1.0	0.141968	**0.170486**	0.154639	$AL_2 \succ AL_3 \succ AL_1$

distribution, with service cost ($K_2 = 0.25283$) receiving the highest weight. This indicates that the radius definition not only represents group-level dispersion among decision-maker assessments but also influences the decision emphasis assigned to each criterion.

In terms of ranking stability, the RAP operator yields the most consistent ranking pattern, namely $AL_3 \succ AL_2 \succ AL_1$, for all values of λ under both IFWA and IFWG aggregation. However, this stability should be interpreted carefully because the values of r_{RAP} are extremely small. When $r_{RAP} \approx 0$, the λ-dependent term in the score function becomes negligible, so the score is mainly determined by the membership and non-membership components. Consequently, the stable ranking produced by RAP is accompanied by a reduced influence of radius-based dispersion information, making the ranking close to an IFS-based evaluation.

By comparison, the ME and RAS operators are more responsive to changes in λ, especially under IFWG aggregation. Higher values of λ may lead to substantial ranking changes and may even place AL_1 as the best alternative under certain operator–aggregation settings. This behavior indicates that ME and RAS retain a stronger radius contribution in the score function, making the resulting rankings more sensitive to variations in the decision-making attitude and to group-level dispersion.

The sensitivity of the ME operator also requires attention. Since ME defines the radius based on the maximum Euclidean distance, a single outlying decision-maker assessment may substantially enlarge the radius and influence the final ranking. Compared with ME, RAP and RAS aggregate all Euclidean distance values through algebraic operations, so their radius

Table 10: Score values and alternative ranking results under IFWG aggregation for each radius operator and variation in λ.

Operator	λ	$S(AL_1)$	$S(AL_2)$	$S(AL_3)$	Ranking order
ME	0.1	0.005236	0.041948	**0.043938**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.2	0.013781	0.045903	**0.047475**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.3	0.022326	0.049859	**0.051012**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.4	0.030871	0.053814	**0.054549**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.5	0.039416	0.057770	**0.058085**	$AL_3 \succ AL_2 \succ AL_1$
ME	0.6	0.047961	**0.061726**	0.061622	$AL_2 \succ AL_3 \succ AL_1$
ME	0.7	0.056506	**0.065681**	0.065159	$AL_2 \succ AL_3 \succ AL_1$
ME	0.8	0.065051	**0.069637**	0.068696	$AL_2 \succ AL_3 \succ AL_1$
ME	0.9	**0.073596**	0.073592	0.072233	$AL_1 \succ AL_2 \succ AL_3$
ME	1.0	**0.082141**	0.077548	0.075770	$AL_1 \succ AL_2 \succ AL_3$
RAP	0.1	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.2	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.3	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.4	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.5	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.6	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.7	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.8	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	0.9	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAP	1.0	0.038991	0.056501	**0.059255**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.1	-0.025060	**0.022154**	0.020452	$AL_2 \succ AL_3 \succ AL_1$
RAS	0.2	-0.009050	**0.030800**	0.030100	$AL_2 \succ AL_3 \succ AL_1$
RAS	0.3	0.006960	0.039445	**0.039747**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.4	0.022970	0.048090	**0.049394**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.5	0.038981	0.056736	**0.059041**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.6	0.054991	0.065381	**0.068688**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.7	0.071001	0.074027	**0.078335**	$AL_3 \succ AL_2 \succ AL_1$
RAS	0.8	0.087011	0.082672	**0.087982**	$AL_3 \succ AL_1 \succ AL_2$
RAS	0.9	**0.103022**	0.091318	0.097629	$AL_1 \succ AL_3 \succ AL_2$
RAS	1.0	**0.119032**	0.099963	0.107276	$AL_1 \succ AL_3 \succ AL_2$

values are not determined solely by the largest distance. Nevertheless, RAP may strongly reduce the radius because of its multiplicative structure, whereas RAS provides a more cumulative representation of group-level dispersion.

Overall, AL_2 and AL_3 are the most competitive alternatives, while AL_1 generally remains in a lower position except under high values of λ in several IFWG-based settings. Therefore, SDD service selection should consider not only the final ranking but also ranking stability through sensitivity analysis. Within the context of this case study, RAP provides the most stable ranking pattern, whereas ME and RAS are more responsive to changes in the decision-making attitude and radius-based dispersion.

4. Conclusion

This study developed an extended CIFS-MCDM framework by comparing the use of ME, RAP, and RAS radius operators for SDD service selection in Malang. The results show that different radius operators affect the criteria weights, score values, and ranking order of alternatives. In the criteria-weighting stage, ME assigns the highest weight to service cost, RAP assigns the highest weight to delivery speed, and RAS assigns the highest weight to service cost with a nearly balanced weight distribution. In the alternative-ranking stage, AL_2 and AL_3 appear as the most competitive alternatives, while AL_1 generally remains in a lower position except under several IFWG-based settings with higher values of λ.

In This case study, the sensitivity analysis shows that the RAP operator provides the most stable ranking pattern, consistently producing $AL_3 \succ AL_2 \succ AL_1$ for all variations of λ under both IFWA and IFWG aggregation. However, this stability is associated with the very small values of r_{RAP}, which reduce the influence of the radius term in the score function. In contrast, the ME and RAS operators are more responsive to changes in the decision-maker's attitude and retain a stronger contribution of radius-based dispersion information.

These findings indicate that the selection of the radius operator is an important aspect of the CIFS-MCDM procedure because it affects both ranking stability and sensitivity to group-level dispersion. The proposed framework can be used as a systematic approach to support SDD service selection under uncertainty. Nevertheless, since this study involves only three alternatives in one local setting, broader applications involving more alternatives, different regions, and larger datasets are needed to further evaluate the generalizability of the proposed framework.

CRediT Authorship Contribution Statement

Dwi Nurkarimah: Conceptualization, Methodology, Writing–Original Draft Preparation. **Noor Hidayat:** Data Curation, Validation, Supervision. **Abdul Rouf Alghofari:** Data Curation, Validation, Supervision.

Declaration of Generative AI and AI-assisted technologies

In the preparation of this manuscript, generative AI technology (ChatGPT Plus, GPT-5 by OpenAI) was used to assist in improving grammar, enhancing clarity, refining the overall flow of the manuscript, and supporting paraphrasing and language editing.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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Data and Code Availability

The anonymized assessment matrix and Excel calculation sheets are provided as supplementary materials.

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