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An Extended Step-Wise Weight Assessment Ratio Analysis with Symmetric Interval Type-2 Fuzzy Sets for Determining the Subjective Weights of Criteria in Multi-Criteria Decision-Making Problems

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Abstract: Determination of subjective weights, which are based on the opinions and preferences of decision-makers, is one of the most important matters in the process of multi-criteria decision-making (MCDM). Step-wise Weight Assessment Ratio Analysis (SWARA) is an efficient method for obtaining the subjective weights of criteria in the MCDM problems. On the other hand, decision-makers may express their opinions with a degree of uncertainty. Using the symmetric interval type-2 fuzzy sets enables us to not only capture the uncertainty of information flexibly but also to perform computations simply. In this paper, we propose an extended SWARA method with symmetric interval type-2 fuzzy sets to determine the weights of criteria based on the opinions of a group of decision-makers. The weights determined by the proposed approach involve the uncertainty of decision-makers' preferences and the symmetric form of the weights makes them more interpretable. To show the procedure of the proposed approach, it is used to determine the importance of intellectual capital dimensions and components in a company. The results show that the proposed approach is efficient in determining the subjective weights of criteria and capturing the uncertainty of information.

Keywords: multi-criteria decision-making (MCDM); group decision-making; interval type-2 fuzzy set (IT2FS); subjective weights; criteria weights; Step-wise Weight Assessment Ratio Analysis (SWARA)

1. Introduction

In discrete multi-criteria decision-making (MCDM) processes, we are usually faced with a set of alternatives that need to be evaluated with respect to a set of criteria. The weights of criteria are important components in the process of MCDM. There are two types of criteria weights: objective weights and subjective weights [1]. The objective weights are derived from the information of decision-matrices and the subjective weights are determined based on the information provided by decision-makers [2]. In other words, the subjective weights refer to the decision-makers' subjective perceptions and judgments about the relative importance of criteria [3]. Entropy, CRITIC (Criteria Importance Through Inter-criteria Correlation) and Standard Deviation (SD) are some of the popular methods for obtaining objective weights; on the other hand, the analytic hierarchy process (AHP), analytic network process (ANP), SIMOS (a method proposed by Simos [4]) and simple multi-attribute ranking technique (SMART) are the most prevalent methods for determination of subjective weights [5].

Another method for determining subjective criteria weights is Step-wise Weight Assessment Ratio Analysis (SWARA). The focus of this study is on the extending of this method.

The SWARA is an efficient and relatively new method which was proposed by Kersuliene et al. [6] for the determination of subjective weights in multi-criteria decision-making problems. This method has lower computational complexity compared to some other methods like AHP. Many researchers have utilized the SWARA method in different MCDM problems. Dehnavi et al. [7] proposed a novel hybrid approach based on the SWARA method, geographical information system (GIS) and adaptive neuro-fuzzy inference system (ANFIS) to evaluate landslide susceptible areas in Iran. Karabasevic et al. [8] developed a framework for multi-criteria assessment of personnel using the ARAS (Additive Ratio ASsessment) and SWARA methods under uncertainty handled by fuzzy sets. Nakhaei et al. [9] proposed a new approach based on SWARA and SMART for the rapid assessment of the vulnerability of office buildings to a blast. They presented a case study of Swiss Re Tower and used the proposed approach. Shukla et al. [10] integrated the SWARA method with PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) and applied it to a comprehensive enterprise resource planning (ERP) system selection framework. Işık and Adalı [11] developed a hybrid MCDM approach based on the SWARA and operational competitiveness ratings analysis (OCRA) methods. They used SWARA to determine criteria weights and OCRA to rank the alternatives in a hotel selection problem. Mavi et al. [12] presented an integrated approach based on SWARA and MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) in the fuzzy environment. Using a combination of sustainability and risk factors, the presented approach was used to evaluate third-party reverse logistics provider. Panahi et al. [13] used the SWARA and GIS to define copper prospectivity mapping in a region in Iran. They validated the obtained results by the operating receiver characteristics (ORC) technique. Stanujkic et al. [14] proposed an MCDM approach that allows the decision-makers involved in a negotiation process to express their preferences in a better way. Their proposed approach, called ARCAS (Additive Ratio Compromise ASsessment), is based on the ARAS and SWARA methods. Karabašević et al. [15] developed an expert-based method for the determination of subjective weights of criteria in a multi-criteria decision-making problem by integrating the SWARA and Delphi methods. Stanujkic et al. [16] presented a modified version of the SWARA method in which the most appropriate alternative is selected on the basis of negotiation. They used an empirical example of the personnel selection problem to illustrate their method. Urosevic et al. [17] developed an integrated MCDM approach based on the SWARA and WASPAS (Weighted Aggregated Sum Product Assessment) methods. They applied the developed approach to an example of personnel selection in the tourism sector. Jamali et al. [18] analyzed the competitive strategies of a LARG (Lean, Agile, Resilient and Green) supply chain in Iranian cement industries using SWARA, SWOT (Strengths, Weaknesses, Opportunities and Threats) and SPACE (Strategic Position and Action Evaluation) techniques. Juodagalvienė et al. [19] proposed a hybrid multi-criteria decision-making approach based on the SWARA and EDAS (Evaluation based on Distance from Average Solution) methods for assessment of architectural shapes of the buildings. Tayyar and Durmu [20] made a comparison between three weighting methods including Max100, SWARA and Pairwise Comparison (or AHP). The results of their study showed that the variation of the weights determined by the Pairwise Comparison method is higher than that of SWARA and Max100 methods. Valipour et al. [21] presented a hybrid MCDM approach based on the SWARA and COPRAS (COmplex PRoportional ASsessment) methods and applied it to a case study of risk assessment in a deep foundation excavation project in Iran. Keshavarz Ghorabaee et al. [22] developed a fuzzy hybrid approach to deal with MCDM problems based on the SWARA, CRITIC and EDAS methods and they used it for the assessment of construction equipment considering the sustainability dimensions. Dahooie et al. [23] proposed a framework of competency with five criteria for choosing the best information technology (IT) expert. They used the SWARA method for weighting the criteria and a grey ARAS (ARAS-G) method for evaluation of alternatives. Interested readers are referred to the recent survey paper presented by Mardani et al. [24].

The fuzzy set theory is an efficient tool to handle the inexact and imprecise information given by experts or decision-makers in an MCDM process [25–31]. Type-1 fuzzy sets are the basic or ordinary fuzzy sets which was introduced by Zadeh [32]. As an extension of the type-1 fuzzy sets, Zadeh [33] presented the concept of type-2 fuzzy sets. By increasing the degree of fuzziness, we can handle inexact and imprecise information more efficiently. Hence, we can say that type-2 fuzzy sets (T2FSs) can improve the process of capturing the uncertainty. On the other hand, type-2 fuzzy sets are computationally intensive and this can be considered as a disadvantage of them. To deal with this matter, we can use interval type-2 fuzzy sets (IT2FSs) in which secondary membership functions are interval sets [34,35]. A symmetric interval type-2 fuzzy set (SIT2FS) is a sub-class of IT2FSs and its primary membership function has symmetrical properties [36]. Using the symmetric IT2FSs simplifies the computations and leads to more interpretable results.

Many studies have been made on interval type-2 fuzzy sets and their applications in real-world problems. This type of fuzzy sets has also been applied to several MCDM processes in past years [37,38]. Soner et al. [39] presented a hybrid MCDM methodology based on the AHP and VIKOR (in Serbian: VIseKriterijumska Optimizacija I Kompromisno Resenje) methods with interval type-2 fuzzy sets. They also provided a practical application of the methodology in maritime transportation industry. Keshavarz Ghorabaee et al. [40] proposed a novel multi-objective methodology for supplier evaluation and order allocation in supply chains based on the EDAS method and IT2FSs and applied it to a problem considering environmental criteria. Qin et al. [41] developed a multi-criteria group decision making approach based upon interval type-2 fuzzy sets, the prospect theory and the TODIM (an acronym in Portuguese of interactive and multi-criteria decision making) method. They also introduced a new distance measure for IT2FSs using α-cut technique. Baykasoğlu and Gölcük [42] presented an approach by integrating TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) with DEMATEL (Decision Making Trial and Evaluation Laboratory) to handle MCDM problems under the uncertain environment defined by IT2FSs. They used the presented approach in a SWOT-based strategy selection problem. Deveci et al. [43] proposed an interval type-2 fuzzy TOPSIS method to deal with multi-criteria decision-making problems under uncertainty. To verify their method, a case study of airline route selection in Turkey was also presented by them. Zhong and Yao [44] developed an extended ELECTRE (ELimination Et Choix Traduisant la REalité) method to deal with multi-criteria group decision making with interval type-2 fuzzy sets based on new measures of proximity and entropy of IT2FSs. Kundu et al. [45] introduced a new ranking method for IT2FSs by using a relative preference index and generalized credibility measures. Based on the ranking method, they presented a fuzzy multi-criteria decision-making methodology and applied it to the transportation mode selection problem. Qin et al. [46] developed a new approach to handle multi-criteria group decision-making problems under interval type-2 fuzzy environment. Their method is based on the LINMAP (Linear Programming Models with the Aid of Multidimensional Analysis of Preference) method and they showed the application of it in supplier selection problems. Ju et al. [47] proposed an interval type-2 fuzzy multi-criteria group decision-making approach with unknown weight information. They integrated the grey relational projection (GRP) and AHP methods in the proposed approach. Yao and Wang [48] presented some factors including hesitant factor, fuzzy factor and interval factor to quantify the hesitancy, fuzziness and interval information related to an IT2FS. Then, based on these factors, they introduced a cross-entropy and an MCDM approach. Liu et al. [49] proposed an integrated approach for multi-criteria group decision-making based on the ANP and VIKOR methods. In a sustainable supplier selection problem, they obtained the weights of criteria by using ANP and made the final evaluation of suppliers via VIKOR. Wu et al. [50] developed a new methodology based on the TOPSIS method to handle large scale group decision making problems with social network information in an interval type-2 fuzzy environment. They demonstrated the feasibility of the methodology using an illustrative example. For more information about the applications of IT2FSs in multi-criteria decision-making, interested readers can refer to a comprehensive review presented by Celik et al. [51].

In this paper, the SWARA method is extended with interval type-2 fuzzy sets. Using interval type-2 fuzzy sets helps us to deal more effectively with the uncertainty of experts' or decision-makers' opinions, judgements and preferences. Accordingly, the subjective weights determined by the extended SWARA could be more justified for the decision-making process. To extend the SWARA method, we utilize a sub-class of IT2FSs called symmetric interval type-2 fuzzy sets. The computations of the process can be simplified when we use symmetric IT2FSs. Moreover, the subjective weights resulted in the form of symmetric IT2FSs is more interpretable. Therefore, in the proposed approach, we can quantify the uncertain information given by decision-makers efficiently and present interpretable subjective weights for criteria.

The rest of this paper is organized as follows. In Section 2, firstly, the concepts and definitions related to type-2 fuzzy sets, interval T2FSs and symmetric IT2FSs are presented and then an extended SWARA method with symmetric IT2FSs is detailed. In Section 3, we illustrated the proposed approach by means of an example of determining the importance of intellectual capital dimensions and components in a company. In Section 4, conclusions are presented.

2. Methodology

In this section, we first present the concepts of type-2 fuzzy sets and definitions and arithmetic operations of symmetric interval type-2 fuzzy sets. Then a new approach based on the SWARA method is proposed to determine the subjective weights of criteria under uncertainty.

2.1. Concepts and Definitions

The concept of type-2 fuzzy sets was firstly presented by Zadeh [33] as an extension of type-1 fuzzy sets (ordinary fuzzy sets). Type-2 fuzzy sets help us to increase the fuzziness of a relation and this can increase the ability to deal with inexact information in a logically correct manner [52]. In the following, we present the important and basic concepts and definitions related to T2FSs.

Definition 1. *A type-2 fuzzy set $\tilde{\tilde{\mathcal{U}}}$ has a two dimensional membership function which can be defined as follows [35]:*

$$\tilde{\tilde{\mathcal{U}}} = \int_{x\in X}\int_{\mu\in\mathcal{D}_X} \omega_{\tilde{\tilde{\mathcal{U}}}}(x,\mu)/(x,\mu) \tag{1}$$

In Equation (1), x is the primary variable with domain X and μ is the secondary variable. $\mathcal{D}_X$ denotes the primary membership function and $\omega_{\tilde{\tilde{\mathcal{U}}}}(x,\mu)$ shows the secondary grade, where $\omega_{\tilde{\tilde{\mathcal{U}}}}(x,\mu) \in [0,\ 1]$ and $\mathcal{D}_X \subseteq [0,\ 1]$. In this equation, the union of all admissible values of x and μ is represented by $\int\int$.

Definition 2. *In a type-2 fuzzy set $\tilde{\tilde{\mathcal{U}}}$, if all values of the secondary grade are equal to one ($\omega_{\tilde{\tilde{\mathcal{U}}}}(x,\ \mu) = 1$), then $\tilde{\tilde{\mathcal{U}}}$ is an interval type-2 fuzzy set which can be described as follows [35]:*

$$\tilde{\tilde{\mathcal{U}}} = \int_{x\in X}\int_{\mu\in\mathcal{D}_X} 1/(x,\mu) \tag{2}$$

Definition 3. *Footprint of Uncertainty (FOU) is the union of all primary memberships described by the area between its bounds called Upper Membership Function (UMF) and Lower Membership Function (LMF). The UMF and LMF of an IT2FS $\tilde{\tilde{\mathcal{U}}}$ are ordinary (type-1) fuzzy sets and their membership functions can be represented by $\overline{\mu}_{\tilde{\tilde{\mathcal{U}}}}(x)$ and $\underline{\mu}_{\tilde{\tilde{\mathcal{U}}}}(x)$, respectively [35].*

Definition 4. *If the FOU of an interval type-2 fuzzy set $\tilde{\tilde{\mathcal{U}}}$ is symmetrical about $x = u$, it can be considered as a sub-class called symmetric IT2FSs. A SIT2FS has the following properties [36].*

$$\overline{\mu}_{\tilde{\tilde{U}}}(u+x) = \overline{\mu}_{\tilde{\tilde{U}}}(u-x) \tag{3}$$

$$\underline{\mu}_{\tilde{\tilde{U}}}(u+x) = \underline{\mu}_{\tilde{\tilde{U}}}(u-x) \tag{4}$$

Definition 5. *A symmetric IT2FS $\tilde{\tilde{U}}$ is a triangular SIT2FS if its UMF and LMF are symmetric triangular fuzzy sets. Based on the definition of symmetric triangular fuzzy sets presented by Ma et al. [53], this kind of fuzzy sets can be defined using the following membership functions.*

$$\overline{\mu}_{\tilde{\tilde{U}}}(x) = \begin{cases} \left(x-u+\overline{\delta}\right)/\overline{\delta}, & u-\overline{\delta} \le x \le u \\ \frac{\left(u+\overline{\delta}-x\right)}{\overline{\delta}}, & u \le x \le u+\overline{\delta} \\ 0, & otherwise \end{cases} \tag{5}$$

$$\underline{\mu}_{\tilde{\tilde{U}}}(x) = \begin{cases} \left(x-u+\underline{\delta}\right)/\underline{\delta}, & u-\underline{\delta} \le x \le u \\ \frac{\left(u+\underline{\delta}-x\right)}{\underline{\delta}}, & u \le x \le u+\underline{\delta} \\ 0, & otherwise \end{cases} \tag{6}$$

where u is the center of the set and $\overline{\delta}$ and $\underline{\delta}$ ($\overline{\delta} > \underline{\delta}$) denote the fuzziness values of the UMF and LMF, respectively. If $\overline{\delta} = \underline{\delta}$ then this fuzzy set is transformed into an ordinary symmetric triangular fuzzy set. Here we assume that both the UMF and LMF are normal triangular fuzzy sets. The graphical representation of this fuzzy set is shown in Figure 1. This kind of fuzzy sets can also be defined as a triplet $\left(u,\ \underline{\delta},\ \overline{\delta}\right)$.

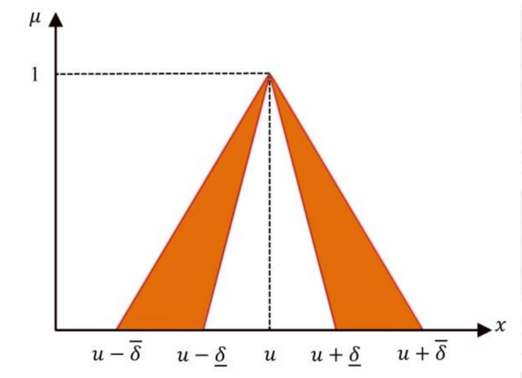

Figure 1. An example of triangular symmetric IT2FS.

Definition 6. *In the membership function of a triangular symmetric IT2FS (Equations (5) and (6)), we can define the fuzziness values ($\overline{\delta}$ and $\underline{\delta}$) by using a coefficient of the center value (u). If $\overline{\delta} = \overline{\rho}u$ and $\underline{\delta} = \underline{\rho}u$, then the range $[\underline{\rho}, \overline{\rho}]$ is defined here as the interval of uncertainty about the center (IUC).*

Definition 7. *Let $\tilde{\tilde{M}}$ and $\tilde{\tilde{N}}$ be two triangular symmetric IT2FSs where $\tilde{\tilde{M}} = \left(m, \underline{\delta}_m, \overline{\delta}_m\right)$ and $\tilde{\tilde{N}} = \left(n, \underline{\delta}_n, \overline{\delta}_n\right)$ and d is a positive crisp number. Then using the arithmetic operations of IT2FSs, we can define the following operations for these fuzzy sets [54].*

$$\tilde{\tilde{M}} \oplus \tilde{\tilde{N}} = \left(m+n, \underline{\delta}_m + \underline{\delta}_n,\ \overline{\delta}_m + \overline{\delta}_n\right) \tag{7}$$

$$\tilde{\tilde{M}} + d = \left(m+d,\ \underline{\delta}_m,\ \overline{\delta}_m\right) \tag{8}$$

$$\tilde{\tilde{M}} \cdot d = \left(m \cdot d, \underline{\delta}_m \cdot d, \overline{\delta}_m \cdot d\right) \tag{9}$$

Definition 8. *Let us denote by $\mathcal{T}(\tilde{\tilde{\mathcal{U}}})$ the defuzzified value of an interval type-2 fuzzy set $\tilde{\tilde{\mathcal{U}}}$. If $\tilde{\tilde{\mathcal{U}}}$ is a triangular symmetric IT2FSs and $\tilde{\tilde{\mathcal{U}}} = (u,\ \underline{\delta}, \overline{\delta})$, the defuzzified value of $\tilde{\tilde{\mathcal{U}}}$ is equal to u ($\mathcal{T}\left(\tilde{\tilde{\mathcal{U}}}\right) = u$).*

2.2. An Extended SWARA with Symmetric IT2FSs

The subjective weights of criteria are usually determined based on the opinion and judgment of the decision-maker(s) or expert(s) in a multi-criteria decision-making process. Because these weights are very important, there have been several methods for determination of them. One of the efficient methods for determination of subjective weights of criteria is the SWARA method [6]. In this section, we propose an extended SWARA method based on the concepts and definitions of symmetric interval type-2 fuzzy sets to determine the subjective criteria weights. The subjective criteria weights can be more sensible if they determined based on the judgments and preferences of a group of decision-makers. The extended SWARA proposed in this study has the ability of determining the weights of criteria for a group decision-making problem. Suppose that we want to determine the subjective weights of M criteria based on the opinions of N decision-makers. The steps of determination of criteria weights using the extended SWARA with SIT2FSs are presented as follows:

Step 1. After formation of a group of decision-makers, each decision-maker sorts the criteria in a descending order based on the expected importance of them, that is, the most important criterion is ranked first. Let us denote by τ_{jk} the rank of jth criterion based on the opinion of kth decision-maker ($j \in \{1,\ 2,\ \ldots, M\}$ and $k \in \{1,\ 2,\ \ldots, N\}$).

Step 2. In this step, we start with the criterion which has the second rank in the sorted list of Step 1 ($\tau_{jk} = 2$) and get the relative importance of each criterion ($S_{\tau_{jk}}$ and τ_{jk} = 2, 3, ..., M) compared to the previous criterion of the list from each decision-maker. Also, the decision-makers are asked to give the IUC related to each value of $S_{\tau_{jk}}$. Suppose that $[\underline{\rho}_{\tau_{jk}}, \overline{\rho}_{\tau_{jk}}]$ is the IUC of $S_{\tau_{jk}}$ values. Then, based on Definitions 5 and 6, the symmetric triangular interval type-2 fuzzy set related to decision-makers' expression is represented as follows:

$$\tilde{\tilde{S}}_{\tau_{jk}} = \left(S_{\tau_{jk}}, \underline{\delta s}_{\tau_{jk}}, \overline{\delta s}_{\tau_{jk}}\right) \tag{10}$$

where $\underline{\delta s}_{\tau_{jk}} = \underline{\rho}_{\tau_{jk}}\, S_{\tau_{jk}}$ and $\overline{\delta s}_{\tau_{jk}} = \overline{\rho}_{\tau_{jk}} S_{\tau_{jk}}$.

Step 3. In this step, we calculate the values of $\tilde{\tilde{K}}_{\tau_{jk}} = \left(K_{\tau_{jk}}, \underline{\delta k}_{\tau_{jk}}, \overline{\delta k}_{\tau_{jk}}\right)$ for each decision-maker and $\tau_{jk} > 1$ as follows:

$$\tilde{\tilde{K}}_{\tau_{jk}} = 1 + \tilde{\tilde{S}}_{\tau_{jk}} \tag{11}$$

Step 4. Calculation of the relative weighting factors $\tilde{\tilde{Q}}_{\tau_{jk}}$ is made in this step by the following equation.

$$\tilde{\tilde{Q}}_{\tau_{jk}} = \begin{cases} \left(1, \underline{\delta q}_1, \overline{\delta q}_1\right) & if\, \tau_{jk} = 1 \\ \left(\dfrac{\mathcal{T}\left(\tilde{\tilde{Q}}_{\tau_{jk}-1}\right)}{\mathcal{T}\left(\tilde{\tilde{K}}_{\tau_{jk}}\right)^2}\right) \cdot \tilde{\tilde{K}}_{\tau_{jk}} & if\, \tau_{jk} > 1 \end{cases} \tag{12}$$

where $\underline{\delta q}_1 = \frac{1}{M-1}\sum_{\tau_{jk}=2}^{M} \underline{\delta k}_{\tau_{jk}}$ and $\overline{\delta q}_1 = \frac{1}{M-1}\sum_{\tau_{jk}=2}^{M} \overline{\delta k}_{\tau_{jk}}$. By using these formulas, we involve a degree of uncertainty in the first rank criterion. Although the average interval of the other criteria is used in this study, this interval can be set by the decision- makers.

Step 5. Using the following equation, we can determine the subjective weights for kth decision-maker in the form of symmetric interval type-2 fuzzy sets:

$$\tilde{\tilde{w}}_{jk} = \left(1/\mathcal{T}\left(\underset{\tau_{jk}=1}{\overset{M}{\oplus}} \tilde{\tilde{Q}}_{\tau_{jk}}\right)\right) \cdot \tilde{\tilde{Q}}_{\tau_{jk}} \tag{13}$$

Step 6. Finally, the aggregated subjective weight of each criterion is calculated as follows:

$$\tilde{\tilde{w}}_{j} = \frac{1}{N} \underset{k=1}{\overset{N}{\oplus}} \tilde{\tilde{w}}_{jk} \tag{14}$$

In a hierarchical structure, a criterion may have some sub-criteria. To determine the subjective weights of sub-criteria, firstly, we should fulfill the presented steps to obtain the subjective weights of each criterion; secondly, the subjective weights of sub-criteria of each criterion should be determined by the same steps and finally, the global subjective weights of sub-criteria ($\tilde{\tilde{w}}_j^G$) are calculated by multiplication of the subjective weights of sub-criteria and their upper level criteria. In this study, we use the defuzzified values of the subjective weights of criteria in the upper level of hierarchical structure to keep the symmetrical property of the weights.

If $\tilde{\tilde{w}}_r$ shows the subjective weight of rth criterion and $\tilde{\tilde{w}}_{rl}$ denote the subjective weight of lth sub-criterion of rth criterion. Then the global subjective weight of lth sub-criterion ($\tilde{\tilde{w}}_{rl}^G$) is calculated as follows:

$$\tilde{\tilde{w}}_{rl}^G = \mathcal{T}\left(\tilde{\tilde{w}}_r\right) \cdot \tilde{\tilde{w}}_{rl} \tag{15}$$

To make the proposed approach clear, we present the flowchart of the procedure in Figure 2.

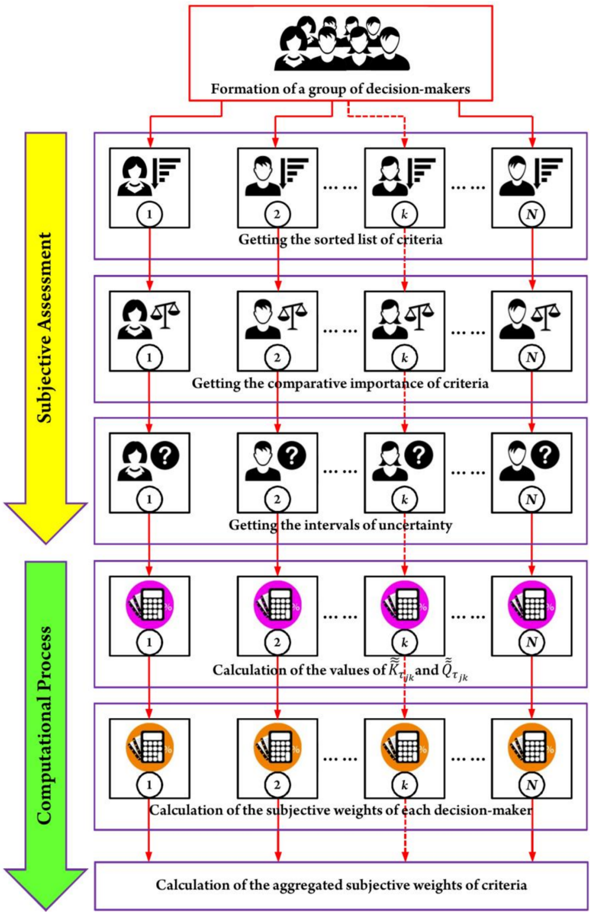

Figure 2. The procedure of the extended SWARA with symmetric IT2FSs.

3. Illustrative Example

In this section, the extended SWARA with SIT2FSs is used to determine the importance of intellectual capital dimensions and components in a company. The hierarchical structure of the multi-criteria decision-making problem is defined in Figure 3 based on the study of Bozbura and Beskese [55]. According to Figure 3, we have three main criteria which include some sub-criteria. Suppose that three experts (decision-makers) from the company are appointed to perform the process of the criteria and sub-criteria assessment. Based on the hierarchical structure, firstly, the proposed approach is used to determine the importance or weights of the main criteria, then the weights of the sub-criteria of each criterion are calculated. Therefore, the procedure of the proposed approach should be performed four times (Once for the main criteria and three for the sub-criteria of them).

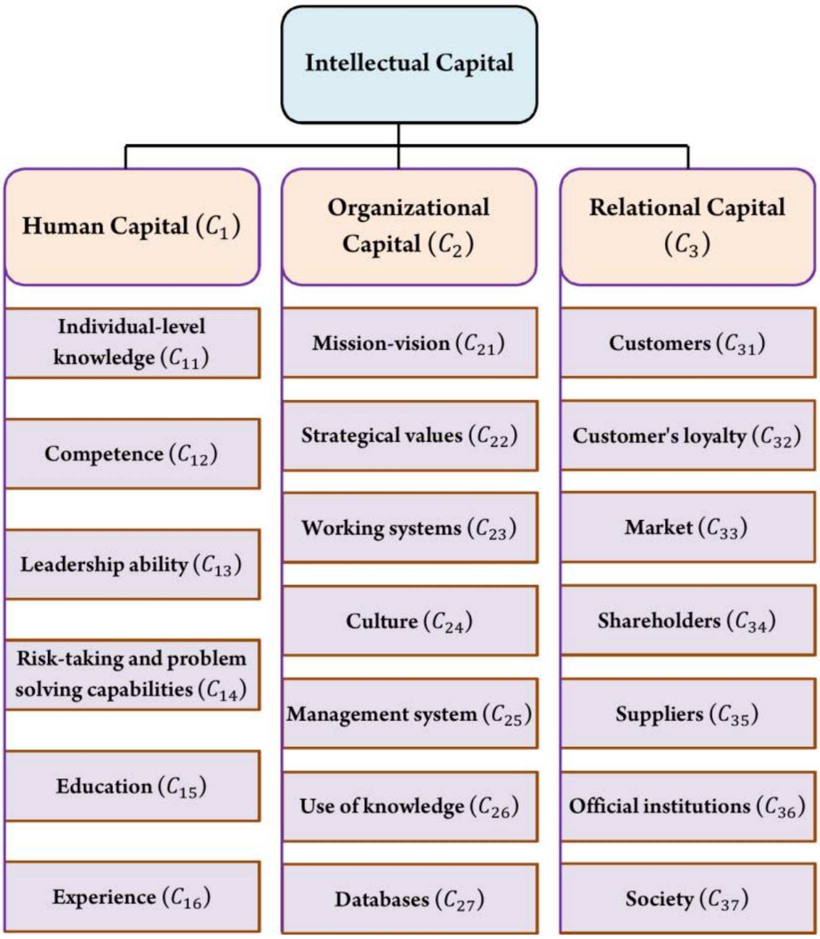

Figure 3. The hierarchical structure of intellectual capital dimensions.

The information given by the first (DM_1), second (DM_2) and third (DM_3) decision-makers about the main criteria are shown in Table 1 and the information related to sub-criteria are presented in Tables 2–4. As can be seen in these tables, according to Step 2 of the proposed approach, the relative importance of each criterion and sub-criterion compared to the previous item of the sorted list ($S_{\tau_{jk}}$) is transformed into a triangular SIT2FS based on the IUC provided by each decision-makers and Equation (10). The values of $\tilde{\tilde{K}}_{\tau_{jk}}$ and $\tilde{\tilde{Q}}_{\tau_{jk}}$, which are calculated using Equations (11) and (12) in Steps 3 and 4, are also presented in Tables 1–4.

Table 1. The information related to the main criteria.

	Sorted	$S_{\text{ø}_{jk}}$	IUC	$\tilde{\tilde{S}}_{\text{ø}_{jk}}$	$\tilde{\tilde{K}}_{\text{ø}_{jk}}$	$\tilde{\tilde{Q}}_{\text{ø}_{jk}}$
DM_1	C_1	—	—	—	—	(1, 0.086, 0.098)
	C_2	0.1	[1.1, 1.2]	(0.1, 0.11, 0.12)	(1.1, 0.11, 0.12)	(0.909, 0.091, 0.099)
	C_3	0.05	[1.25, 1.5]	(0.05, 0.063, 0.075)	(1.05, 0.063, 0.075)	(0.866, 0.052, 0.062)
DM_2	C_2	—	—	—	—	(1, 0.094, 0.11)
	C_1	0.05	[1.15, 1.2]	(0.05, 0.058, 0.06)	(1.05, 0.058, 0.06)	(0.952, 0.052, 0.054)
	C_3	0.1	[1.3, 1.6]	(0.1, 0.13, 0.16)	(1.1, 0.13, 0.16)	(0.866, 0.102, 0.126)
DM_3	C_2	—	—	—	—	(1, 0.306, 0.36)
	C_1	0.5	[1.1, 1.3]	(0.5, 0.55, 0.65)	(1.5, 0.55, 0.65)	(0.667, 0.244, 0.289)
	C_3	0.05	[1.25, 1.4]	(0.05, 0.063, 0.07)	(1.05, 0.063, 0.07)	(0.635, 0.038, 0.042)

As an example, here we calculate the value of $\tilde{\tilde{S}}_2$ for the second rank main criteria of the first decision-maker. According to Table 1, the value of S_2 is equal to 0.1 for DM_1 and the interval of uncertainty about the center is [1.1, 1.2] for S_2. Based on Step 2 and Definition 6, we can calculate $\underline{\delta s}_2$ and $\overline{\delta s}_2$ as follows: $\underline{\delta s}_2 = \underline{\rho}_2\ S_2 = 1.1 \times 0.1 = 0.11$ and $\overline{\delta s}_2 = \overline{\rho}_2 S_2 = 1.2 \times 0.1 = 0.12$. Then we have $\tilde{\tilde{S}}_2 = (0.1, 0.11, 0.12)$. The other values of $S_{\tau_{jk}}$ are calculated in the same way.

Table 2. The information related to the sub-criteria of the first criterion (C_1).

	Sorted	$S_{\text{ø}_{jk}}$	IUC	$\tilde{\tilde{S}}_{\text{ø}_{jk}}$	$\tilde{\tilde{K}}_{\text{ø}_{jk}}$	$\tilde{\tilde{Q}}_{\text{ø}_{jk}}$
DM_1	C_{11}	—	—	—	—	(1, 0.177, 0.194)
	C_{16}	0.2	[1.05, 1.15]	(0.2, 0.21, 0.23)	(1.2, 0.21, 0.23)	(0.833, 0.146, 0.16)
	C_{15}	0.25	[1.1, 1.2]	(0.25, 0.275, 0.3)	(1.25, 0.275, 0.3)	(0.667, 0.147, 0.16)
	C_{14}	0.15	[1.05, 1.1]	(0.15, 0.158, 0.165)	(1.15, 0.158, 0.165)	(0.58, 0.079, 0.083)
	C_{13}	0.1	[1.25, 1.5]	(0.1, 0.125, 0.15)	(1.1, 0.125, 0.15)	(0.527, 0.06, 0.072)
	C_{12}	0.1	[1.15, 1.25]	(0.1,0.115,0.125)	(1.1, 0.115, 0.125)	(0.479, 0.05, 0.054)
DM_2	C_{16}	—	—	—	—	(1, 0.162, 0.181)
	C_{11}	0.25	[1.15, 1.25]	(0.25, 0.288, 0.313)	(1.25, 0.288, 0.313)	(0.8, 0.184, 0.2)
	C_{14}	0.05	[1.15, 1.25]	(0.05, 0.058, 0.063)	(1.05, 0.058, 0.063)	(0.762, 0.042, 0.045)
	C_{15}	0.1	[1.05, 1.1]	(0.1, 0.105, 0.11)	(1.1, 0.105, 0.11)	(0.693, 0.066, 0.069)
	C_{12}	0.2	[1.25,1.5]	(0.2, 0.25, 0.3)	(1.2, 0.25, 0.3)	(0.577, 0.12, 0.144)
	C_{13}	0.1	[1.1, 1.2]	(0.1, 0.11, 0.12)	(1.1, 0.11, 0.12)	(0.525, 0.052, 0.057)
DM_3	C_{11}	—	—	—	—	(1, 0.191, 0.209)
	C_{15}	0.05	[1.15, 1.25]	(0.05, 0.058, 0.063)	(1.05, 0.058, 0.063)	(0.952, 0.052, 0.057)
	C_{16}	0.1	[1.05, 1.1]	(0.1, 0.105, 0.11)	(1.1, 0.105, 0.11)	(0.866, 0.083, 0.087)
	C_{14}	0.3	[1.3, 1.4]	(0.3, 0.39, 0.42)	(1.3, 0.39, 0.42)	(0.666, 0.2, 0.215)
	C_{12}	0.25	[1.1, 1.2]	(0.25, 0.275, 0.3)	(1.25, 0.275, 0.3)	(0.533, 0.117, 0.128)
	C_{13}	0.1	[1.25, 1.5]	(0.1, 0.125, 0.15)	(1.1, 0.125, 0.15)	(0.484, 0.055, 0.066)

Table 3. The information related to the sub-criteria of the second criterion (C_2).

	Sorted	$S_{\text{ø}_{jk}}$	IUC	$\tilde{\tilde{S}}_{\text{ø}_{jk}}$	$\tilde{\tilde{K}}_{\text{ø}_{jk}}$	$\tilde{\tilde{Q}}_{\text{ø}_{jk}}$
DM_1	C_{25}	—	—	—	—	(1, 0.235, 0.255)
	C_{23}	0.3	[1.2, 1.3]	(0.3, 0.36, 0.39)	(1.3, 0.36, 0.39)	(0.769, 0.213, 0.231)
	C_{26}	0.15	[1.1, 1.15]	(0.15, 0.165, 0.173)	(1.15, 0.165, 0.173)	(0.669, 0.096, 0.1)
	C_{27}	0.35	[1.05, 1.15]	(0.35, 0.368, 0.402)	(1.35, 0.368, 0.402)	(0.495, 0.135, 0.148)
	C_{24}	0.2	[1.1, 1.25]	(0.2, 0.22, 0.25)	(1.2, 0.22, 0.25)	(0.413, 0.076, 0.086)
	C_{21}	0.15	[1.25, 1.3]	(0.15, 0.188, 0.195)	(1.15, 0.188, 0.195)	(0.359, 0.059, 0.061)
	C_{22}	0.1	[1.1, 1.2]	(0.1, 0.11, 0.12)	(1.1, 0.11, 0.12)	(0.326, 0.033, 0.036)

Table 3. *Cont.*

	Sorted	$S_{\emptyset_{jk}}$	IUC	$\tilde{\tilde{S}}_{\emptyset_{jk}}$	$\tilde{\tilde{K}}_{\emptyset_{jk}}$	$\tilde{\tilde{Q}}_{\emptyset_{jk}}$
DM_2	C_{23}	—	—	—	—	(1, 0.238, 0.252)
	C_{25}	0.4	[1.1, 1.15]	(0.4, 0.44, 0.46)	(1.4, 0.44, 0.46)	(0.714, 0.224, 0.235)
	C_{27}	0.2	[1.2, 1.25]	(0.2, 0.24, 0.25)	(1.2, 0.24, 0.25)	(0.595, 0.119, 0.124)
	C_{26}	0.2	[1.3, 1.35]	(0.2, 0.26, 0.27)	(1.2, 0.26, 0.27)	(0.496, 0.107, 0.112)
	C_{21}	0.1	[1.15, 1.25]	(0.1, 0.115, 0.125)	(1.1, 0.115, 0.125)	(0.451, 0.047, 0.051)
	C_{22}	0.15	[1.1, 1.25]	(0.15, 0.165, 0.188)	(1.15, 0.165, 0.188)	(0.392, 0.056, 0.064)
	C_{24}	0.2	[1.05, 1.1]	(0.2, 0.21, 0.22)	(1.2, 0.21, 0.22)	(0.327, 0.057, 0.06)
DM_3	C_{25}	—	—	—	—	(1, 0.156, 0.168)
	C_{26}	0.1	[1.05, 1.1]	(0.1, 0.105, 0.11)	(1.1, 0.105, 0.11)	(0.909, 0.087, 0.091)
	C_{23}	0.1	[1.15, 1.25]	(0.1, 0.115,0.125)	(1.1, 0.115, 0.125)	(0.826, 0.086, 0.094)
	C_{21}	0.15	[1.15, 1.3]	(0.15, 0.173,0.195)	(1.15, 0.173, 0.195)	(0.719, 0.108, 0.122)
	C_{27}	0.25	[1.1, 1.2]	(0.25, 0.275,0.3)	(1.25, 0.275, 0.3)	(0.575, 0.126, 0.138)
	C_{24}	0.2	[1.05, 1.1]	(0.2, 0.21,0.22)	(1.2, 0.21, 0.22)	(0.479, 0.084, 0.088)
	C_{22}	0.05	[1.15, 1.2]	(0.05, 0.058,0.06)	(1.05, 0.058, 0.06)	(0.456, 0.025, 0.026)

Table 4. The information related to the sub-criteria of the third criterion (C_3).

	Sorted	$S_{\emptyset_{jk}}$	IUC	$\tilde{\tilde{S}}_{\emptyset_{jk}}$	$\tilde{\tilde{K}}_{\emptyset_{jk}}$	$\tilde{\tilde{Q}}_{\emptyset_{jk}}$
DM_1	C_{33}	—	—	—	—	(1, 0.145, 0.153)
	C_{34}	0.2	[1.25, 1.3]	(0.2, 0.25, 0.26)	(1.2, 0.25, 0.26)	(0.833, 0.174, 0.181)
	C_{31}	0.25	[1.1, 1.15]	(0.25, 0.275, 0.288)	(1.25, 0.275, 0.288)	(0.667, 0.147, 0.153)
	C_{32}	0.05	[1.05, 1.1]	(0.05, 0.053, 0.055)	(1.05, 0.053, 0.055)	(0.635, 0.032, 0.033)
	C_{35}	0.05	[1.2, 1.3]	(0.05, 0.06, 0.065)	(1.05, 0.06, 0.065)	(0.605, 0.035, 0.037)
	C_{36}	0.1	[1.25, 1.35]	(0.1, 0.125, 0.135)	(1.1, 0.125, 0.135)	(0.55, 0.062, 0.067)
	C_{37}	0.1	[1.1, 1.15]	(0.1, 0.11, 0.115)	(1.1, 0.11, 0.115)	(0.5, 0.05, 0.052)
DM_2	C_{34}	—	—	—	—	(1, 0.183, 0.2)
	C_{33}	0.3	[1.15, 1.25]	(0.3, 0.345, 0.375)	(1.3, 0.345, 0.375)	(0.769, 0.204, 0.222)
	C_{32}	0.1	[1.05, 1.15]	(0.1, 0.105, 0.115)	(1.1, 0.105, 0.115)	(0.699, 0.067, 0.073)
	C_{31}	0.25	[1.25, 1.4]	(0.25, 0.313, 0.35)	(1.25, 0.313, 0.35)	(0.559, 0.14, 0.157)
	C_{35}	0.05	[1.1, 1.2]	(0.05, 0.055, 0.06)	(1.05, 0.055, 0.06)	(0.533, 0.028, 0.03)
	C_{37}	0.1	[1.05, 1.1]	(0.1, 0.105, 0.11)	(1.1, 0.105, 0.11)	(0.484, 0.046, 0.048)
	C_{36}	0.15	[1.15, 1.25]	(0.15, 0.173, 0.188)	(1.15, 0.173, 0.188)	(0.421, 0.063, 0.069)
DM_3	C_{33}	—	—	—	—	(1, 0.205, 0.225)
	C_{34}	0.25	[1.15, 1.25]	(0.25, 0.288, 0.313)	(1.25, 0.288, 0.313)	(0.8, 0.184, 0.2)
	C_{31}	0.1	[1.1, 1.2]	(0.1, 0.11, 0.12)	(1.1, 0.11, 0.12)	(0.727, 0.073, 0.079)
	C_{35}	0.1	[1.25, 1.5]	(0.1, 0.125, 0.15)	(1.1, 0.125, 0.15)	(0.661, 0.075, 0.09)
	C_{32}	0.15	[1.1, 1.2]	(0.15, 0.165, 0.18)	(1.15, 0.165, 0.18)	(0.575, 0.082, 0.09)
	C_{37}	0.2	[1.15, 1.2]	(0.2, 0.23, 0.24)	(1.2, 0.23, 0.24)	(0.479, 0.092, 0.096)
	C_{36}	0.3	[1.05, 1.15]	(0.3, 0.315, 0.345)	(1.3, 0.315, 0.345)	(0.369, 0.089, 0.098)

According to the values of $\tilde{\tilde{K}}_{\tau_{jk}}$ and $\tilde{\tilde{Q}}_{\tau_{jk}}$ and Equation (13) of Step 5, the subjective weights of the main criteria and their sub-criteria can be calculated for each decision-maker. The results of this step are presented in Table 5.

Table 5. The subjective weights of the criteria and sub-criteria for each decision-maker ($\tilde{\tilde{w}}_{jk}$).

	DM_1	DM_2	DM_3
C_1	(0.36, 0.031, 0.035)	(0.338, 0.019, 0.019)	(0.29, 0.106, 0.126)
C_{11}	(0.245, 0.043, 0.047)	(0.184, 0.042, 0.046)	(0.222, 0.042, 0.046)
C_{12}	(0.117, 0.012, 0.013)	(0.132, 0.028, 0.033)	(0.118, 0.026, 0.028)
C_{13}	(0.129, 0.015, 0.018)	(0.12, 0.012, 0.013)	(0.108, 0.012, 0.015)
C_{14}	(0.142, 0.019, 0.02)	(0.175, 0.01, 0.01)	(0.148, 0.044, 0.048)
C_{15}	(0.163, 0.036, 0.039)	(0.159, 0.015, 0.016)	(0.212, 0.012, 0.013)
C_{16}	(0.204, 0.036, 0.039)	(0.23, 0.037, 0.042)	(0.192, 0.018, 0.019)
C_2	(0.328, 0.033, 0.036)	(0.355, 0.033, 0.039)	(0.434, 0.133, 0.156)
C_{21}	(0.089, 0.015, 0.015)	(0.113, 0.012, 0.013)	(0.145, 0.022, 0.025)
C_{22}	(0.081, 0.008, 0.009)	(0.099, 0.014, 0.016)	(0.092, 0.005, 0.005)
C_{23}	(0.191, 0.053, 0.057)	(0.252, 0.06, 0.063)	(0.166, 0.017, 0.019)
C_{24}	(0.102, 0.019, 0.021)	(0.082, 0.014, 0.015)	(0.097, 0.017, 0.018)
C_{25}	(0.248, 0.058, 0.063)	(0.18, 0.056, 0.059)	(0.201, 0.031, 0.034)
C_{26}	(0.166, 0.024, 0.025)	(0.125, 0.027, 0.028)	(0.183, 0.017, 0.018)
C_{27}	(0.123, 0.033, 0.037)	(0.15, 0.03, 0.031)	(0.116, 0.025, 0.028)
C_3	(0.312, 0.019, 0.022)	(0.307, 0.036, 0.045)	(0.276, 0.016, 0.018)
C_{31}	(0.139, 0.031, 0.032)	(0.125, 0.031, 0.035)	(0.158, 0.016, 0.017)
C_{32}	(0.133, 0.007, 0.007)	(0.157, 0.015, 0.016)	(0.125, 0.018, 0.02)
C_{33}	(0.209, 0.03, 0.032)	(0.172, 0.046, 0.05)	(0.217, 0.045, 0.049)
C_{34}	(0.174, 0.036, 0.038)	(0.224, 0.041, 0.045)	(0.173, 0.04, 0.043)
C_{35}	(0.126, 0.007, 0.008)	(0.119, 0.006, 0.007)	(0.143, 0.016, 0.02)
C_{36}	(0.115, 0.013, 0.014)	(0.094, 0.014, 0.015)	(0.08, 0.019, 0.021)
C_{37}	(0.104, 0.01, 0.011)	(0.108, 0.01, 0.011)	(0.104, 0.02, 0.021)

Based on the values of subjective weights presented in Table 5 and Equation (14) of Step 6, we can determine the aggregated subjective weights for the main criteria and their sub-criteria. Because of the hierarchical structure of the criteria and sub-criteria, the weights of sub-criteria are local in this step. The global subjective weights of sub-criteria are calculated by multiplying the local weights of them by the weights of the upper level criteria. The local and global subjective weights are represented in Table 6. It should be noted that Equation (15) is used to calculate the global weights.

Table 6. The aggregated local and global subjective weights.

	Aggregated Local Weights	**Global Weights of Sub-Criteria**
C_1	(0.329, 0.052, 0.06)	—
C_{11}	(0.217, 0.042, 0.046)	(0.071, 0.014, 0.015)
C_{12}	(0.122, 0.022, 0.025)	(0.04, 0.007, 0.008)
C_{13}	(0.119, 0.013, 0.015)	(0.039, 0.004, 0.005)
C_{14}	(0.155, 0.024, 0.026)	(0.051, 0.008, 0.009)
C_{15}	(0.178, 0.021, 0.023)	(0.059, 0.007, 0.008)
C_{16}	(0.209, 0.03, 0.033)	(0.069, 0.01, 0.011)
C_2	(0.372, 0.066, 0.077)	—
C_{21}	(0.116, 0.016,0.018)	(0.043, 0.006, 0.007)
C_{22}	(0.091, 0.009, 0.01)	(0.034, 0.003, 0.004)
C_{23}	(0.203, 0.043, 0.046)	(0.076, 0.016, 0.017)
C_{24}	(0.094, 0.017, 0.018)	(0.035, 0.006, 0.007)
C_{25}	(0.21, 0.048, 0.052)	(0.078, 0.018, 0.019)
C_{26}	(0.158, 0.023, 0.024)	(0.059, 0.009, 0.009)
C_{27}	(0.13, 0.029, 0.032)	(0.048, 0.011, 0.012)
C_3	(0.298, 0.024, 0.028)	—
C_{31}	(0.141, 0.026, 0.028)	(0.042, 0.008, 0.008)
C_{32}	(0.138, 0.013, 0.014)	(0.041, 0.004, 0.004)
C_{33}	(0.199, 0.04, 0.044)	(0.059, 0.012, 0.013)
C_{34}	(0.19, 0.039, 0.042)	(0.057, 0.012, 0.013)
C_{35}	(0.129, 0.01, 0.012)	(0.038, 0.003, 0.004)
C_{36}	(0.096, 0.015, 0.017)	(0.029, 0.004, 0.005)
C_{37}	(0.105, 0.013, 0.014)	(0.031, 0.004, 0.004)

The global weights can be used if we have some alternatives which need to be evaluated with respect to these criteria. Here, the local weights are enough to evaluate the importance of criteria. To show the uncertainty of the subjective weights determined (local subjective weights of sub-criteria) in the form of symmetric interval type-2 fuzzy sets, the graphical representation of them is depicted in Figure 4.

As can be seen in Figure 4 and Table 6, based on the experts' assessments, C_{11} (Individual-level knowledge) and C_{16} (Experience) are the most important and C_{12} (Competence) and C_{13} (Leadership ability) are the least important sub-criteria of C_1 (Human Capital). In the second criterion (Organizational Capital), we can say that C_{25} (Management system) and C_{23} (Working systems) have more importance than the other sub-criteria. Also, we can see the higher weights of C_{33} and C_{34} in the third criterion, which shows that "Market" and "Shareholders" are more important that the other sub-criteria in the "Relational Capital" dimension.

This example shows that the defuzzified subjective weights of some sub-criteria in different main criteria are very close to each other. For example, we can see small difference between the defuzzified subjective weights of C_{12} and C_{13} in the first criterion, C_{22} and C_{24} in the second criterion and C_{31} and C_{32} in the third criterion. However, these sub-criteria can be differentiated by using on the level of uncertainty or their domains based on the results obtained by the proposed approach.

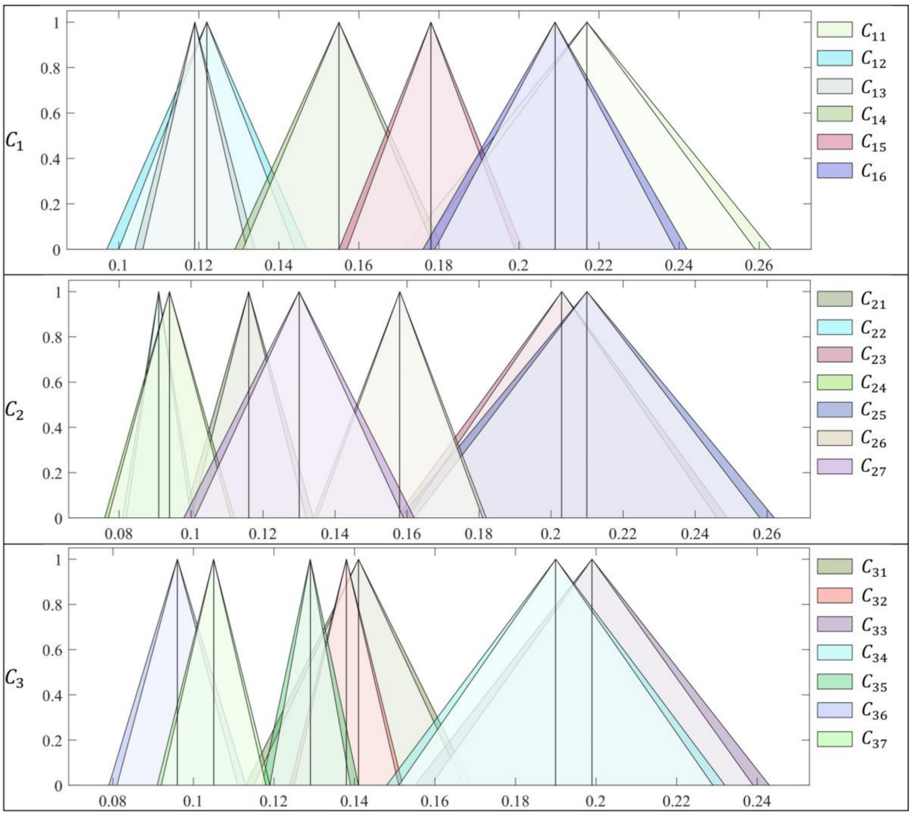

Figure 4. The symmetric IT2FSs related to each sub-criterion.

4. Conclusions

The importance of criteria weights in the process of multi-criteria decision-making has led to developing several methods for determination of them. Some methods have been developed to obtain the objective weights of criteria based on the information of decision-matrices and some other have been devised to determine the subjective weights according to the judgments and preferences of experts or decision-makers. The SWARA method is an efficient method for determination of subjective weights of criteria. Because we are usually confronted with imprecise information given by decision-makers, we need a tool that can be able to handle the uncertainty of information. In this study, we have proposed an extended SWARA method for determination of subjective weights under uncertainty. To model the uncertainty associated with the decision-makers' judgments and preferences, the concept of interval type-2 fuzzy sets has been used. In this regard, a sub-class of IT2FSs—called symmetric interval type-2 fuzzy sets—has been utilized to extend the SWARA method. The symmetrical properties of this sub-class of IT2FSs help us to capture the uncertainty of information flexibly and to make the computations simply. The extended SWARA method has been developed to elicit the preferences of a group of decision-makers under uncertainty and give an aggregated subjective weight for each criterion in the form of symmetric interval type-2 fuzzy sets. The symmetric form of the subjective weights determined by the proposed approach helps us to interpret them in a more efficient way. The application of the extended SWARA method has been presented as a numerical example to determine the weights of dimensions and components of intellectual capital in a company. Future research can apply the proposed approach to different real-world MCDM problems like assessment of green supply chain indicators, evaluation of risk factors and assessment of service quality dimensions. Also, a comparative study of the proposed approach and the AHP method with IT2FSs can be made in future research. Moreover, the proposed approach can be integrated with the other MCDM methods such as TOPSIS, VIKOR, PROMETHEE and EDAS to propose new hybrid approaches to deal with decision-making problems.

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