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A Hybrid MCDM Approach in Third-Party Logistics (3PL) Provider Selection

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Abstract: Third-party logistics (3PL) is becoming more and more popular because of globalization, e-commerce development, and increasing customer demand. More and more companies are trying to move away from their own account transportation to third-party accounts. One reason for using 3PLs is that the company can focus more on its core activities, while the 3PL service provider can provide distribution activities in a more professional way, save costs and time, and increase the level of customer satisfaction. An emerging issue for companies in the logistics industry is how they can decide on the 3PL evaluation and selection process for outsourcing activities. For the first time, the entropy and the criteria importance through intercriteria correlation (CRITIC) methods were coupled in order to obtain hybrid criteria weights that are of huge importance to decide on the 3PL provider evaluation and selection process. The obtained criteria weights were further utilized within the additive ratio assessment (ARAS) method to rank the alternatives from the best to the worst. The introduced hybrid–ARAS approach can be highly beneficial, since combining two methods gives more robust solutions on one hand, while on the other hand eliminating subjectivity. Comparative and sensitivity analyses showed the high reliability of the proposed hybrid–ARAS method. A hypothetical case study is presented to illustrate the potentials and applicability of the hybrid–ARAS method. The results showed that 3PL-2 was the best possible solution for our case.

Keywords: 3PL logistics; decision making; ARAS; entropy; CRITIC

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1. Introduction

Third-party logistics (3PL) selection is becoming more and more popular because of globalization, e-commerce development, and increasing customer demand. Today's society, through the needs of different entities, represents a source of numerous new requirements and expectations for companies in the postal and logistics industries [1]. Systems for the distribution of goods, both at the national and international levels, are very important for appropriate business functioning and for the normal life of citizens [2]. Because of e-commerce development, there is increasing pressure on 3PL service providers all over the world. Wang et al. [3] emphasized that more trustworthy delivery, high inventory turnover, and inventory staged in forwarding locations near consumers are all effects of the e-commerce trend. According to Wang [4], e-commerce was sped up by the COVID-19 outbreak. According to Wang et al. [5], today's business globalization, customer satisfaction, and strong competition have forced many companies to work closely with external business partners. Third-party logistics service providers have had a significant impact on society on a global scale. They are not responsible not only for moving goods from the point of origin to the point of the destination, but in some cases for packaging, storage, etc. Third-party logistics services depend on the contracts they sign with collaborating companies.

Based on the aforementioned facts, the selection and evaluation process of 3PL service providers, is not an easy task for logisticians, since multiple factors affect the decision-making process. A poor choice of business partner can greatly negatively affect a company. The resulting losses can be financial, material, loss of reputation, loss of users, and many others. Furthermore, Soh [6] stated that if an appropriate 3PL provider was not selected, serious problems could occur, such as low-quality logistics services and contract nonfulfillment. He also emphasized that the decision-making problem for selecting the best 3PL provider had been receiving much attention recently among scholars as well as business practitioners. Nevertheless, Hsu et al. [7] stated that engaging 3PL could reduce fixed costs and increase flexibility, allowing organizations to focus on their core competencies and thereby enhancing their efficiency. Since 3PL evaluation and selection is a multidisciplinary field, there are many research questions that have been addressed by various authors in the field.

In this article, two research questions were dealt with: research question 1 (RQ1) refers to the combination of objective methods that allow the evaluation criteria for the 3PL provider selection process to obtain the best possible result; research question 2 (RQ2) is directed to the 3PL provider selection process.

To answer the aforementioned research questions, knowledge from various multidisciplinary fields was applied. Given the fact that no complete numerical data were available to create a real-life case study, given the time constraints of this research, some hypothetical data were used. The 3PL evaluation and selection process, in this paper, starts with a discussion with the experts in the field of logistics. The experts, according to their knowledge and experience, helped the authors define some of the criteria that should be of vital importance for companies that deal with the decision-making process. The number of alternatives (possible 3PL providers) depends on the company, but in this hypothetical case, there were five possible alternatives. Not all criteria were equally important, so it was necessary to assign them degrees of importance. For this part of the paper, the entropy and the CRITIC methods were coupled, and the new hybrid criteria importance is obtained. To obtain the final rank of the alternatives considered, the ARAS MCDM method is used.

The main contribution of this article lies in the proposed entropy–CRITIC (hybrid)–ARAS methodology, which, according to the authors' knowledge and the reviewed literature in the field, has not previously applied to this problem. The proposed methodology is general and can be applied to any other MCDM problem dealing with the selection of collaboration partners as well as any interrelated criteria. In addition, this paper contributes a combination of two objective methods to obtain hybrid criteria weights, since combining two methods gives more robust solutions on one hand while eliminating subjectivity on the other hand.

In this article, the methodology was applied only to a hypothetical example, which should be emphasized as a limitation. However, the authors intend to test the methodology for the real-life case study. Another weak point of the paper is that the considered criteria for 3PL selection were mostly part of the economic pillar. Nevertheless, future directions include addressing the other aspects such as environmental, social, and technical ones.

Since there is an increasing number of logistics companies that provide various logistics services as third parties, it is not easy to evaluate and select the best collaborative partner. The authors of this paper had the main motivation to propose methodology that on the one hand should be easy to implement and on the other hand should help decision makers select the best 3PL. The methodology upgraded the ARAS method by combining objective methods in order to eliminate subjectivity in the assessment of criterion weights and obtain more robust solutions using the ARAS method.

This paper is organized as follows: After the introductory section, Section 2 provides the current state of the methods used in the 3PL logistics field. The methodology proposed to solve the 3PL evaluation and selection problem is elaborated in Section 3. The application of the hybrid MCDM method to a hypothetical example is elaborated in Section 4. Section 5 gives some managerial insights into the 3PL logistics field. Section 6 is the conclusion and gives some future research directions.

2. Literature Review

As pointed out above, 3PL service provider evaluation and selection are not easy tasks for decision makers, given the fact that multiple criteria and many existing methods ought to be taken into consideration. Researchers have created many methods to solve the 3PL evaluation and selection problem. Most of these methods have belonged to the class of multicriteria decision-making methods. In addition to multicriteria analysis methods, many other methods, such as statistical or mathematical programming methods and integrated approaches, have been used. This section provides a review of the literature in the field of 3PL service providers based on the methods that other authors used to solve the 3PL evaluation and selection problem. Jovčić et al. [8] provided an extensive review of the literature regarding the most commonly used methods for 3PL provider evaluation and selection.

One of the most often used multicriteria analysis methods is the analytic hierarchy process (AHP). Saaty [9] originally developed this method. After its introduction, the AHP was widely used in many fields to solve multicriteria decision-making problems; one of those fields was logistics. Korpela and Touminen [10] applied the AHP to find the best possible solution of 3PL warehousing in the processing industry. Yahya and Kingsman [11] used the AHP to determine priorities in selecting suppliers. Akarte et al. [12] proposed a web-based AHP system to evaluate casting suppliers. Muralidharan et al. [13] developed a five-step AHP method to rank suppliers. Liu and Hai [14] applied the AHP to evaluate and select suppliers. So et al. [15] used the AHP to assess the quality of service of suppliers in Korea, while Göl and Çatay [16] applied the AHP to select the best 3PL service provider in a Turkish automotive company. Chan et al. [17] considered the supplier selection issue in the airline industry by using the AHP. Hou and Su [18] assessed and selected suppliers in the mass-customization environment by utilizing the AHP. Gomez et al. [19] proposed a model to evaluate the performance of suppliers by using the AHP. Hudymáčová [20] applied the AHP in supplier selection. Asamoah [21] applied the AHP in a pharmaceutical manufacturing company in Ghana. Hruška et al. [22] solved a 3PL selection problem by AHP in the production company in the Czech Republic. Jayant and Singh [23] applied an AHP–VIKOR hybrid MCDM approach for 3PL selection. Tuljak-Suban and Bajec [24] upgraded the AHP with the graph theory and matrix approach (GTMA). Aguezzoul and Pache [25] combined the AHP with the ELECTRE I methodology to solve the 3PL selection problem.

The analytic network process (ANP) is also a frequently used method for 3PL evaluation and selection problems. Meade and Sarkis [26] proposed a conceptual model to evaluate and select a third-party reverse logistics provider (3PRLP). Sarkis and Talluri [27] applied the ANP to evaluate and select the best supplier, considering seven evaluating criteria. Bayazit [28] applied the ANP to tackle the supplier selection problem. Jkharkharia and Shankar [29] applied the ANP to select the best logistics service provider. Further research regarding 3PRLP evaluation and selection was proposed by Zareinejad and Javanmard [30]. They applied ANP, intuitionistic fuzzy sets (IFS), and grey relation analysis (GRA). In their study, the ANP was used to identify the most important attributes in the selection and evaluation of 3PRLP. The technique for order of preference by similarity to ideal solution (TOPSIS) is one of the most frequently applied approaches in 3PL. Mostly, this method is coupled with fuzzy logic, ANP, AHP, etc. There have been many studies in the literature that may confirm it. Chen and Yang [31] proposed restricted fuzzy-AHP and fuzzy-TOPSIS to assess and choose the best supplier. Zeydan et al. [32] used a combination of fuzzy-AHP, fuzzy-TOPSIS, and DEA methods in the automotive industry to evaluate and select suppliers. Singh et al. [33] applied the TOPSIS method for supplier selection in the automotive industry as well. Jayant et al. [34] evaluated and selected reverse third-party logistics service providers (R3PLs) in the mobile phone industry by coupling the AHP (to evaluate the criteria for R3PLs) and TOPSIS (to select the best one). Laptate [35] used fuzzy modified TOPSIS for supplier selection problems in the supply chain. ELECTRE (ELimination Et Choice Translating REality) is a family of multicriteria decision analysis methods. Aguezzoul and Pires [36] used the ELECTRE method for 3PL performance evaluation and selection in a complex strategic decision process that involved various qualitative and quantitative criteria. Before that, Govindan et al. [37] used the fuzzy-ELECTRE method to rank 3PRL providers. The method was applied to a battery recycling case. When it comes to the combination of fuzzy logic with the multicriteria decision-making methods, there have been many studies in the scientific literature. According to Cheng [38] and Cheng et al. [39], a fuzzy-AHP approach handles issues that use the theory of fuzzy sets as well as hierarchical structure analysis. On the other hand, Ayhan [40] declared that the fuzzy-AHP approach was an extended AHP model into a fuzzy domain. This method has found application in various fields. For example, Kilincci and Onal [41] applied fuzzy-AHP to select suppliers for a washing machine company. When it comes to a low carbon supply chain, Shaw et al. [42] coupled the fuzzy-objective linear programming (LP) with the fuzzy-AHP in order to choose an optimal supplier solution. First, to determine the weights of the predetermined criteria, the Fuzzy-AHP was used. Second, the best supplier was determined by using fuzzy-objective LP. Zhang et al. [43], Zhang and Feng [44], Göl and Catay [16], and Soh [6] combined the AHP and fuzzy approaches to solve a 3PL service provider assessment issue. To compute the importance of individual parameters and subcriteria in fourth-party logistics (4PL), Cheng et al. [45] utilized the fuzzy-AHP approach. Arikan [46] dealt with the fuzzy-AHP method for multiple-objective supplier selection problems. Jagannath et al. [47] evaluated and selected 3PL providers from a sustainability perspective using the interval-valued fuzzy-rough approach. Rezaeisaray et al. [48] conducted a study on a pipe and fittings manufacturing company using a novel hybrid MCDM model for outsourcing supplier selection. They concluded that among the selective criteria for outsourcing, business development, focus on basic activities, and order delays were the three most important ones. They also ranked suppliers to facilitate decision making for selection. Sremac et al. [49] assessed logistics providers by combining the rough stepwise weight assessment ratio analysis and rough weighted aggregated sum product assessment approaches. Zarbakhshnia et al. [50] proposed a multiple attribute decision-making (MADM) model to rank and select 3PRLPs, using fuzzy stepwise weight assessment ratio analysis (SWARA) to weight the evaluation criteria. To rank and select sustainable 3PRLPs, the COPRAS (complex proportional assessment of alternatives) method was used. Özcan and Ahıskalı [51] solved the 3PL service provider selection problem by combining multicriteria decision-making methods with linear programming models. Some statistical methods that deal with the 3PL supplier selection problem can be found in the literature. For example, the correlation method was used by various authors [52–54]. Lai [55] conducted cluster analysis, which analyzed the service capability and performance of logistics service providers. Sinkovics and Roath [56] used descriptive statistics in 3PL relationships, considering six parameters: customer orientation, competitor orientation, operational flexibility, collaboration, logistics performance, and market performance. Knemeyer and Murphy [57] evaluated the performance of 3PL arrangements from a marketing perspective. Regarding mathematical programming methods (linear and nonlinear programming, dual and multiobjective programming, data envelopment analysis (DEA)), various research papers in the field of logistics service providers can be found. For example, Falsini et al. [58] carried out a study regarding logistic service provider evaluation and selection based on an integration of AHP, DEA, and linear programming methods. Zhou et al. [59] used the DEA method to evaluate the efficiency of Chinese 3PL. Hamdan and Rogers [60] evaluated the efficiency of 3PL operations using the DEA method. Kumar et al. [61] solved a multiobjective 3PL allocation problem for fish distribution. Tsai et al. [62] applied the new fuzzy DEA model to solving MCDM problems in supplier selection. Liu et al. [63] compared suppliers from a collaboration perspective for the new energy vehicle manufacturers in China. Hoseini et al. [3] used the combination of the fuzzy-best-worst method and the fuzzy inference system to solve the supplier selection issue in the construction industry. Kurniawan and Puspitasari [64] evaluated the criteria for supplier selection by applying fuzzy logic and the best-worst method. Whang et al. [65]

used the fuzzy-AHP and fuzzy-VIKOR Methods in sustainable supply chain third-party logistics. For better transparency, the aforementioned literature review on the methods for 3PL evaluation and selection is summarized in Table 1.

Table 1. Review based on the methods for 3PL evaluation and selection.

Author	Method
Korpela and Touminen [10]; Yahya and Kingsman [11]; Akarte et al. [12]; Liu and Hai [14]; So et al. [15]; Göl and Çatay [16]; Chan et al. [17]; Hou and Su [18]; Gomez et al. [19]; Hudymáčová [20]; Asamoah [21]; Hruška et al. [22]	AHP
Sarkis and Talluri [27]; Meade and Sarkis [26]; Bayazit [28]; Jkharkharia and Shankar [29]; Zareinejad and Javanmard [30]	ANP
Kumar et al. [61]; Zhou et al. [59]; Hamdan and Rogers [60]	DEA
Govindan et al. [37]	fuzzy-ELECTRE method
Chen and Yang [31]	fuzzy-AHP and fuzzy-TOPSIS (integrated approach)
Zeydan et al. [32]	fuzzy-AHP, fuzzy-TOPSIS, and DEA
Singh et al. [33]	TOPSIS
Falsini et al. [58]	AHP, DEA, and linear programming
Arikan [46]	fuzzy-AHP
Jayant et al. [34]	AHP–TOPSIS
Jayant and Singh [23]	AHP–VIKOR
Laptate [35]	fuzzy-modified TOPSIS
Rezaeisaray et al. [48]	DEMATEL, FANP, and DEA
Aguezzoul and Pires [36]	ELECTRE
Cheng [39]; Cheng et al. [42]; Zhang et al. [43]; Zhang and Feng [44]; Göl and Catay [16]; Cheng et al. [45]; Soh [6]; Kilincci and Onal [41]; Shaw et al. [42]; Ayhan [40]; Arikan [46]	fuzzy-AHP and fuzzy-objective linear programming (integrated approach)
Lai et al. [52]; Sinkovics and Roath [56]; Knemeyer and Murphy [57]; Sheen and Tai [53]; Yeung [54]; Lai [55]	Statistical methods
Sremac et al. [49]	rough SWARA, rough WASPAS, rough SAW, rough EDAS, rough MABAC, rough TOPSIS
Zarbakhshnia et al. [50]	SWARA, COPRAS
Jagannath et al. [47]	interval-valued fuzzy rough approach
Tuljak-Suban and Bajec [24]	AHP method with the Graph Theory and Matrix Approach (GTMA)
Aguezzoul and Pache [25]	AHP–ELECTRE I
Özcan and Ahıskalı [51]	MCDM–linear programming
Hoseini et al. [64]	fuzzy-best-Worst method and FIS
Whang et al. [3]	fuzzy-AHP and fuzzy-VIKOR
Kurniawan and Puspitasari [65]	fuzzy-best-worst method
Our study	Hybrid-ARAS method

Based on an extensive review of the literature in the field of third-party logistics, the most often used methods were multicriteria decision-making methods in combination with fuzzy logic. At present, in order to support the 3PL evaluation and selection process, there are many new multicriteria methods, such as SWARA, EDAS, MACBAC, and WASPAS, that are based on group decision making in a fuzzy environment. The main advantage of the methods mentioned above is the fact that when coupled with fuzzy logic, they have the power to help decision makers decide in an uncertain environment. In other words, the methods can help decision makers decide when the input data are not defined as crisp values but are given descriptively through linguistic statements. In this study, a hybrid MCDM approach is proposed to evaluate and rank the best 3PL service provider when crisp input data are given. Future research based on this paper should address the hybrid

MCDM approach in regard to the fuzzy domain as well. No previous research has been conducted that applies the hybrid–ARAS method in the way that is proposed here. One of the advantages of the method we propose is that it combines two objective methods to obtain more robust solutions and at the same time eliminate subjectivity.

3. Methodology

This paper combined three possible methods to solve a hypothetical example of the 3PL selection problem. The data for 3PL providers is usually, as a rule, privately owned. Moreover, some data are not freely available to the general public or the scientific community, probably because of corporate policy to protect proprietary information. Furthermore, the COVID-19 crisis additionally hampered obtaining data. However, the input data for 3PL service providers were formulated based on interviews with experts. The methodology proposed is presented in Figure 1. The first phase was problem formulation. In this case, the 3PL service provider selection problem was considered. From the extensive literature review as well as the Experts' opinions, the authors of this paper identified the criteria for 3PL provider selection. The criteria that were taken into consideration were mostly part of the economic pillar. The CRITIC (criteria importance through intercriteria correlation) and entropy methods were used to find the criteria importance for the 3PL service provider selection. By combining those two methods, the hybrid criteria weights were determined. The main reason for coupling the CRITIC and entropy methods was that both are used to obtain objective criteria weights, and when they are coupled together, a more robust solution is obtained (the subjectivity is eliminated). To find the final rank of the best possible 3PL provider, the criteria importance obtained by the hybrid method were further used within the ARAS method. The ARAS method is a relatively new MCDM method used to rank alternatives. and, according to the authors' knowledge and the literature review, it has not been previously applied and coupled with the hybrid criteria weights as it was here.

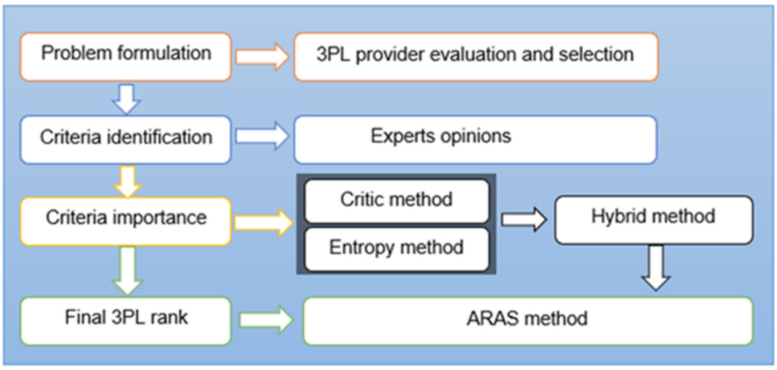

Figure 1. A flowchart of the methodology used for 3PL service provider evaluation and selection (Source: Authors).

In the second part of the paper, the hybrid criteria importance was integrated into the ARAS method to obtain the best 3PL solution.

3.1. CRITIC (Criteria Importance through Intercriteria Correlation) Method

In a decision-making process, the importance of criteria plays an important role, since not all criteria are equally important [66]. In this article, we applied the CRITIC method, since it is very useful in obtaining objective criteria importance. The CRITIC method was originally developed by Diakoulaki et al. [67]. The criteria importance calculated by the CRITIC method considers both conflicts among criteria and contrast intensity of each criterion [66]. Ghorabaee et al. [68] declared that in this method, the correlation coefficient is used to observe the conflict between criteria, while the standard deviation is used to consider the contrast intensity of each criterion. According to Diakoulaki et al. [67], the CRITIC method should be described as follows:

Step 1 computes the transformations of performance values (x_{ij}) and obtains criteria vectors. It is calculated by following Equation (1):

$$x_{ij}{}^{T} = \begin{cases} \frac{x_{ij} - x_j^-}{x_j^* - x_j^-} \; if\ j \in B; \\ \frac{x_j^- - x_{ij}}{x_j^- - x_j^*} \; if\ j \in N; \end{cases} \tag{1}$$

where $x_{ij}{}^{T}$ explains the transformed value, x_j represents the vector of jth criterion, and x_j^* and x_j^- represent the ideal and anti-ideal values with respect to jth criterion. If $j \in B$ then $x_j^* = max_i x_{ij}$ and $x_j^- = min_i x_{ij}$. If $j \in N$ then $x_j^* = min_i x_{ij}$ and $x_j^- = max_i x_{ij}$.

Step 2 calculates the standard deviation 6_j of each criterion utilizing the corresponding vector.

Step 3 defines a square ($m \times m$) matrix R with r_{jk} elements, where $k = 1, 2, \ldots, m$:

$$R = \left[r_{jk} \right]_{m \times m} \tag{2}$$

The elements of this matrix are the linear correlation coefficients between the x_j and x_k vectors.

Step 4 computes the information measure of each criterion by using Equation (3):

$$H_j = 6_j \sum_{k=1}^{m} (1 - r_{jk}) \tag{3}$$

Step 5 calculates the criteria importance by utilizing Equation (4):

$$W_j = \frac{H_j}{\sum_{k=1}^{m} H_k} \tag{4}$$

3.2. Entropy Method

According to Zhang [69], the entropy weight method was originally a concept of thermodynamics, which was first added into the information theory by C.E. Shannon and is now applied widely in the fields of engineering technology, social economy, etc. When it comes to multicriteria, Ranđelović et al. [70] emphasized that entropy was mainly used to determine the priority of an alternative. According to Ranđelović et al. [70] the method of entropy is described as follows: let us assume that $c_j = (a_{1j}, a_{2j}, \ldots a_{mj})$ describes a priority vector according to an exact criterion $j,\ j = 1, \ldots, n$. The entropy value for this vector can be calculated by applying Equation (5):

$$H_{Wj} = -\sum_{i=1}^{m} a_{ij} \ln (a_{ij}),\ j = 1, \ldots n \tag{5}$$

In addition, Ranđelović et al. [70] emphasized that in the theory of information, the entropy value H_{Wj} could be defined as a unit of discrete random variable X uncertainty, which could have a value from the fixed set $(x_1, x_2, \ldots x_n)$ in such a way that the feasibility that X is equal to x_j is given by w_j and may be presented by Equation (6):

$$P(X = x_j) = w_j \tag{6}$$

3.3. Hybrid Criteria Weights

To obtain the hybrid criteria weights, the authors of this paper combined the criteria weights obtained by the entropy and CRITIC methods. The combination of those two methods is demonstrated in the following equation:

$$Hybrid\ Weight\ (n^*) = 0.5 \cdot Entropy\ Weight\ (n^*) + 0.5 \cdot CRITIC\ Weight\ (n^*) \tag{7}$$

where (n^*) represents the hybrid weight of the nth criterion.

The hybrid criteria weights were chosen to test how those weights may affect the ranking of the final alternatives, as well as to notice whether there was any difference if the entropy and CRITIC methods were coupled with the ARAS method separately. In addition, the combination of two objective methods gave more robust and stable results.

3.4. The Additive Ratio Assessment (ARAS) Method

The additive ratio assessment (ARAS) method is an MCDM method originally developed by Zavadskas and Turskis [71]. Bošković et al. [66] declared that the ARAS method was very efficient and easy to implement in situations where multiple criteria are considered. There are several steps of the ARAS method described by Zavadskas and Turskis [71]:

Step 1 formulates an initial decision-making matrix which consists of m alternatives (rows) compared on n criteria (columns). The initial decision-making matrix is presented below:

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; i = \overline{0,\ m},\ j = \overline{1, n} \tag{8}$$

where m represents a number of alternatives, n represents a number of criteria describing each alternative, x_{ij} describes the performance value of the ith alternative in terms of the jth criterion, and x_{0j} shows an optimal value of jth criterion.

If the optimal value of jth criterion is unknown, then:

$$\begin{array}{l} x_{0j} = max_i x_{ij},\ \text{if } max_i x_{ij} \text{ is preferable;} \\ x_{0j} = min_i x^*_{ij},\ \text{if } min_i x^*_{ij} \text{ is preferable.} \end{array} \tag{9}$$

Usually, the performance values x_{ij} and the criteria weights W_j are considered as the entries of a DMM. The system of criteria and the values and initial weights of criteria were determined by experts. The information can be corrected by the interested parties by considering their goals and opportunities.

Step 2 is the normalization of the input data of the initial decision-making matrix from the step 1. The normalization means that all the input data should be between an interval from 0 to 1. The normalized values $\overline{x_{ij}}$ in the normalized decision-making matrix $\overline{X}$ are obtained by applying Equations (11) and (12):

$$\overline{X} = \begin{bmatrix} \overline{x}_{01} & \cdots & \overline{x}_{0j} & \cdots & \overline{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x}_{i1} & \cdots & \overline{x}_{ij} & \cdots & \overline{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x}_{m1} & \cdots & \overline{x}_{mj} & \cdots & \overline{x}_{mn} \end{bmatrix}; i = \overline{0,\ m},\ j = \overline{1, n}; \tag{10}$$

For the criteria with the highest preferable merits, the normalization is computed by utilizing Equation (11):

$$\overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}; \tag{11}$$

For the criteria with the lowest preferable merits, the normalization is obtained by Equation (12):

$$x_{ij} = \frac{1}{x^*_{ij}}; \overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}; \tag{12}$$

Step 3 involves defining a normalized-weighted matrix $\hat{X}$. It is possible to evaluate criteria with weights $0 < W_j < 1$. Only well-founded weights should be used, because weights are always subjective and influence the solution. The values of weight W_j are usually determined by the expert evaluation method. The sum of the weights W_j is limited as follows:

$$\sum_{j=1}^{n} w_j = 1; \tag{13}$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; i = \overline{0,\ m},\ j = \overline{1, n} \tag{14}$$

Normalized-weighted values of all the criteria are calculated as follows:

$$\hat{x}_{ij} = \overline{x}_{ij} \cdot W_j; i = \overline{0,\ m}; \tag{15}$$

where W_j is the weight (importance) of the jth criterion and $\overline{x}_{ij}$ is the normalized rating of the jth criterion.

Step 4 determines the value of optimality function:

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij};\ i = \overline{0,\ m}; \tag{16}$$

where the optimality function of ith alternative is marked with S_i.

The maximum value of S_i reflects the best option, while on the contrary, the minimum value reflects the worst option. In other words, the greater the value of the optimality function S_i, the more effective the alternative. The preferences of alternatives can be observed according to the value S_i.

Step 5 computes the level of the alternative utility. To do so, it is necessary to make a comparison of the solutions with is ideal solution (S_0). The calculation of the utility level K_i of an alternative a_i is calculated by Equation (17):

$$K_i = \frac{S_i}{S_0}; i = \overline{0,\ m}; \tag{17}$$

where S_i and S_0 are the optimality criterion values. The calculated values K_i are between 0 and 1.

4. Application of the Hybrid–ARAS Method to 3PL Evaluation and Selection

The previously described methodology was applied to a hypothetical example, and the results are described in this section. The main reason for the hypothetical example was, as aforementioned, because it was hard to obtain real data for 3PL selection given the time constraints of this research, etc. However, three experts helped the authors define the criteria that influence the decision-making process and agreed on their ranking by the entropy and *CRITIC* methods. In this case, the authors selected five 3PL providers as the possible alternatives. According to the experts' opinions, five criteria that should be taken into consideration when evaluating and selecting 3PL providers were selected. These criteria were price (C_1), delivery service (C_2), quality of service (QoS) from customer experience (C_3), territorial coverage of the EU (C_4), and flexibility (C_5). The selected criteria are completely expressed in the following table (Table 2). It is important to point out that the considered criteria were mostly included in the economic aspect. When it comes to the consulted experts' knowledge and expertise, expert 1 held a managerial position in a tire manufacturing company with four years of experience and had a Ph.D. in the field of logistics; expert 2 held a managerial position in a multinational beverage company with five years of experience and had a Master's degree; and Expert 3 was a manager of a cold chain company with more than eight years of experience and a Ph.D. in the field of logistics and supply chains. Because of the COVID-19 outbreak, the authors interviewed the experts by telephone. The experts gave some limited information about themselves but required complete anonymity because of the business policies of their firms. The hypothetical input data used in the ARAS decision-making matrix were formulated in collaboration with the experts as well; the experts agreed that the data should respond to real conditions in the 3PL logistics market.

Table 2. Criteria for 3PL evaluation and selection (Source: Authors).

Price (C_1)	This criterion is expressed as the price that a company pays to the 3PL provider for its service provided. It is expressed in eurocent per km. Different 3PL providers request different prices for their services.
Delivery service (C_2)	This criterion is expressed as the percentage of goods delivered in a promised timeframe.
QoS from customer experience (C_3)	This criterion is expressed on a scale from 1 to 10, where 10 expresses maximal quality from the customer perspective.
Territorial coverage of the EU (C_4)	This criterion is expressed as the percentage of EU territory covered by the 3PL provider.
Flexibility (C_5)	This criterion represents the readiness of the 3PL provider to accommodate changing customer demands and expectations. It is expressed on a scale from 1 to 10, where 10 denotes the maximal degree of flexibility.

After the description of the criteria, the entropy and CRITIC methods were used in order to obtain the criteria weights. First, the weights were obtained by each separate method. Second, hybrid weights were obtained by combining the results of the two methods by applying Equation (7). The entropy method was applied to find criteria importance. After applying the entropy method, the following criteria weights were obtained (Tables 3–5).

Table 3. Initial entropy decision-making matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
3PL-1	0.95	99.98	9	88	9
3PL-2	0.92	99.95	10	92	10
3PL-3	0.99	99.90	10	75	9
3PL-4	0.90	98.98	8	85	8
3PL-5	1.20	99.97	8	95	10
Sum	4.96	498.78	45	435	46

Table 4. Normalization of the entropy decision-making matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
3PL-1	0.1915	0.2004	0.2000	0.2023	0.1957
3PL-2	0.1855	0.2004	0.2222	0.2115	0.2174
3PL-3	0.1996	0.2003	0.2222	0.1724	0.1957
3PL-4	0.1815	0.1984	0.1778	0.1954	0.1739
3PL-5	0.2419	0.2004	0.1778	0.2184	0.2174

Table 5. Computed entropy value (h) and final weights (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)	h = 1/ln(m)
3PL-1	−0.3165	−0.3222	−0.3219	−0.3233	−0.3192	−0.62133
3PL-2	−0.3125	−0.3221	−0.3342	−0.3286	−0.3318	
3PL-3	−0.3216	−0.3221	−0.3342	−0.3031	−0.3192	
3PL-4	−0.3097	−0.3209	−0.3071	−0.3190	−0.3042	
3PL-5	−0.3433	−0.3221	−0.3071	−0.3323	−0.3318	
Sum	−1.6037	−1.6094	−1.6045	−1.6062	−1.6061	
e_j	0.9964	1.0000	0.9969	0.9980	0.9979	Sum = 0.0107
$d_j = 1 - e_j$	0.0036	0.0000	0.0031	0.0020	0.0021	$d_j = 1 - e_j$
Weights	0.3323	0.0004	0.2871	0.1861	0.1941	1

According to the entropy method, the highest importance was assigned to price and QoS, while lesser importance was assigned to territorial coverage of the EU, delivery service, and flexibility. By applying the previously described CRITIC method, the following criteria weights were calculated (Tables 6–9).

Table 6. Initial CRITIC decision-making matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
3PL-1	0.95	99.98	9	88	9
3PL-2	0.92	99.95	10	92	10
3PL-3	0.99	99.90	10	75	9
3PL-4	0.90	98.98	8	85	8
3PL-5	1.20	99.97	8	95	10
Sum	4.96	498.78	45	435	46
min/max	min	max	max	max	max
Best	0.90	99.98	10	95	10
Worst	1.20	98.98	8	75	8

Table 7. Initial CRITIC decision-making matrix with standard deviations (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
3PL-1	0.8333	1.0000	0.5000	0.6500	0.5000
3PL-2	0.9333	0.9700	1.0000	0.8500	1.0000
3PL-3	0.7000	0.9200	1.0000	0.0000	0.5000
3PL-4	1.0000	0.0000	0.0000	0.5000	0.0000
3PL-5	0.0000	0.9900	0.0000	1.0000	1.0000
Standard deviation σ_j	0.4037	0.4349	0.5000	0.3857	0.4183

Table 8. $m \times m$ matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
Price (EUR/km)	1.0000	−0.4378	0.3922	−0.3934	−0.5625
Delivery service (%)	−0.4378	1.0000	0.5174	0.2035	0.8135
QoS from customer experience (Scale 1–10)	0.3922	0.5174	1.0000	−0.4213	0.2988
Territorial coverage of the EU (%)	−0.3934	0.2035	−0.4213	1.0000	0.5811
Flexibility	−0.5625	0.8135	0.2988	0.5811	1.0000

Table 9. $m \times m$ matrix with the final weights (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)	Sum by Rows	6_j	H_j	W_j
Price (EUR/km)	0.0000	1.4378	0.6078	1.3934	1.5625	5.0015	0.4037	2.0192	0.2642
Delivery service (%)	1.4378	0.0000	0.4826	0.7965	0.1865	2.9035	0.4349	1.2627	0.1652
QoS from customer experience (Scale 1–10)	0.6078	0.4826	0.0000	1.4213	0.7012	3.2130	0.5000	1.6065	0.2102
Territorial coverage of the EU (%)	1.3934	0.7965	1.4213	0.0000	0.4189	4.0302	0.3857	1.5544	0.2034
Flexibility (1–10)	1.5625	0.1865	0.7012	0.4189	0.0000	2.8691	0.4183	1.2002	0.1570
								7.6430	1

According to this method, the highest importance was assigned to price, followed by QoS from customer experience, territorial coverage of the EU, delivery service, and flexibility. The following table (Table 10) compares the criteria weights obtained from both methods and the hybrid weights obtained by applying Equation (7).

Table 10. Obtained hybrid criteria weights (Source: Authors).

Criteria Weights	Entropy Weights	CRITIC Weights	Hybrid Weights
Price (EUR/km)	0.3323	0.2642	0.2983
Delivery service (%)	0.0004	0.1652	0.0828
QoS from customer Experience (1–10)	0.2871	0.2102	0.2486
Territorial coverage of the EU (%)	0.1861	0.2034	0.1947
Flexibility	0.1941	0.157	0.1755
			1

The hybrid method ranked the criteria in a following way: the highest importance was assigned to price (0.2983), second place was related to QoS from the customer perspective (0.2486), third place was related to territorial coverage of the EU (0.1947), and flexibility (0.1755) and delivery service (0.0828) had less importance. Using the criteria weights obtained by the hybrid method, the final ranking of the 3PL providers was obtained by applying the ARAS method. For better clarity, the obtained criteria weights by the hybrid method are presented in Figure 2.

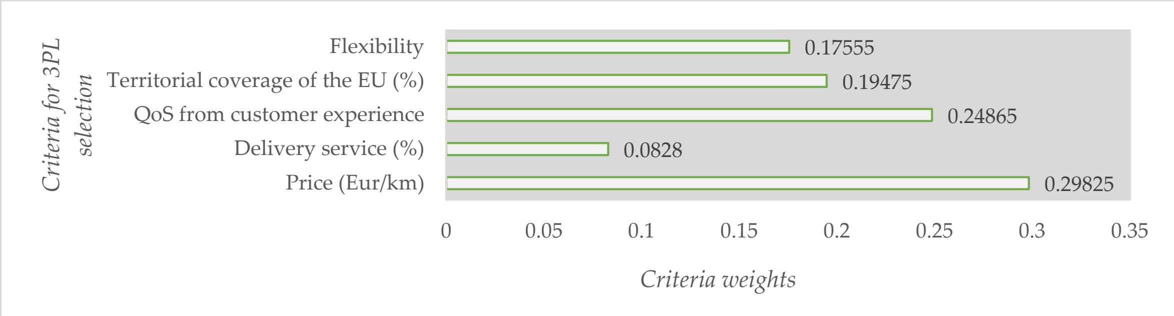

Figure 2. Obtained hybrid criteria weights (Source: Authors).

4.1. Application of the Hybrid–ARAS Method to 3PL Evaluation and Selection Problem

After the criteria weights were determined, the ARAS method was applied to obtain the final ranking of the 3PL providers. The input data used in the ARAS decision-making matrix are presented in Table 11.

Table 11. Initial ARAS decision-making matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
0—optimal value	0.90	99.98	10	95	10
3PL-1	0.95	99.98	9	88	9
3PL-2	0.92	99.95	10	92	10
3PL-3	0.99	99.90	10	75	9
3PL-4	0.90	98.98	8	85	8
3PL-5	1.20	99.97	8	95	10
min/max	min	max	max	max	max
sum	6.2	598.8	55.0	530.0	56.0

The normalization of the input data is presented in Table 12.

Table 12. Normalization of the input data (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	Territorial Coverage of the EU (%)	Flexibility (Scale 1–10)
0	0.1791	0.1670	0.1818	0.1792	0.1786
3PL-1	0.1696	0.1670	0.1636	0.1660	0.1607
3PL-2	0.1752	0.1669	0.1818	0.1736	0.1786
3PL-3	0.1628	0.1668	0.1818	0.1415	0.1607
3PL-4	0.1791	0.1653	0.1455	0.1604	0.1429
3PL-5	0.1343	0.1670	0.1455	0.1792	0.1786
min/max	min	max	max	max	max
Hybrid Weights	0.2983	0.0828	0.2487	0.1948	0.1756

The weighted decision-making matrix is described in Table 13.

Table 13. Weighted D–M matrix (Source: Authors).

	Price (EUR/km)	Delivery Service (%)	QoS from Customer Experience (Scale 1–10)	EU Territorial Coverage (%)	Flexibility (Scale 1–10)	S	K	Rank
0	0.0534	0.0138	0.0452	0.0349	0.0314	0.1787	Preference	
3PL-1	0.0506	0.0138	0.0407	0.0323	0.0282	0.1657	0.9270	2
3PL-2	0.0523	0.0138	0.0452	0.0338	0.0314	0.1765	0.9873	1
3PL-3	0.0486	0.0138	0.0452	0.0276	0.0282	0.1634	0.9141	3
3PL-4	0.0534	0.0137	0.0362	0.0312	0.0251	0.1596	0.8930	4
3PL-5	0.0401	0.0138	0.0362	0.0349	0.0314	0.1563	0.8747	5

As shown in Figure 3, by applying the hybrid–ARAS method, the best alternative was shown to be 3PL-2, with the preference value of 0.9873, followed by 3PL-1, with the preference of 0.9270; 3PL-3, with the preference of 0.9141; 3PL-4, with the preference of 0.8930; and in the last place 3PL-5, with the preference of 0.8747.

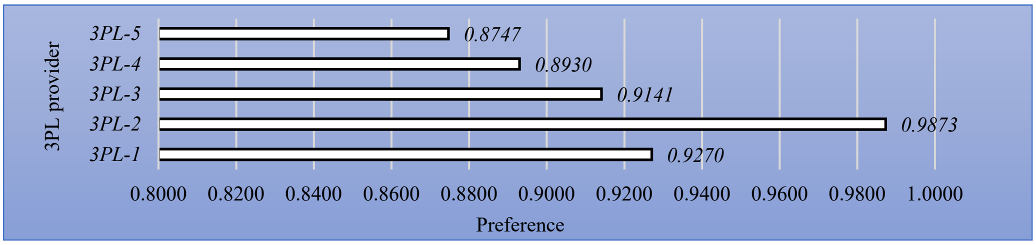

Figure 3. Final ranking of 3PL providers obtained by the hybrid–ARAS method (Source: Authors).

4.2. Sensitivity Analysis

To test the stability of the proposed hybrid–ARAS method, a sensitivity analysis was conducted. The main purpose of the analysis was to examine how the change in trade-off parameter ξ affected the final ranking of the alternatives. In this regard, the parameter ξ was changed within the interval of [0, 1] with an increment value of 0.1 (Figure 4).

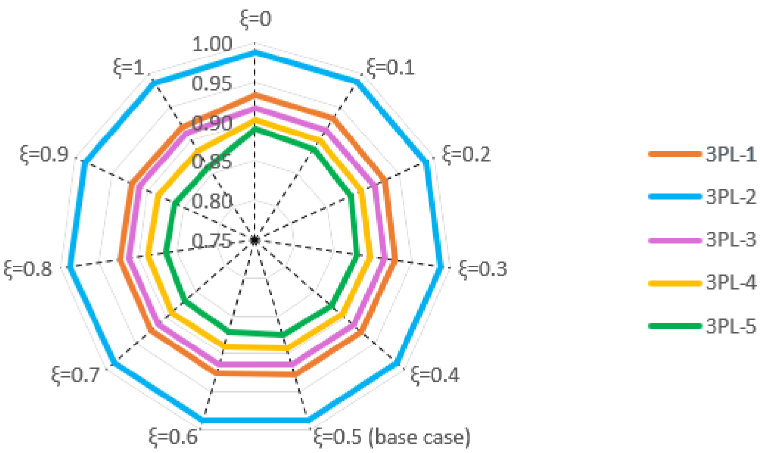

Figure 4. The sensitivity analysis to changes in the trade-off parameter ξ (Source: Authors).

When ξ = 1, only the entropy ARAS method was applied to prioritize the 3PL providers. When ξ = 0, only the CRITIC ARAS method was used to evaluate the 3PL providers. Therefore, in the base case scenario, ξ was set to 0.5 to equally appraise both methods and generate hybrid criteria importance. According to Figure 4, 3PL-2 was the best alternative under all ξ values. In addition, there was no change in the ranks of any 3PL provider in all 10 new test cases; i.e., the 3PL service provider ranking order was 3PL-2

> 3PL-1 > 3PL-3 > 3PL-4 > 3PL-5. The sensitivity analysis revealed that the proposed model has a high level of stability.

4.3. Comparative Analysis

A comparative analysis was performed to check the reliability of the results obtained through the hybrid–ARAS method for 3PL selection. The 3PL selection process was solved with two state-of-the art MCDM approaches, WASPAS [72] and EDAS [73]. The result of the comparative analysis is presented in Figure 5.

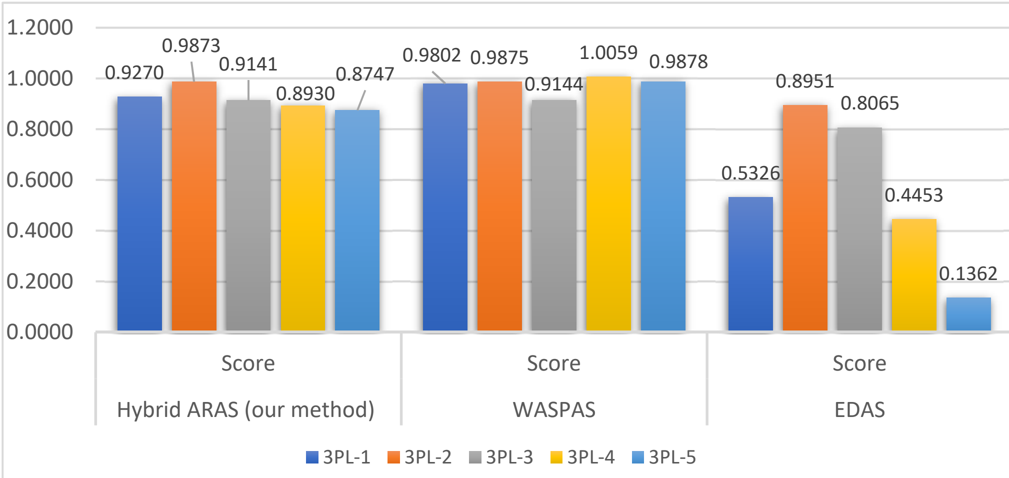

Figure 5. The comparative analysis of the hybrid–ARAS approach with WASPAS and EDAS.

The proposed hybrid–ARAS and EDAS methods ranked 3PL-2 as the best solution and 3PL-5 as the worst one. When it comes to 3PL-4, it was ranked as the fourth best option according to hybrid–ARAS and EDAS, but the WASPAS method ranked it as the best solution. According to the results, the model is reliable.

5. Managerial Insights

Since third-party logistics play an important role in the logistics market, managers all around the world should carefully monitor and identify the most important parameters that may affect this field. Not all the parameters are equally important, so sorting out the most important ones may greatly influence the 3PL business. When identifying the criteria for 3PL selection, each company should consider the whole picture of its business environment and select the most important criteria to attract the best collaboration partner according to its expectations. In addition, collaboration between experts is of crucial importance for 3PL selection. The wrong choice of a 3PL provider can have negative consequences for a company such as loss of profit, business image, reputation, customer loyalty, etc. The recommendation for managers should be to eliminate subjectivity and combine one or more objective methods to identify the priority of the criteria with MCDM methods in order to obtain the best possible 3PL provider to collaborate with. The results of using more objective methods are more robust and confident, which leads to a more stable managerial solution.

6. Discussion and Conclusions

This paper aimed to propose a possible hybrid–ARAS approach to the 3PL evaluation and selection process. The main reason for the methodology proposed was to give a theoretical contribution in the 3PL logistics field that could help managers and scientists think about the possible approaches for evaluating and selecting 3PL service providers. Three methods were combined in order to obtain a ranking of the best alternatives. The first method was the entropy method, applied to obtain objective criteria importance. The second was the CRITIC method, utilized to obtain objective criteria importance. The third was the ARAS method combined with the entropy and CRITIC methods in order to obtain a ranking of the possible alternatives. Furthermore, the combination of the entropy and CRITIC methods resulted in obtaining *hybrid* criteria weights, which were further coupled with the ARAS method to rank the best alternative. In each case, either separate (entropy–ARAS; CRITIC–ARAS) or coupled (hybrid–ARAS), the final ranking results were not changed. The main idea of coupling the former two methods was to obtain objective criteria weights, which should eliminate subjectivity and give more robust results.

To examine the stability of the proposed hybrid–ARAS method, a sensitivity analysis was conducted. The results of the analysis revealed that there was no changing in the ranking alternatives when 10 variations in criteria were taken. In addition, a comparative analysis was carried out to compare the obtained results. The results of the comparative analysis revealed that the model is reliable.

The major contributions of this paper are: (i) for the first time, a new combination of methods was introduced to rank 3PL service providers; (ii) a combination CRITIC–entropy (hybrid) method was employed to prioritize the criteria that influence the 3PL evaluation and selection process—a more robust solution was obtained by coupling two objective methods into a hybrid one, and subjectivity was eliminated; (iii) a new hybrid–ARAS method was developed to rank 3PL service providers; (iv) the methodology was very simply described and easy to implement and should be beneficial for the 3PL logistics field.

In our hypothetical case, the hybrid–ARAS MCDM approach for 3PL evaluation and selection process generated the following ranking order: *A2* (3PL-2) > *A1* (3PL-1) > *A3* (3PL-3) > *A4* (3PL-4) > *A5* (3PL-5). This approach identified 3PL-2 as the best possible alternative. On the other hand, the worst-ranked alternative was 3PL-5. As a result, it would be strongly recommended to select 3PL-2, since it was shown as the best alternative according to the methodology.

Limitations of this paper can indicate possible areas for its extension. The limitations included: (1) the methodology was not applied to a real-life case, but only to a hypothetical example; (2) the criteria influencing the decision-making process were filtered not only according to a review of the literature, but by the consideration of experts' opinions—indeed, filtering was mostly performed according to discussion with experts in the field. However, the methodology is general and can be applied with any other criteria influencing the 3PL evaluation and selection process. The main point of the paper was to show the applicability of the methodology in order to respond to the aforementioned research questions; (3) there were only considered criteria from the economic pillar. However, there is space to include any other aspects that should matter in the decision-making process, such as environmental, technical, and social aspects; (4) the authors did not consider how 3PL logistics may fit with the industry 4.0.

This study can be seen as an important trigger for future papers in the field. The future directions inspired by this paper should be to (a) apply the methodology to real-life cases; (b) include the criteria most often used by other authors in the field; (c) apply the methodology in the fuzzy and picture fuzzy environment, since fuzzy logic deals with uncertainty, which often factors into the decision-making process; (d) examine how 3PL logistics may fit with the industry 4.0.

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