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ASSESSMENT OF THIRD-PARTY LOGISTICS PROVIDERS USING A CRITIC–WASPAS APPROACH WITH INTERVAL TYPE-2 FUZZY SETS

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Abstract. The assessment of Third-Party Logistics (3PL) provider becomes an important issue for enterprises trying to achieve operational efficiency and customer service improvement as well as capital expenditure and logistics costs reduction. It can be said that evaluation and selection of an appropriate 3PL provider is a kind of Multi-Criteria Decision-Making (MCDM) problem. Uncertainty is an unavoidable part of information in the decision-making process. Interval Type-2 Fuzzy Sets (IT2FSs) are very flexible to model the uncertainty of the MCDM problems. In this study, a new integrated approach based on the CRiteria Importance Through Inter-criteria Correlation (CRITIC) and Weighted Aggregated Sum Product ASsessment (WASPAS) methods is proposed to evaluate 3PL providers with IT2FSs. In the proposed approach, objective weights resulted from the CRITIC method are combined with subjective weights expressed by decision-makers (DMs) to determine more realistic weights for criteria. A computational study is performed to illustrate the proposed approach and the applicability of it. In addition, a sensitivity analysis is carried out using different sets of criteria weights to demonstrate the stability of the proposed approach. The results show the stability of ranking results and prove the efficiency of the proposed approach to handle MCDM problems with IT2FSs.

Keywords: third-party logistics; interval type-2 fuzzy sets; WASPAS method; CRITIC method; multi-criteria group decision-making.

Introduction

Logistics management is an important operation of enterprises and has a meaningful role in supply chains integration in different industries. With the pressure of increasing costs of enterprises and globalization of business activities, logistics outsourcing becomes an essential part of any businesses. Enterprises often outsource their logistics to a Third-Party Logistics (3PL) provider in order to focus on their main business (Guarnieri *et al.* 2015). Logistics outsourcing can bring various cost saving opportunities, increase supply chain flexibility and improve logistics efficiency with a professional help from 3PL providers (Bhatnagar *et al.* 1999). Selection of suitable 3PL providers is an indispensable strategic decision for companies that want to focus on their core competencies as competitive advantages and entrust their other activities to some technical and specialized companies (Marasco 2008). Therefore, how to choose the most suitable 3PL provider becomes an important problem for enterprises. 3PL provider selection starts with the establishment of decision criteria relevant to the identification and evaluation of candidate 3PL providers with the highest potential for meeting the firm's service (Boyson *et al.* 1999). According to the characteristics of the Multi-Criteria Decision-Making (MCDM) processes, we can categorize the 3PL provider selection as an MCDM problem (Mardani *et al.* 2016).

Many researchers have studied the multi-criteria 3PL provider selection problem in the literature. Chen *et al.* (2011) studied on organization of supply chains using 3PL providers outsourcing. They used a negotiation mechanism and Analytic Hierarchy Process (AHP) to evaluate the alternatives and select the best one to arrange a partnership in an apparel supply chain. Falsini *et al.* (2012) proposed a hybrid approach by integrating linear programming with AHP and Data Envelopment Analysis (DEA) methods to deal with the evaluation of 3PL providers with multiple criteria. They aggregated experts' expressions with objective information that obtained from the analyses of historical data to handle the

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weaknesses of the AHP method. Wong (2012) applied the fuzzy Analytic Network Process (ANP) and Preemptive Fuzzy Integer Goal Programming (PFIGP) to develop an integrated Decision Support System (DSS) for selection of 3PL provider in the global supply chain. Perçin and Min (2013) proposed a hybrid methodology using Quality Function Deployment (QFD) and fuzzy MCDM methods for dealing with the problem of 3PL provider selection. In their methodology, QFD was utilized to recognize particular needs of customers and match the characteristics of 3PL provider alternatives to those needs. They also used the fuzzy linear regression for determining a practical relationship between the characteristics of 3PL providers and defined needs. Finally, a goal programming model was applied to select the appropriate 3PL provider. Sahu *et al.* (2015) presented a fuzzy based appraisement platform for evaluation and selection of 3PL providers. They applied the theory of Interval-Valued Fuzzy Numbers (IVFNs) for the evaluation and selection process. Yayla *et al.* (2015) proposed a hybrid fuzzy MCDM methodology based on the fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy AHP to provide a systematic decision support tool for 3PL provider evaluation.

In the process of 3PL provider evaluation, we are usually confronted with uncertain environment, and input information is not accurately known. As can be seen in the literature, most of the studies have used fuzzy approaches in the process of 3PL provider evaluation and selection. This study also uses the theory of fuzzy sets in the decision-making process. To deal with the fuzziness of real-world problems, we can use Type-2 Fuzzy Set (T2FS) which proposed by Zadeh (1975) as an extension of type-1 fuzzy set. T2FSs have three dimensions, and a fuzzy set on the interval [0, 1] is used to represent the membership function of it. Interval Type-2 Fuzzy Sets (IT2FSs), which are a special type of T2FSs, have been used by many researchers to develop MCDM approaches under uncertain conditions.

Celik *et al.* (2013) developed a new interval type-2 fuzzy MCDM method by integrating the TOPSIS and grey relational analysis (GRA) to evaluate the satisfaction of customers in Istanbul public transportation with the aim of improving it. Chen (2014) developed a new approach for decision-making with multiple criteria and interval type-2 fuzzy information based on a new signed distance-based method and the Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) method. Keshavarz Ghorabaee *et al.* (2015) developed an extended *VIseKriterijumska Optimizacija I Kompromisno Resenje* (VIKOR) method for evaluating and selecting projects with IT2FSs. They compared the proposed method with some existing method to represent the effectiveness of it. Kiliç and Kaya (2016) proposed a new approach by using IT2FSs to assess and prioritize provinces for public grants allocation. A MCDM method based on the AHP and TOPSIS was also developed by them for assessment of investment project with IT2FSs (Kiliç, Kaya 2015). Keshavarz Ghorabaee (2016) presented an MCDM method for robot selection in the interval type-2 fuzzy environment based on the VIKOR method and made a comparison and a sensitivity analysis to demonstrate the efficiency of the method. The application of the IT2FSs in evaluation of green 3PL providers was presented by Celik *et al.* (2016) using a new extension of the *ELimination Et Choix Traduisant la REalité* (ELECTRE) method.

Zavadskas *et al.* (2012) proposed and optimized the Weighted Aggregated Sum Product ASsessment (WASPAS) method as a MCDM method. This method has been applied to many real-life MCDM problems in different fields like location evaluation problem (Hashemkhani Zolfani *et al.* 2013), daylighting problem (Šiožinytė, Antuchevičienė 2013), wind turbines evaluation (Bagočius *et al.* 2014), solar projects assessment (Vafaeipour *et al.* 2014), manufacturing MCDM problems (Chakraborty, Zavadskas 2014) and intelligent sensors evaluation (Bitarafan *et al.* 2014). Also, an extended WASPAS method with interval-valued intuitionistic fuzzy numbers was proposed by Zavadskas *et al.* (2014).

In the this study, a new integrated approach based on the CRiteria Importance Through Inter-criteria Correlation (CRITIC) and WASPAS methods is proposed for multi-criteria assessment of 3PL providers with IT2FSs. The flexibility of IT2FSs could help Decision-Makers (DMs) to define the problem in a more intelligent manner. Hence, the accuracy of assessment of alternatives in the decision-making process is increased by using the proposed approach. The CRITIC method is an efficient method for determining objective weights of criteria. This method incorporates both contrast intensity of each criterion and conflict between criteria to obtain the weights of criteria (Diakoulaki *et al.* 1995). In the proposed approach, objective weights determined by CRITIC method are combined with subjective weights expressed by DMs to obtain more realistic weights for decision-making. The concepts and arithmetic operators of IT2FSs are also utilized in the proposed approach. A computational study is performed to illustrate the process of the proposed approach for evaluation of 3PL providers. To show the stability of the results, a sensitivity analysis is carried out by varying the weights of criteria and a parameter of the proposed approach.

The outline of the rest of this paper is as follows. In Section 1, the concepts of IT2FSs and the arithmetic operations of them, the steps of the classical WASPAS method and the CRITIC method are summarized. In Section 2, a new integrated method based on the CRITIC and WASPAS methods is presented for solving multi-criteria group decision-making problems with IT2FSs. In Section 3, an example of 3PL provider selection problem is presented to illustrate the procedure of the proposed approach. In Section 4, a sensitivity analysis is performed to show the stability of the results of the proposed approach. Finally, the conclusions are discussed.

1. Basics of the Prop Method

As previously mentioned, evaluation of 3PL providers can be considered as an MCDM problem. In this evaluation process DMs usually express their assessments with uncertainty. IT2FS is an efficient tool to capture the uncertainty of information expressed by DMs. To use IT2FSs evaluation of 3PL providers, the arithmetic operations of them are needed for computations, and so some basic definitions and arithmetic operators of IT2FSs are presented in this section. Moreover, an integrated approach based on the WASPAS and CRITIC methods is used in this study for evaluation of 3PL providers under uncertainty. Usually the weights of criteria are subjectively expressed by DMs, and the information of decision matrix, which can lead to objective weights, is neglected in most cases. The CRITIC method, which is described in this section, is an efficient method that can help to obtain objective weights of criteria. Then the objective weights can be combined with subjective weights expressed by DMs to determine more realistic weights for evaluation of 3PL providers. The WASPAS method is used in this research for final evaluation of 3PL providers. The steps of the classical WASPAS method are used to extend the WASPAS–CRITIC integrated approach with IT2FSs.

1.1. Interval Type-2 Fuzzy Sets

One of the useful extensions of type-1 fuzzy sets is T2FSs. Unlike the type-1 fuzzy sets, which are defined in two dimensions, T2FSs are defined in three dimensions by two values of membership degrees. In this section, some concepts and arithmetic operations of this type of fuzzy sets are defined.

Definition 1. A two dimensional membership function is used to describe a T2FS $\tilde{\mathcal{M}}$, expressed as follows (Mendel *et al.* 2006):

$$\tilde{\tilde{\mathcal{M}}} = \int_{x \in X} \int_{u \in J_X} \frac{\mu_{\tilde{\tilde{\mathcal{M}}}}(x,u)}{(x,u)}, \quad (1)$$

where: $\mu_{\tilde{\tilde{\mathcal{M}}}}$ denote the two dimensional membership function of $\tilde{\tilde{\mathcal{M}}}$ and X represent the domain of $\tilde{\tilde{\mathcal{M}}}$. J_X, which is in the range of 0 to 1, describes the primary membership function and $\int\int$ indicates the union of all allowed values of x and u. If all values of $\mu_{\tilde{\tilde{\mathcal{M}}}}(x,u)$ are equal to 1 for a T2FS $\tilde{\tilde{\mathcal{M}}}$, then $\tilde{\tilde{\mathcal{M}}}$ is defined as an IT2FS.

Definition 2. If the Upper Membership Function (UMF) and the Lower Membership Function (LMF) of an IT2FS $\tilde{\mathcal{M}}$ are trapezoidal fuzzy sets, we can call it a trapezoidal IT2FS. Then this fuzzy set $\tilde{\mathcal{M}}$ is described as follows (Chen, Lee 2010):

$$\tilde{\tilde{\mathcal{M}}} = \left(\tilde{\mathcal{M}}^{\mathcal{F}} : \mathcal{F} \in \{U,L\}\right) = \left(m_i^{\mathcal{F}}; H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right), \quad (2)$$

where: $\tilde{\mathcal{M}}^U$ is the UMF and $\tilde{\mathcal{M}}^L$ is the LMF of $\tilde{\tilde{\mathcal{M}}}$. Moreover, $H_j\left(\tilde{\mathcal{M}}^U\right)$ and $H_j\left(\tilde{\mathcal{M}}^L\right)$, which are in the range of 0 to1, show the values of membership degree of the related elements m_{j+1}^U and m_{j+1}^L (j = 1, 2), respectively. An example of a trapezoidal IT2FS is shown in Fig. 1.

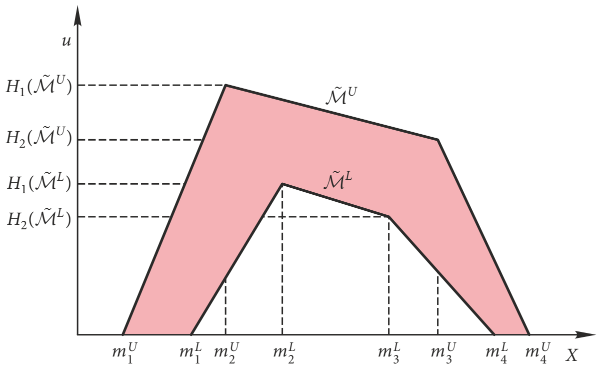

Fig. 1. A trapezoidal IT2FS

Definition 3. Suppose that $\tilde{\tilde{\mathcal{M}}}$ and $\tilde{\tilde{\mathcal{N}}}$ are two trapezoidal IT2FSs and d is a crisp number where:

$$\tilde{\tilde{\mathcal{M}}} = \left(\tilde{\mathcal{M}}^{\mathcal{F}} : \mathcal{F} \in \{U,L\}\right) = \left(m_i^{\mathcal{F}}; H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right);$$

$$\tilde{\tilde{\mathcal{N}}} = \left(\tilde{\mathcal{N}}^{\mathcal{F}} : \mathcal{F} \in \{U,L\}\right) = \left(n_i^{\mathcal{F}}; H_1\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right).$$

Then the arithmetic operations of IT2FSs are defined as follows (Keshavarz Ghorabaee *et al.* 2015, 2016):

– *Addition:*

$$\tilde{\tilde{\mathcal{M}}} \oplus \tilde{\tilde{\mathcal{N}}} = \left(m_i^{\mathcal{F}} + n_i^{\mathcal{F}};\ \min\left(H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_1\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right)\right),\ \min\left(H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right)\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right); \quad (3)$$

$$\tilde{\tilde{\mathcal{M}}} + d = \left(m_i^{\mathcal{F}} + d;\ H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right). \quad (4)$$

– *Multiplication:*

$$\tilde{\tilde{\mathcal{M}}} \otimes \tilde{\tilde{\mathcal{N}}} = \left(X_i^{\mathcal{F}};\ \min\left(H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_1\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right)\right),\ \min\left(H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right), H_2\left(\tilde{\mathcal{N}}^{\mathcal{F}}\right)\right) : i \in \{1,2,3,4\},\ \mathcal{F} \in \{U,L\}\right); \quad (5)$$

$$X_i^{\mathcal{F}} = \begin{cases} \min\left(m_i^{\mathcal{F}} n_i^{\mathcal{F}}, m_i^{\mathcal{F}} n_{5-i}^{\mathcal{F}}, m_{5-i}^{\mathcal{F}} n_i^{\mathcal{F}}, m_{5-i}^{\mathcal{F}} n_{5-i}^{\mathcal{F}}\right) & \text{if } i = 1,2; \\ \max\left(m_i^{\mathcal{F}} n_i^{\mathcal{F}}, m_i^{\mathcal{F}} n_{5-i}^{\mathcal{F}}, m_{5-i}^{\mathcal{F}} n_i^{\mathcal{F}}, m_{5-i}^{\mathcal{F}} n_{5-i}^{\mathcal{F}}\right) & \text{if } i = 3,4; \end{cases} \quad (6)$$

$$d.\tilde{\tilde{\mathcal{M}}}=\begin{cases}\left(d.m_i^{\mathcal{F}};H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right),H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right):i\in\{1,2,3,4\},\ \mathcal{F}\in\{U,L\}\right)\text{ if } d\geq 0;\\ \left(d.m_{5-i}^{\mathcal{F}};H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right),H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right):i\in\{1,2,3,4\},\ \mathcal{F}\in\{U,L\}\right)\text{ if } d\leq 0.\end{cases} \quad (7)$$

– *Exponentiation:*

$$\tilde{\tilde{\mathcal{M}}}^{\wedge p}=\left(\left(m_i^{\mathcal{F}}\right)^p;\ H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right),H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right):\ i\in\{1,2,3,4\},\ \mathcal{F}\in\{U,L\}\right). \quad (8)$$

Definition 4. The crisp score of a trapezoidal IT2FS is defined as follows (Keshavarz Ghorabaee *et al.* 2015):

$$\kappa\left(\tilde{\tilde{\mathcal{M}}}\right)=\frac{1}{2}\left(\sum_{\mathcal{F}\in\{U,L\}}\frac{a}{b}\right), \quad (9)$$

where:

$$a=m_1^{\mathcal{F}}+\left(1+H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right)\right)m_2^{\mathcal{F}}+\left(1+H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right)\right)m_3^{\mathcal{F}}+m_4^{\mathcal{F}};$$

$$b=4+H_1\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right)+H_2\left(\tilde{\mathcal{M}}^{\mathcal{F}}\right).$$

1.2. WASPAS Method

The WASPAS method is an MCDM method which integrates the Weighted Sum Model (WSM) and Weighted Product Model (WPM) for decision-making process (Zavadskas *et al.* 2012). Suppose that w_j denotes the weight of j-th criterion, and x_{ij} represents the performance value of i-th alternative according to j-th criterion ($i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$). The process of evaluating the alternatives using the WASPAS method is summarized in this section.

Step 1. Obtain linear normalization of performance values as follows:

$$\bar{x}_{ij}=\begin{cases}\dfrac{x_{ij}}{\max\limits_i x_{ij}}, \text{ if } j\in B;\\ \dfrac{\min\limits_i x_{ij}}{x_{ij}}, \text{ if } j\in N,\end{cases} \quad (10)$$

where: B and N represent the sets of beneficial and non-beneficial criteria, respectively.

Step 2. Calculate the measures of WSM $Q_i^{(1)}$ and WPM $Q_i^{(2)}$ for each alternative as follows:

$$Q_i^{(1)}=\sum_{j=1}^{m}w_j\bar{x}_{ij}; \quad (11)$$

$$Q_i^{(2)}=\prod_{j=1}^{m}\left(\bar{x}_{ij}\right)^{w_j}. \quad (12)$$

Step 3. Calculate the aggregated measure of the WASPAS method for each alternative as follows:

$$Q_i=\lambda Q_i^{(1)}+(1-\lambda)Q_i^{(2)}, \quad (13)$$

where: λ is the parameter of the WASPAS method and could be changed in the range of 0 to 1. When $\lambda = 1$, the WASPAS method is transformed to WSM, and $\lambda = 0$ leads to WPM model.

Step 4. Rank the alternatives according to decreasing values of Q_i.

1.3. CRITIC Method

In the decision-making problems, criteria can be viewed as a source of information. The importance weight of criteria could reflect the amount of information contained in each of them. This weight is referred to as 'objective weight'. The CRITIC is a method for determining the objective weights of criteria in the MCDM problems (Diakoulaki *et al.* 1995). The weights derived by this method incorporate both contrast intensity of each criterion and conflict between criteria. Contrast intensity of criteria is considered by the standard deviation and conflict between them is measured by the correlation coefficient. Suppose that x_{ij} represents the performance value of i-th alternative according to j-th criterion ($i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$), w_j denotes the weight of j-th criterion, B is the set of beneficial criteria and N is the set of non-beneficial criteria. In this section, the process of obtaining the weights of criteria based on this method is summarized.

Step 1. Calculate the transformations of performance values and obtain criteria vectors as follows:

$$x_{ij}^T=\begin{cases}\dfrac{x_{ij}-x_j^-}{x_j^*-x_j^-} \text{ if } j\in B;\\ \dfrac{x_j^- - x_{ij}}{x_j^- - x_j^*} \text{ if } j\in N;\end{cases} \quad (14)$$

$$\mathbf{x}_j=\left(x_{1j}^T,x_{2j}^T,\ldots,x_{nj}^T\right), \quad (15)$$

where: x_{ij}^T is the transformed value; $\mathbf{x}_j$ denotes the vector of j-th criterion; x_j^* and x_j^- are the ideal and anti-ideal values with respect to j-th criterion. If $j\in B$, $x_j^*=\max\limits_i x_{ij}$ and $x_j^-=\min\limits_i x_{ij}$, and if $j\in N$, $x_j^*=\min\limits_i x_{ij}$ and $x_j^-=\max\limits_i x_{ij}$.

Step 2. Calculate the standard deviation σ_j of each criterion using the corresponding vector.

Step 3. Construct a $m\times m$ square matrix R with elements r_{jk} ($R=\left[r_{jk}\right]_{m\times m}$ and $k = 1, 2, \ldots, m$). The elements of this matrix are the linear correlation coefficient between the vectors $\mathbf{x}_j$ and $\mathbf{x}_k$.

Step 4. Calculate the information measure of each criterion as follows:

$$\mathrm{H}_j=\sigma_j\sum_{k=1}^{m}\left(1-r_{jk}\right). \quad (16)$$

Step 5. Determine the criteria weights as follows:

$$w_j=\frac{H_j}{\sum_{k=1}^{m}H_k}. \quad (17)$$

2. Proposed Method

Group decision-making is an efficient way to deal with the conflictive expression of DMs about their preferences which is usually the result of different expertise, different backgrounds and different level of knowledge of them about alternatives. The preferences of DMs are commonly expressed by linguistic terms. In an uncertain environment, fuzzy sets could be used to quantify these linguistic terms. In this environment, the DMs can express their preferences by IT2FSs with more degrees of flexibility. In this research, a new approach by integrating the CRITIC and WASPAS methods is proposed to deal with multi-criteria group decision-making problem with IT2FSs. To adapt these methods to the interval type-2 fuzzy environment, some modifications are performed in the process of them. In a decision-making process, the weights of criteria are needed to be determined. There are two types of criteria weights: objective weights and subjective weights. The objective weights are computed based on decision matrix and the subjective weights are usually determined according to evaluations of DMs. Each of these types is important in decision-making processes, but considering both of them is usually neglected. Moreover, decision matrix contains two sources of information for determination of objective weights: contrast intensity of each criterion and conflict between criteria. The CRITIC method is an efficient method which involves both of these information sources in determination of objective weights. In the proposed approach, a new procedure is used for calculation of criteria weights in which the weights resulted from the CRITIC method are combined with the weights expressed by DMs. By using this procedure, we can determine aggregated weights which include information about DMs preferences (subjective weights) as well as information emitted from decision matrix (objective weights). These weights could be considered as more realistic weights for decision-making process. Fig. 2 presents the proposed approach framework for evaluation.

The concepts and operators of IT2FSs, which presented in previous sections, are used to develop an integrated approach based on the CRITIC and WASPAS methods. In this section, the integrated approach is presented to handle group decision-making problems with multiple criteria. Suppose that $\mathcal{A}_1$ to $\mathcal{A}_n$ indicate n alternatives for evaluation, $\mathcal{C}_1$ to $\mathcal{C}_m$ denote m criteria and there is a group of k DMs (from $\mathcal{D}_1$ to $\mathcal{D}_k$). The following steps describe the procedure of the CRITIC–WASPAS approach:

Step 1. According to evaluations performed by DMs, the decision matrix of each DM X_p is constructed, shown as follows:

$$X_p = \left[\tilde{\tilde{X}}_{ijp}\right]_{n\times m} = \begin{bmatrix} \tilde{\tilde{X}}_{11p} & \tilde{\tilde{X}}_{12p} & \cdots & \tilde{\tilde{X}}_{1mp} \\ \tilde{\tilde{X}}_{21p} & \tilde{\tilde{X}}_{22p} & \cdots & \tilde{\tilde{X}}_{2mp} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{X}}_{n1p} & \tilde{\tilde{X}}_{n2p} & \cdots & \tilde{\tilde{X}}_{nmp} \end{bmatrix}, \quad (18)$$

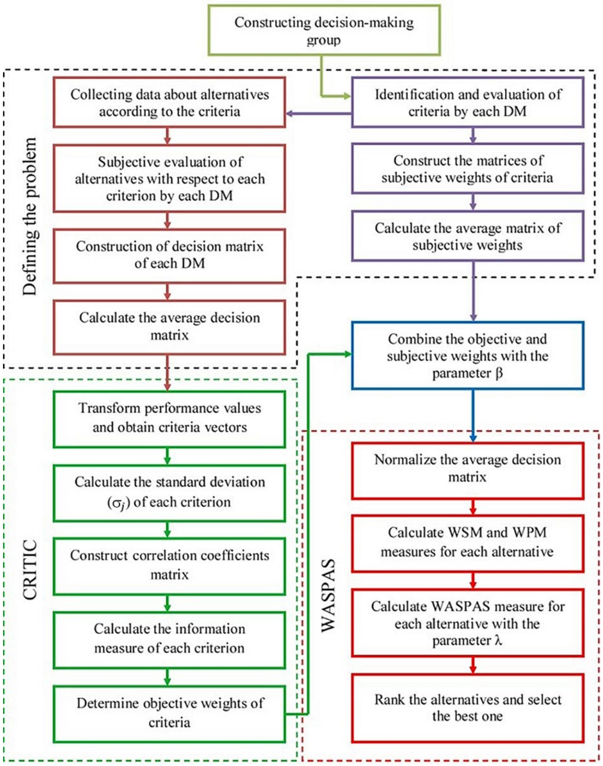

Fig. 2. The framework of the proposed approach

where: $\tilde{\tilde{X}}_{ijp}$ in the above equation shows the performance value of i-th alternative $\mathcal{A}_i$ with respect to j-th criterion $\mathcal{C}_j$ expressed by p-th DM ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$ and $p = 1, 2, \ldots, k$).

Step 2. The average decision matrix $\bar{X}$ is determined using the following equations:

$$\tilde{\tilde{X}}_{ij} = \frac{1}{k} \bigoplus_{p=1}^{k} \tilde{\tilde{X}}_{ijp}; \quad (19)$$

$$\bar{X} = \left[\tilde{\tilde{X}}_{ij}\right]_{n\times m}, \quad (20)$$

where: $\tilde{\tilde{X}}_{ij}$ symbolize the average performance value of i-th alternative $\mathcal{A}_i$ with respect to j-th criterion $\mathcal{C}_j$ ($i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$).

Step 3. Calculate an objective weight w_j^o for each criterion using the CRITIC method, described in the previous section. The transformations of performance values are calculated based on the crisp score (Definition 4) of average decision matrix elements shown as follows:

$$x_{ij}^T = \begin{cases} \dfrac{\kappa\left(\tilde{\tilde{X}}_{ij}\right) - \min_i \kappa\left(\tilde{\tilde{X}}_{ij}\right)}{\max_i \kappa\left(\tilde{\tilde{X}}_{ij}\right) - \min_i \kappa\left(\tilde{\tilde{X}}_{ij}\right)} & \text{if } j \in B; \\[2ex] \dfrac{\max_i \kappa\left(\tilde{\tilde{X}}_{ij}\right) - \kappa\left(\tilde{\tilde{X}}_{ij}\right)}{\max_i \kappa\left(\tilde{\tilde{X}}_{ij}\right) - \min_i \kappa\left(\tilde{\tilde{X}}_{ij}\right)} & \text{if } j \in N. \end{cases} \quad (21)$$

After using the procedure described in Section 1.3 and Eq. (16), the objective weights of criteria are determined as follows:

$$w_j^o = \frac{H_j}{\sum_{k=1}^{m} H_k}. \quad (22)$$

Step 4. The matrix of subjective weights W_p^s expressed by p-th DM is constructed as follows:

$$W_p^s = \left[\tilde{\tilde{w}}_{jp}^s\right]_{m\times 1} = \begin{bmatrix} \tilde{\tilde{w}}_{1p}^s \\ \tilde{\tilde{w}}_{2p}^s \\ \vdots \\ \tilde{\tilde{w}}_{mp}^s \end{bmatrix}. \quad (23)$$

In the above equation $\tilde{\tilde{w}}_{jp}^s$ denotes the subjective weight of j-th criterion $\mathcal{C}_j$ given by p-th DM (j = 1, 2, …, m and p = 1, 2, …, k).

Step 5. Calculate the average subjective weight $\tilde{\tilde{w}}_j^s$ for each criterion, shown as follows:

$$\tilde{\tilde{w}}_j^s = \frac{1}{k} \bigoplus_{p=1}^{k} \tilde{\tilde{w}}_{jp}^s. \quad (24)$$

Step 6. Combine the subjective and objective weights of each criterion and compute the aggregated weight of criteria $\tilde{\tilde{w}}_j$, shown as follows:

$$\tilde{\tilde{w}}_j = \beta \tilde{\tilde{w}}_j^s + (1-\beta) w_j^o, \quad (25)$$

where: β is the aggregating coefficient, which could be changed in the range of 0 to 1.

Step 7. Normalize the average decision matrix by the following equations:

$$\tilde{\tilde{X}}_{nij} = \begin{cases} \dfrac{\tilde{\tilde{X}}_{ij}}{\max_i \kappa\left(\tilde{\tilde{X}}_{ij}\right)} \text{ if } j \in B; \\ 1 - \dfrac{\tilde{\tilde{X}}_{ij}}{\max_i \kappa\left(\tilde{\tilde{X}}_{ij}\right)} \text{ if } j \in N, \end{cases} \quad (26)$$

where: B and N denote the sets of beneficial and non-beneficial criteria, respectively.

Step 8. Calculate WSM $\tilde{\tilde{Q}}_i^{(1)}$ and WPM $\tilde{\tilde{Q}}_i^{(2)}$ measures for each alternative, shown as follows:

$$\tilde{\tilde{Q}}_i^{(1)} = \bigoplus_{j=1}^{m} \left(\tilde{\tilde{w}}_j \otimes \tilde{\tilde{X}}_{nij}\right); \quad (27)$$

$$\tilde{\tilde{Q}}_i^{(2)} = \bigotimes_{j=1}^{m} \left(\left(1 + \tilde{\tilde{X}}_{nij}\right)^{\kappa\left(\tilde{\tilde{w}}_j\right)}\right). \quad (28)$$

Step 9. Compute the normalized values of $\tilde{\tilde{Q}}_i^{(1)}$ and $\tilde{\tilde{Q}}_i^{(2)}$ as follows:

$$\tilde{\tilde{Q}}_i^{(1s)} = \frac{\tilde{\tilde{Q}}_i^{(1)}}{\max_i \kappa\left(\tilde{\tilde{Q}}_i^{(1)}\right)}; \quad (29)$$

$$\tilde{\tilde{Q}}_i^{(2s)} = \frac{\tilde{\tilde{Q}}_i^{(2)}}{\max_i \kappa\left(\tilde{\tilde{Q}}_i^{(2)}\right)}. \quad (30)$$

Step 10. Calculate the WASPAS measure by aggregating $\tilde{\tilde{Q}}_i^{(1s)}$ and $\tilde{\tilde{Q}}_i^{(2s)}$, shown as follows:

$$\tilde{\tilde{Q}}_i = \lambda \tilde{\tilde{Q}}_i^{(1s)} \oplus (1-\lambda) \tilde{\tilde{Q}}_i^{(2s)}. \quad (31)$$

Step 11. Rank the alternatives with respect to decreasing ranking values of $\tilde{\tilde{Q}}_i$ or $\mathcal{RV}\left(\tilde{\tilde{Q}}_i\right)$. It should be noted that the method proposed by Keshavarz Ghorabaee *et al.* (2014) is used in this step for computing the ranking value of trapezoidal IT2FSs.

3. Example of 3PL Provider Evaluation

This section presents the application of the proposed integrated approach for evaluation of 3PL provider. Suppose that a home appliance manufacturer wants select a distribution agent from some 3PL providers. First, twenty potential agents were considered by the company as the candidates. However, after some initial and basic evaluations with respect to reputation of the candidates and the relative distances of them from the company, eight 3PL providers (from $\mathcal{A}_1$ to $\mathcal{A}_8$) remained for additional evaluation and selecting the best one. A group of three DMs including production manager $\mathcal{D}_1$, marketing and sales manager $\mathcal{D}_2$ and financial manager $\mathcal{D}_3$ were formed by the chief executive officer of the company from middle-level managers of the company. The decision-making group gathered some information about the alternatives and defined seven criteria (from $\mathcal{C}_1$ to $\mathcal{C}_7$) according to the previous studies (Aguezzoul 2014; Sahu *et al.* 2015) for evaluation of them. These criteria and their definitions are represented as follows:

- *Expected cost* $\mathcal{C}_1$. It is defined as the total cost which is expected for outsourcing of logistics. It may comprise some elements such as contract price, expected leasing cost, cost savings, operational cost, cost reduction, warehousing cost, etc.
- *Services* $\mathcal{C}_2$. It refers to all dimensions of services provided by a 3PL company which can include variety of available services, extent of services, providing specialized services, value-added services, pre and post-sale services to customer, etc.
- *Quality* $\mathcal{C}_3$. This criterion is defined as all aspects that are related to the quality of the 3PL providers including environmental issues, SQAS/ISO standards (ISO 9000:2015; SQAS 2012), commitment to continuous improvement, management of risks, etc.
- *Flexibility* $\mathcal{C}_4$. This criterion is related to the ability of the 3PL company to adjust its conditions to the changing requirements of customers.

It can comprise many elements such as capacity to adapt to meet future requirement, flexibility of the system, responsiveness to service requests or market, ability to deal with the particular needs of business, capability of quick response.
- *Delivery* $\mathcal{C}_5$. This is very important criterion which is related to ability of the 3PL providers to perform delivery activities well. It can include many elements such as on-time shipment and deliveries, on-time performance, accuracy of transit and delivery time, speed of delivery, rate of on-time delivery, etc.
- *Risk* $\mathcal{C}_6$. It includes loss of functional control which could damage cooperation between the user and the 3PL, complexity in operations and delivery process of the 3PL provider.
- *Financial position* $\mathcal{C}_7$. This criterion is related to the financial performance of the 3PL providers. It helps to ensure that the cooperation can be continued, and the equipment and services used in the operations of logistics can be upgraded.

The '*Expected cost*' $\mathcal{C}_1$ and '*Risk*' $\mathcal{C}_6$ are non-beneficial criteria, and the other criteria are beneficial. The linguistic terms shown in Table 1 and the data, which is collected from market research, past performance data, past complaints data, statistical data, assets evaluation data and some other resources, are used by DMs to express the significance of the criteria and the performance values of alternatives with respect to each criterion. The performance values of the eight alternatives on various criteria, and the subjective importance of the criteria are expressed by the three DMs. The procedure of using the proposed approach is presented as follows.

Step 1. The decision matrices X_1, X_2, and X_3 of the alternatives from $\mathcal{A}_1$ to $\mathcal{A}_8$ are shown in Table 2.

Step 2. The average decision matrix $\overline{X}$ is calculated based on Step 1, Table 1 and Eqs (19) and (20).

Step 3. The objective weights w_j^o of the criteria are determined based on Step 2 and Eqs (21) and (22) as follows: $w_1^o = 0.090$; $w_2^o = 0.145$; $w_3^o = 0.118$; $w_4^o = 0.119$; $w_5^o = 0.145$; $w_6^o = 0.170$ and $w_7^o = 0.213$.

Step 4. The subjective weighting matrix of each DM W_1^s, W_2^s and W_3^s are shown in Table 3.

Step 5. The average subjective weight of each criterion is calculated based on Step 4 and Eq. (24).

Step 6. Based on Step 3, Step 5 and Eq. (25), the aggregated weights of criteria (with β = 0.5) are calculated. The results of this step are shown in Table 4. According to this table and the crisp score of the criteria weights, it can be said that the financial position, risk level and services level of the 3PL provider are the three important criteria for the company.

Step 7. The normalized decision matrix is obtained according to Step 2 and Eq. (26). The results are shown in Table 5.

Step 8. The WSM and WPM measures can be calculated for each alternative based on Steps 6 and 7, and Eqs (27) and (28).

Step 9. According to Step 8, and Eqs (29) and (30), the normalized values of WSM and WPM measures are obtained.

Steps 10 and 11. Based on Step 9 and Eq. (31), the WASPAS measure (with λ = 0.5) is calculated for each alternative. The values of $\tilde{\tilde{Q}}_i$ and the corresponding ranking values are represented in Table 6. According to this table, the ranking order of alternatives is $\mathcal{A}_5 \succ \mathcal{A}_1 \succ \mathcal{A}_2 \succ \mathcal{A}_8 \succ \mathcal{A}_4 \succ \mathcal{A}_7 \succ \mathcal{A}_3 \succ \mathcal{A}_6$. Therefore, $\mathcal{A}_5$ is chosen as the best alternative.

Table 1. Linguistic terms and their corresponding IT2FSs

Linguistic terms	IT2FSs
Very low (VL)	((0,0,0,0.1;1,1),(0,0,0,0.05;0.9,0.9))
Low (L)	((0,0.1,0.15,0.3;1,1),(0.05,0.1,0.15,0.2;0.9,0.9))
Medium low(ML)	((0.1,0.3,0.35,0.5;1,1),(0.2,0.3,0.35,0.4;0.9,0.9))
Medium (M)	((0.3,0.5,0.55,0.7;1,1),(0.4,0.5,0.55,0.6;0.9,0.9))
Medium high (MH)	((0.5,0.7,0.75,0.9;1,1),(0.6,0.7,0.75,0.8;0.9,0.9))
High (H)	((0.7,0.85,0.9,1;1,1),(0.8,0.85,0.9,0.95;0.9,0.9))
Very high (VH)	((0.9,1,1,1;1,1),(0.95,1,1,1;0.9,0.9))

Table 2. Decision matrices of different DMs

DMs	Alternatives	Criteria						
		$\mathcal{C}_1$	$\mathcal{C}_2$	$\mathcal{C}_3$	$\mathcal{C}_4$	$\mathcal{C}_5$	$\mathcal{C}_6$	$\mathcal{C}_7$
$\mathcal{D}_1$	$\mathcal{A}_1$	VL	H	VH	VH	MH	L	H
	$\mathcal{A}_2$	ML	MH	M	VH	M	L	VH
	$\mathcal{A}_3$	VH	MH	ML	M	ML	M	M
	$\mathcal{A}_4$	M	VH	MH	MH	H	VH	L
	$\mathcal{A}_5$	VL	VH	H	MH	H	L	VH
	$\mathcal{A}_6$	VH	VL	L	ML	M	MH	MH
	$\mathcal{A}_7$	MH	ML	MH	VH	MH	H	M
	$\mathcal{A}_8$	M	H	VH	MH	H	MH	VL
$\mathcal{D}_2$	$\mathcal{A}_1$	L	H	VH	H	M	L	H
	$\mathcal{A}_2$	L	M	MH	VH	M	VL	H
	$\mathcal{A}_3$	H	MH	M	ML	L	M	M
	$\mathcal{A}_4$	ML	H	H	MH	MH	H	ML
	$\mathcal{A}_5$	VL	VH	H	H	VH	ML	VH
	$\mathcal{A}_6$	MH	ML	ML	L	ML	MH	H
	$\mathcal{A}_7$	M	M	MH	H	M	MH	MH
	$\mathcal{A}_8$	M	MH	H	M	MH	MH	L
$\mathcal{D}_3$	$\mathcal{A}_1$	ML	H	H	H	H	L	MH
	$\mathcal{A}_2$	M	H	MH	H	MH	VL	H
	$\mathcal{A}_3$	H	H	ML	ML	M	ML	MH
	$\mathcal{A}_4$	MH	VH	MH	M	H	MH	ML
	$\mathcal{A}_5$	VL	VH	H	H	VH	VL	VH
	$\mathcal{A}_6$	VH	L	VL	L	MH	M	M
	$\mathcal{A}_7$	MH	M	M	MH	H	M	M
	$\mathcal{A}_8$	M	MH	MH	M	MH	M	ML

Table 3. Weights of the criteria evaluated by the DMs

Criteria	DMs		
	$\mathcal{D}_1$	$\mathcal{D}_2$	$\mathcal{D}_3$
$\mathcal{C}_1$	MH	MH	M
$\mathcal{C}_2$	H	H	MH
$\mathcal{C}_3$	MH	H	MH
$\mathcal{C}_4$	M	M	ML
$\mathcal{C}_5$	M	MH	M
$\mathcal{C}_6$	VH	VH	H
$\mathcal{C}_7$	H	VH	VH

Table 4. The aggregated weights of criteria

	$\tilde{w}_j^U$						$\tilde{w}_j^L$						$\kappa\left(\tilde{\tilde{w}}_j\right)$
	w_{1j}^U	w_{2j}^U	w_{3j}^U	w_{4j}^U	$H_1\left(\tilde{w}_j^U\right)$	$H_2\left(\tilde{w}_j^U\right)$	w_{1j}^L	w_{2j}^L	w_{3j}^L	w_{4j}^L	$H_1\left(\tilde{w}_j^L\right)$	$H_2\left(\tilde{w}_j^L\right)$	
$\tilde{\tilde{w}}_1$	0.26	0.36	0.39	0.46	1	1	0.31	0.36	0.39	0.41	0.9	0.9	0.37
$\tilde{\tilde{w}}_2$	0.39	0.47	0.50	0.56	1	1	0.44	0.47	0.50	0.52	0.9	0.9	0.48
$\tilde{\tilde{w}}_3$	0.34	0.43	0.46	0.53	1	1	0.39	0.43	0.46	0.48	0.9	0.9	0.44
$\tilde{\tilde{w}}_4$	0.18	0.28	0.30	0.38	1	1	0.23	0.28	0.30	0.33	0.9	0.9	0.29
$\tilde{\tilde{w}}_5$	0.26	0.36	0.38	0.46	1	1	0.31	0.36	0.38	0.41	0.9	0.9	0.37
$\tilde{\tilde{w}}_6$	0.50	0.56	0.57	0.58	1	1	0.53	0.56	0.57	0.58	0.9	0.9	0.56
$\tilde{\tilde{w}}_7$	0.52	0.58	0.59	0.61	1	1	0.56	0.58	0.59	0.60	0.9	0.9	0.58

Table 5. The normalized decision matrix

	$\tilde{X}_{ij}^U$						$\tilde{X}_{ij}^L$					
	x_{1ij}^U	x_{2ij}^U	x_{3ij}^U	x_{4ij}^U	$H_1\left(\tilde{X}_{ij}^U\right)$	$H_2\left(\tilde{X}_{ij}^U\right)$	x_{1ij}^L	x_{2ij}^L	x_{3ij}^L	x_{4ij}^L	$H_1\left(\tilde{X}_{ij}^L\right)$	$H_2\left(\tilde{X}_{ij}^L\right)$
$\tilde{\tilde{X}}_{n11}$	0.67	0.82	0.85	0.96	1	1	0.76	0.82	0.85	0.91	0.9	0.9
$\tilde{\tilde{X}}_{n21}$	0.45	0.62	0.67	0.85	1	1	0.56	0.62	0.67	0.76	0.9	0.9
$\tilde{\tilde{X}}_{n31}$	–0.10	–0.03	0.01	0.16	1	1	–0.06	–0.03	0.01	0.07	0.9	0.9
$\tilde{\tilde{X}}_{n41}$	0.23	0.40	0.45	0.67	1	1	0.34	0.40	0.45	0.56	0.9	0.9
$\tilde{\tilde{X}}_{n51}$	0.89	1	1	1	1	1	0.95	1	1	1	0.9	0.9
$\tilde{\tilde{X}}_{n61}$	–0.06	–0.01	0.01	0.16	1	1	–0.03	–0.01	0.01	0.08	0.9	0.9
$\tilde{\tilde{X}}_{n71}$	0.08	0.25	0.30	0.52	1	1	0.19	0.25	0.30	0.41	0.9	0.9
$\tilde{\tilde{X}}_{n81}$	0.23	0.40	0.45	0.67	1	1	0.34	0.40	0.45	0.56	0.9	0.9
$\tilde{\tilde{X}}_{n12}$	0.71	0.86	0.91	1.01	1	1	0.81	0.86	0.91	0.96	0.9	0.9
$\tilde{\tilde{X}}_{n22}$	0.51	0.69	0.74	0.88	1	1	0.61	0.69	0.74	0.79	0.9	0.9
$\tilde{\tilde{X}}_{n32}$	0.57	0.76	0.81	0.95	1	1	0.68	0.76	0.81	0.86	0.9	0.9
$\tilde{\tilde{X}}_{n42}$	0.84	0.96	0.98	1.01	1	1	0.91	0.96	0.98	1	0.9	0.9
$\tilde{\tilde{X}}_{n52}$	0.91	1.01	1.01	1.01	1	1	0.96	1.01	1.01	1.01	0.9	0.9
$\tilde{\tilde{X}}_{n62}$	0.03	0.14	0.17	0.30	1	1	0.08	0.14	0.17	0.22	0.9	0.9
$\tilde{\tilde{X}}_{n72}$	0.24	0.44	0.49	0.64	1	1	0.34	0.44	0.49	0.54	0.9	0.9
$\tilde{\tilde{X}}_{n82}$	0.57	0.76	0.81	0.95	1	1	0.68	0.76	0.81	0.86	0.9	0.9
$\tilde{\tilde{X}}_{n13}$	0.88	1	1.02	1.05	1	1	0.95	1	1.02	1.04	0.9	0.9
$\tilde{\tilde{X}}_{n23}$	0.46	0.67	0.72	0.88	1	1	0.56	0.67	0.72	0.77	0.9	0.9
$\tilde{\tilde{X}}_{n33}$	0.18	0.39	0.44	0.60	1	1	0.28	0.39	0.44	0.49	0.9	0.9
$\tilde{\tilde{X}}_{n43}$	0.60	0.79	0.84	0.98	1	1	0.70	0.79	0.84	0.90	0.9	0.9
$\tilde{\tilde{X}}_{n53}$	0.74	0.90	0.95	1.05	1	1	0.84	0.90	0.95	1	0.9	0.9
$\tilde{\tilde{X}}_{n63}$	0.04	0.14	0.18	0.32	1	1	0.09	0.14	0.18	0.23	0.9	0.9
$\tilde{\tilde{X}}_{n73}$	0.46	0.67	0.72	0.88	1	1	0.56	0.67	0.72	0.77	0.9	0.9

End of Table 5

	$\tilde{X}_{ij}^{U}$						$\tilde{X}_{ij}^{L}$					
	x_{1ij}^{U}	x_{2ij}^{U}	x_{3ij}^{U}	x_{4ij}^{U}	$H_1\left(\tilde{X}_{ij}^{U}\right)$	$H_2\left(\tilde{X}_{ij}^{U}\right)$	x_{1ij}^{L}	x_{2ij}^{L}	x_{3ij}^{L}	x_{4ij}^{L}	$H_1\left(\tilde{X}_{ij}^{L}\right)$	$H_2\left(\tilde{X}_{ij}^{L}\right)$
$\tilde{\tilde{X}}_{n83}$	0.74	0.90	0.93	1.02	1	1	0.83	0.90	0.93	0.97	0.9	0.9
$\tilde{\tilde{X}}_{n14}$	0.81	0.95	0.98	1.05	1	1	0.90	0.95	0.98	1.02	0.9	0.9
$\tilde{\tilde{X}}_{n24}$	0.88	1	1.02	1.05	1	1	0.95	1	1.02	1.04	0.9	0.9
$\tilde{\tilde{X}}_{n34}$	0.18	0.39	0.44	0.60	1	1	0.28	0.39	0.44	0.49	0.9	0.9
$\tilde{\tilde{X}}_{n44}$	0.46	0.67	0.72	0.88	1	1	0.56	0.67	0.72	0.77	0.9	0.9
$\tilde{\tilde{X}}_{n54}$	0.67	0.84	0.90	1.02	1	1	0.77	0.84	0.90	0.95	0.9	0.9
$\tilde{\tilde{X}}_{n64}$	0.04	0.18	0.23	0.39	1	1	0.11	0.18	0.23	0.28	0.9	0.9
$\tilde{\tilde{X}}_{n74}$	0.74	0.90	0.93	1.02	1	1	0.83	0.90	0.93	0.97	0.9	0.9
$\tilde{\tilde{X}}_{n84}$	0.39	0.60	0.65	0.81	1	1	0.49	0.60	0.65	0.70	0.9	0.9
$\tilde{\tilde{X}}_{n15}$	0.53	0.72	0.77	0.91	1	1	0.63	0.72	0.77	0.83	0.9	0.9
$\tilde{\tilde{X}}_{n25}$	0.39	0.60	0.65	0.81	1	1	0.49	0.60	0.65	0.70	0.9	0.9
$\tilde{\tilde{X}}_{n35}$	0.14	0.32	0.37	0.53	1	1	0.23	0.32	0.37	0.42	0.9	0.9
$\tilde{\tilde{X}}_{n45}$	0.67	0.84	0.90	1.02	1	1	0.77	0.84	0.90	0.95	0.9	0.9
$\tilde{\tilde{X}}_{n55}$	0.88	1	1.02	1.05	1	1	0.95	1	1.02	1.04	0.9	0.9
$\tilde{\tilde{X}}_{n65}$	0.32	0.53	0.58	0.74	1	1	0.42	0.53	0.58	0.63	0.9	0.9
$\tilde{\tilde{X}}_{n75}$	0.53	0.72	0.77	0.91	1	1	0.63	0.72	0.77	0.83	0.9	0.9
$\tilde{\tilde{X}}_{n85}$	0.60	0.79	0.84	0.98	1	1	0.70	0.79	0.84	0.90	0.9	0.9
$\tilde{\tilde{X}}_{n16}$	0.65	0.83	0.88	1	1	1	0.77	0.83	0.88	0.94	0.9	0.9
$\tilde{\tilde{X}}_{n26}$	0.81	0.94	0.96	1	1	1	0.88	0.94	0.96	0.98	0.9	0.9
$\tilde{\tilde{X}}_{n36}$	0.26	0.44	0.50	0.73	1	1	0.38	0.44	0.50	0.61	0.9	0.9
$\tilde{\tilde{X}}_{n46}$	–0.13	-0.03	0.01	0.18	1	1	–0.07	–0.03	0.01	0.09	0.9	0.9
$\tilde{\tilde{X}}_{n56}$	0.65	0.81	0.84	0.96	1	1	0.75	0.81	0.84	0.90	0.9	0.9
$\tilde{\tilde{X}}_{n66}$	0.03	0.20	0.26	0.50	1	1	0.15	0.20	0.26	0.38	0.9	0.9
$\tilde{\tilde{X}}_{n76}$	–0.01	0.15	0.20	0.42	1	1	0.09	0.15	0.20	0.30	0.9	0.9
$\tilde{\tilde{X}}_{n86}$	0.03	0.20	0.26	0.50	1	1	0.15	0.20	0.26	0.38	0.9	0.9
$\tilde{\tilde{X}}_{n17}$	0.64	0.81	0.86	0.98	1	1	0.74	0.81	0.86	0.91	0.9	0.9
$\tilde{\tilde{X}}_{n27}$	0.78	0.91	0.95	1.01	1	1	0.86	0.91	0.95	0.98	0.9	0.9
$\tilde{\tilde{X}}_{n37}$	0.37	0.57	0.62	0.78	1	1	0.47	0.57	0.62	0.68	0.9	0.9
$\tilde{\tilde{X}}_{n47}$	0.07	0.24	0.29	0.44	1	1	0.15	0.24	0.29	0.34	0.9	0.9
$\tilde{\tilde{X}}_{n57}$	0.91	1.01	1.01	1.01	1	1	0.96	1.01	1.01	1.01	0.9	0.9
$\tilde{\tilde{X}}_{n67}$	0.51	0.69	0.74	0.88	1	1	0.61	0.69	0.74	0.79	0.9	0.9
$\tilde{\tilde{X}}_{n77}$	0.37	0.57	0.62	0.78	1	1	0.47	0.57	0.62	0.68	0.9	0.9
$\tilde{\tilde{X}}_{n87}$	0.03	0.14	0.17	0.30	1	1	0.08	0.14	0.17	0.22	0.9	0.9

Table 6. The calculated WASPAS measure $\tilde{\tilde{Q}}_i$ and the corresponding ranking values

	$\tilde{Q}_i^U$						$\tilde{Q}_i^L$						$\mathcal{RV}(\tilde{\tilde{Q}}_i)$
	q_{i1}^U	q_{i2}^U	q_{i3}^U	q_{i4}^U	$H_1(\tilde{Q}_i^U)$	$H_2(\tilde{Q}_i^U)$	q_{i1}^L	q_{i2}^L	q_{i3}^L	q_{i4}^L	$H_1(\tilde{Q}_i^L)$	$H_2(\tilde{Q}_i^L)$	
$\tilde{\tilde{Q}}_1$	0.62	0.87	0.95	1.15	1	1	0.76	0.87	0.95	1.04	0.9	0.9	0.19576
$\tilde{\tilde{Q}}_2$	0.54	0.79	0.86	1.06	1	1	0.67	0.79	0.86	0.93	0.9	0.9	0.19423
$\tilde{\tilde{Q}}_3$	0.23	0.41	0.47	0.68	1	1	0.32	0.41	0.47	0.55	0.9	0.9	0.17908
$\tilde{\tilde{Q}}_4$	0.29	0.48	0.54	0.75	1	1	0.39	0.48	0.54	0.62	0.9	0.9	0.18452
$\tilde{\tilde{Q}}_5$	0.74	0.99	1.04	1.18	1	1	0.87	0.99	1.04	1.10	0.9	0.9	0.19628
$\tilde{\tilde{Q}}_6$	0.16	0.28	0.33	0.51	1	1	0.22	0.28	0.33	0.40	0.9	0.9	0.16313
$\tilde{\tilde{Q}}_7$	0.27	0.47	0.54	0.77	1	1	0.37	0.47	0.54	0.63	0.9	0.9	0.18451
$\tilde{\tilde{Q}}_8$	0.28	0.48	0.54	0.77	1	1	0.39	0.48	0.54	0.63	0.9	0.9	0.18484

4. Sensitivity Analysis

In this section, for showing the stability of the results of the proposed approach, different sets of criteria weights are used to carry out a sensitivity analysis. According to the number of criteria, seven sets with a simple pattern are defined for this analysis. The weights of criteria in each set are shown in Table 7.

As can be seen, one criterion has the highest and one criterion has the lowest weight in each set. Using this pattern helps us to consider a wide extent of weights for all criteria in the sensitivity analysis. Three values for β parameter, (β = 0.2, 0.5, 0.8) are also considered in this analysis. The effect of moving from the subjective weights to objective weights could be seen by varying β parameter. The ranking results with different values of β in different sets of criteria weights are shown in Table 8. To compare the results, the Spearman's rank correlation coefficients r_s are utilized to test the association between the ranking obtained by the proposed approach in different states. Table 9 represents the correlation between the ranking of the alternatives in the distinct sets of weights for the criteria and different values of β parameter. According to this table, all correlation coefficients have values more than 0.9. Hence it can be said that the WASPAS–CRITIC approach has a good stability when the weights of criteria and values of β parameter are varied.

Table 7. The weights for sensitivity analysis

Sets	Criteria						
	$\mathcal{C}_1$	$\mathcal{C}_2$	$\mathcal{C}_3$	$\mathcal{C}_4$	$\mathcal{C}_5$	$\mathcal{C}_6$	$\mathcal{C}_7$
1	0.0357	0.0714	0.1071	0.1429	0.1786	0.2143	0.2500
2	0.0714	0.1071	0.1429	0.1786	0.2143	0.2500	0.0357
3	0.1071	0.1429	0.1786	0.2143	0.2500	0.0357	0.0714
4	0.1429	0.1786	0.2143	0.2500	0.0357	0.0714	0.1071
5	0.1786	0.2143	0.2500	0.0357	0.0714	0.1071	0.1429
6	0.2143	0.2500	0.0357	0.0714	0.1071	0.1429	0.1786
7	0.2500	0.0357	0.0714	0.1071	0.1429	0.1786	0.2143

Table 8. Ranking of the alternatives in the sensitivity analysis

	Alternatives	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
β = 0.2	$\mathcal{A}_1$	2	2	2	2	2	2	2
	$\mathcal{A}_2$	3	3	3	3	3	3	3
	$\mathcal{A}_3$	7	7	7	7	7	7	7
	$\mathcal{A}_4$	5	6	5	5	4	4	5
	$\mathcal{A}_5$	1	1	1	1	1	1	1
	$\mathcal{A}_6$	8	8	8	8	8	8	8
	$\mathcal{A}_7$	4	4	4	4	5	5	4
	$\mathcal{A}_8$	6	5	6	6	6	6	6
β = 0.5	$\mathcal{A}_1$	2	2	2	2	2	2	2
	$\mathcal{A}_2$	3	3	3	3	3	3	3
	$\mathcal{A}_3$	7	7	7	7	7	7	7
	$\mathcal{A}_4$	6	6	4	4	4	4	6
	$\mathcal{A}_5$	1	1	1	1	1	1	1
	$\mathcal{A}_6$	8	8	8	8	8	8	8
	$\mathcal{A}_7$	4	5	6	5	6	6	4
	$\mathcal{A}_8$	5	4	5	6	5	5	5
β = 0.8	$\mathcal{A}_1$	2	2	2	2	2	2	2
	$\mathcal{A}_2$	3	3	3	3	3	3	3
	$\mathcal{A}_3$	7	7	7	7	7	7	7
	$\mathcal{A}_4$	6	5	4	4	4	4	6
	$\mathcal{A}_5$	1	1	1	1	1	1	1
	$\mathcal{A}_6$	8	8	8	8	8	8	8
	$\mathcal{A}_7$	4	6	6	6	6	6	4
	$\mathcal{A}_8$	5	4	5	5	5	5	5

Table 9. Correlation results in the sensitivity analysis

		Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
β = 0.2	Set 1	1	0.98	1	1	0.98	0.98	1
	Set 2	0.98	1	0.98	0.98	0.93	0.93	0.98
	Set 3	1	0.98	1	1	0.98	0.98	1
	Set 4	1	0.98	1	1	0.98	0.98	1
	Set 5	0.98	0.93	0.98	0.98	1	1	0.98
	Set 6	0.98	0.93	0.98	0.98	1	1	0.98
	Set 7	1	0.98	1	1	0.98	0.98	1
β = 0.5	Set 1	1	0.98	0.90	0.93	0.90	0.90	1
	Set 2	0.98	1	0.93	0.90	0.93	0.93	0.98
	Set 3	0.90	0.93	1	0.98	1	1	0.90
	Set 4	0.93	0.90	0.98	1	0.98	0.98	0.93
	Set 5	0.90	0.93	1	0.98	1	1	0.90
	Set 6	0.90	0.93	1	0.98	1	1	0.90
	Set 7	1	0.98	0.90	0.93	0.90	0.90	1
β = 0.8	Set 1	1	0.93	0.90	0.90	0.90	0.90	1
	Set 2	0.93	1	0.98	0.98	0.98	0.98	0.93
	Set 3	0.90	0.98	1	1	1	1	0.90
	Set 4	0.90	0.98	1	1	1	1	0.90
	Set 5	0.90	0.98	1	1	1	1	0.90
	Set 6	0.90	0.98	1	1	1	1	0.90
	Set 7	1	0.93	0.90	0.90	0.90	0.90	1

Conclusions

Outsourcing of logistics is usually imply to use an external company, which is called 3PL provider or 3PL provider, that can accomplish some or all of logistics-related activities of the firm. To perform this outsourcing operation, 3PL providers should be evaluated with respect to the firm's criteria. The process of evaluation of 3PL providers could be defined as a MCDM problem.

In this research, a new integrated approach based on the CRITIC and WASPAS methods has been proposed for multi-criteria evaluation of 3PL providers with IT2FSs. The CRITIC method has been used to determine objective weights for criteria, and this objective weight has been combined with the subjective weights expressed by DMs. By using the proposed integrated approach, more realistic weights for criteria can be obtained because the aggregated weights, which have been used in the evaluation process include both the subjective information of DMs and objective information of decision matrix.

The proposed approach has been applied to a numerical example of 3PL provider evaluation with eight alternatives and seven criteria. The aggregated weights of the criteria indicate that financial position, risk level and services level of the 3PL provider have more importance for the company than the other criteria.

However, a sensitivity analysis, which has been made with different sets of criteria weight and different values of the parameter of weight combination shows that the proposed method gives stable ranking results for 3PL providers. This fact has been demonstrated by comparing the results using the Spearman's rank correlation coefficients. Therefore, it can be concluded that the proposed CRITIC–WASPAS approach is efficient for MCDM.

Future research can compare the proposed approach with other approaches and apply it to other problems such as project selection, personnel selection, supplier selection, material selection and location selection.

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