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Research Article

Logistics Service Provider Selection through an Integrated Fuzzy Multicriteria Decision Making Approach

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Nowadays, the demand of third-party logistics provider becomes an increasingly important issue for companies to improve their customer service and to decrease logistics costs. This paper presents an integrated fuzzy approach for the evaluation and selection of 3rd party logistics service providers. This method consists of two techniques: (1) use fuzzy analytic hierarchy process to identify weights of evaluation criteria; (2) apply fuzzy technique for order preference by similarity to ideal solution (TOPSIS) method to evaluate and sequence alternatives and to make the final selection. Finally, an actual industrial application is performed in logistics department of a tire manufacturing company. For this, first, eight logistics supplier selection criteria were determined, and then the best alternative among seven logistics service provider companies was selected by the proposed method.

1. Introduction

Logistics plays an important role in integrating the supply chain of industries. Because the market becomes more global, logistics is now seen as an important area where industries can decrease costs and improve their customer service quality [1].

Nowadays, many companies are searching to outsource their logistics operations to what they call as Third Party Logistics Service Providers (LSPs) to introduce products and service innovations quickly to their markets [2]. Therefore there is an increasing trend that manufacturing companies outsource their logistics activities to meet their increasing need for logistics services. This trend has increased importance of the concept of third party LSPs [3]. In today's economic environment, many firms name third party LSPs as more qualified and economic in accomplishing their partial or all logistic requirements [4].

Outsourcing means that an organization hires an outside organization to provide a good or service that it traditionally had provided itself, because this third party is an "expert" in efficiently providing this good or service, while the organization itself may not be [5].

Because of development of supply chain partnerships, cost reduction, restructuring of the company, success of the firms using contract logistics, globalization, improvement of services, and efficient operations, companies need to outsource their logistics activities to 3PL service providers [6]. The outsourcing of logistics activities to third-party LSPs has now become a common practice. An LSP is defined as a provider of logistics services that performs the logistics functions on behalf of their clients [7].

The LSP selection is a complex multicriteria decision making (MCDM) problem that includes both quantitative and qualitative criteria some of which can conflict each other and is vital in enhancing the competitiveness of companies [8]. It is an important function of the logistics departments as it brings significant savings for the organization. While choosing the appropriate LSP, logistics managers might be uncertain whether the selection will satisfy completely the needs of the organization [9].

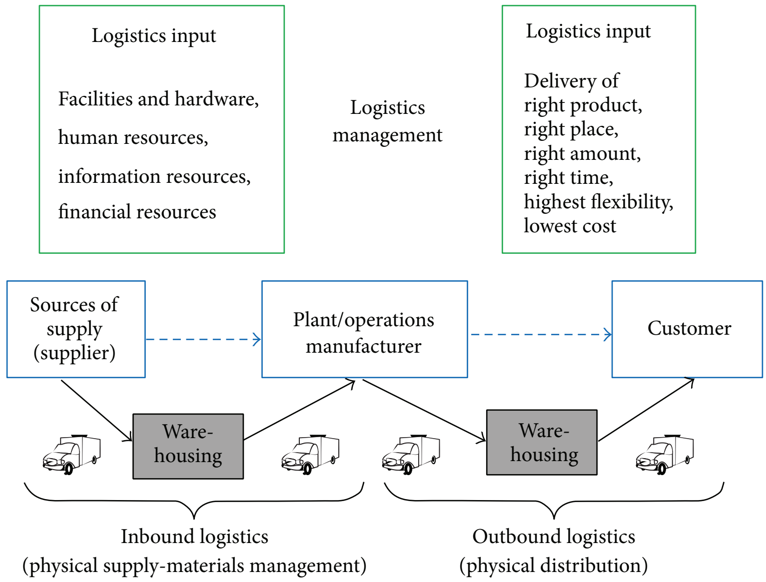

Figure 1: Logistics management [12].

Because of some troubles in MCDM problems such as subjectivity, uncertainty, and ambiguity in assessment process [10], this study uses fuzzy analytic hierarchy process (FAHP) to establish the evaluation structure and calculate the importance weights of assessment criteria according to a group of decision-makers and applies fuzzy technique for order preference by similarity to an ideal solution (TOPSIS) [11] to obtain the final ranking order of LSPs.

This research evaluates the performance of 3rd party LSPs of a tire company in a developing country, Turkey, via the proposed FAHP and fuzzy TOPSIS techniques with MCDM. The fuzzy AHP is used to determine the preference weights of evaluation criteria. Then, this research illustrates that the fuzzy TOPSIS is integrated with fuzzy AHP to evaluate and determine performance levels of seven logistics service providers (LSPs) and find out the best alternatives among these seven LSP companies.

The remainder of this paper is organized as follows. Section 2 presents a literature survey of logistics management, third party logistics, and third party logistics service provider. Also in this section we mentioned logistics service providers in Turkey. This section also includes criteria used for evaluating performances of third party LSPs and evaluation methods third party LSPs performances. Section 3 includes methodology related with selection of logistics service providers, fuzzy set theory, fuzzy AHP, and fuzzy TOPSIS. A Case study for the proposed methodology about selection of logistics service provider is performed for a tire manufacturing company. In Section 5, conclusion, limitation, and managerial implications of the study are discussed.

2. Literature Review

2.1. Logistics Management. According to definition by the Council of Supply Chain Management Professionals [12], it is accepted that logistics management is a part of supply chain management (SCM). It is the part "*. . . that plans implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.*"

Logistics is an integration of information, transportation, material handling, stock and storage, and packaging operations. Logistics activities contain purchasing, transportation, quality, control, customs and insurance, handling, ware housing, inventory management, order processing, sales-demand forecast, logistics information management, distribution, labeling, packaging, fleet management, management of separate parts, product returns, and shipment planning [13]. Logistics includes the flow of goods, services, and information related to movements of goods and services from the suppliers to a satisfied customer without waste [14].

Council of Logistics Management defined logistics as the process of planning, implementing, and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods, and related information from origin to consumption for the purpose of conforming to customer wants [15]. According to this definition, logistics includes all activities related to the product, service, and information flow between supplier, manufacturer, and customer (Figure 1).

2.2. Third Party Logistics. There is an emerging trend for logistics outsourcing in the global market. Lambert et al. [15] state that logistics outsourcing is *"the use of a third-party provider for all or part of an organization's logistics operations."* Rabinovich et al. [16] defined logistics outsourcing relationships as *"long and short-term contracts or alliances between manufacturing and service firms and third party* *logistics providers.*" According to Banrodt and Davis, third-party logistics is defined as logistics outsourcing [17].

Lieb [14] expressed that third-party logistics involves the using of external companies to carry out logistics functions traditionally performed within an organization. Third party LSPs provide multiple logistics services to their customers such as direct transportation service, warehouse operations and management, shipment planning and consolidation, management of logistics information systems, carrier selection, rate negotiation, product returns, fleet management, labeling, packaging, relabeling/repackaging, order processing and fulfillment, product assembly/installation, inventory management, and customer spare parts [8, 9].

Lieb [14] defined third-party logistics as the using of external companies to perform logistics functions that have traditionally been executed within an organization. Third-party logistics is defined as "activities carried out by an external company on behalf of a client company and these activities consist of at least the provision of management of multiple logistics services. These activities are offered in an integrated way, not on a stand-alone basis. The cooperation between the shipper and the external company is an intended continuous relationship taking at least one year" [18]. According to the Council of Supply Chain Management Professionals, third-party logistics is defined as "a firm that provides multiple logistics services for use by customers, and preferably, these services are integrated together by the provider" [12].

Third-party logistics can be defined as specialized companies from outside of the firm fulfill the some or all of the logistics activities performed traditionally within the organization through outsourcing [19]. The functions performed by the third party can include the entire logistics process or selected activities within that process. 3PL services mostly focused their attention on transportation and warehousing, and so forth, and these 3PLSPs must have professional experiences in each service [20].

Third-party logistics is the function by which the owner of goods (the client company) outsources various elements of the supply chain to a third-party logistics company that can perform the management function of the clients inbound freight, customs, warehousing, order fulfillment, distribution, and outbound freight to the clients [21].

Bask [22] defined third-party logistics as relationships between interfaces in the supply chains and 3PL providers, where logistics services are offered, from basic to customized ones, in a shorter or longer-term relationship, with the aim of effectiveness and efficiency.

2.3. Third Party Logistics Service Provider. According to a survey performed by Forrester Research, 78% of Fortune 500 companies have outsourced transportation services, 54% of them have outsourced their distribution services, and 46% of them have outsourced their manufacturing activities. As a result, third-party logistics sector reached a scale of 50 billion $ throughout the world. To prefer outsourcing in primarily transportation and shipping services cause to transform some specialized transportation and shipping companies into third-party-logistics companies which are able to serve in all logistics functions [23].

3PL service providers can be defined as external suppliers which fulfill a portion or all of a company's logistics functions of a company. Logistic functions released to third-party companies are services such as especially transportation, storage, distribution. These functions are required a high level of business investment [23]. Third-party logistics services mostly focused their attention on transportation and warehousing, and so forth and these third-party LSPs should have professional experiences in each service [20].

2.4. Logistics Service Providers in Turkey. Logistics industry constitutes approximately 10–15% of the total global GDP and is an integral portion of Turkey's economy. The Turkey logistics sector's value in 2008 was 60 billion U.S. dollar. Current size of 3PL service providers is 22 billion U.S. dollar. According to LODER, Turkey's current logistics industry size is estimated to be USD 80–100 billion and is forecasted to reach USD 108–140 billion by 2017. The average growth in the fields of transportation, storage and communication was 6.4% between 2003 and 2013 [24].

According to Logistics Performance Index (LPI) prepared by World Bank, Turkey is ranked 27th with 3.22 point. Turkey moved up from 39th place in 2010 to 27th in 2013, out of the 155 countries in the index. Moreover, it is ranked third in the top 10 upper middle income performing countries. [24, 25]. According to Agility Emerging Markets Logistics Index prepared by Transport Intelligence, Turkey is ranked as the 11th best country in logistics out of 41 emerging markets [24].

There are a large number of logistics provider firms in Turkey. These are newly founded small and medium sized firms with a transportation background. The most important Turkish logistics service providers are Arkas Denizcilik, Omsan, Barsan, Reysas, Borusan, Balnak, Türksped, and Horoz Lojistik. Rapidly growing trade with Turkey has created a promising perspective for the logistics sector, and the trend is expected to continue. For this reason, international logistics companies are increasing their presence in the country [26]. All of the top 10 global third-party logistics companies have understood the strategic importance of Turkey and either directly operate or have agencies in Turkey [24]. All major international logistics companies such as DHL, TNT, Kühne & Nagel, Mars, Schenker, Ceva, and Panalpina are already active in Turkey. Initially, firms were focused on only one or a few number of logistics operations, but by the rimes of progress, in order to meet increasing customer demands, LSPs improved their services in terms of modern logistics concepts; this structuring compels the logistics firms to improve their technological facilities and change management styles in order to offer customers more flexible and quality logistics service [13].

2.5. Selecting Criteria for Evaluating 3rd Party Logistics Service Provider. Deciding to use a third party LSP is a decision that depends on a variety of factors that differ from company to company. The decision to outsource certain business functions will depend on the company's plans, future objectives, product lines, expansion, acquisitions, and so forth [27].

Measures indicating the success of logistics management can be summarized as cost reduction, maximized on time delivery, minimized lead times, rapid respond to the market, higher flexibility, increased number of solution alternatives, improved information reliability, faster communication, minimized rate of consumption, damage and loss, minimized number of total inventory through the supply chain, transformation of fixed costs into variable costs, increased efficiency and productivity in logistics activities, reduction of logistics management expenses, focus on core competencies, improved customer relations, customer focus, and creating win-win relationships in the supply chain [28].

The needs of the firm can be satisfied by the third party logistics organization in optimum by defining the firm's goals and selection criteria. To know what metrics are used to evaluate the selection criteria of logistics service provider is an important issue. Generally, the companies have a variety of different characteristics related suppliers; but, if they use same methodology to evaluate the different types of suppliers, and the result cannot represent the real situation. Therefore, when determining the logistics service provider criteria, it should be considered that the criteria of selection differ in the different types of LSP [20].

According to Menon et al. [29], the firm's competitiveness strategy and its external environment affect the selection criteria. The important criteria for the selection of a third-party LSP are on time shipment and deliveries, superior error rates, financial stability, creative management, ability to deliver as promised, availability of top management, responsiveness to unforeseen occurrences, and meeting performance and quality requirements before price\discussions occur. Meade and Sarkis [30] developed conceptual model for selecting and evaluating third-party reverse logistics providers. In this study, the most important factors for third-party logistics selection are time, quality, cost, and flexibility. Aghazadeh [31] used criteria for selecting effective third-party LSP as similar value, information technology systems, and key management. Efendigil et al. [32] select the third party reverse logistics providers by using performance indicators like: on time delivery ratio, confirmed fill rate, service quality level, unit operation cost, capacity usage ratio, total order cycle time, system flexibility index, integration level index, increment in market share, research and development ratio, environmental expenditures, and customer satisfaction index. According to Chen and Wu [20] some frequently used criteria from literature are price, delivery performance, range of services provided, the ability of response, human resources, IT capability, speed and punctuality, finance status, past experiences, expertise technology, product reliability, reputation, the quality of service, market share, geographical location, and surge capacity.

In 2003, the International Warehouse Logistics Association, which comprises more than 550 logistics companies of North America, identified third-party LSP selection criteria (in a descending order) as follows: price, reliability, service quality, on-time performance, cost reduction, flexibility and innovation, good communication, management quality, location, customize service, speed of service, order cycle time, easy to work with, customer support, vendor reputation, technical competence, special expertise, systems capabilities, variety of available services, decreased labor problems, personal relationships, decreased asset commitment, and early notification of disruptions [33].

2.6. Selecting and Evaluating Methods for 3rd Party Logistics Service Providers. Because of increasing importance of logistics outsourcing, selecting correct third-party LSP is a more critical issue for companies. There are lots of factors affecting selection of the service provider. Therefore it is a multicriteria decision making (MCDM) problem. In the literature, a variety number of techniques are used to evaluate third party performance and some MCDM methods are used to select 3PL service provider. For example, Yan et al. [1] propose a case-based reasoning (CBR) model framework for a third-party LSP evaluation and selection system. Thakkar et al. [34] applied an approach integrating interpretive structural model (ISM) and ANP for a proper selection of third-party logistics.

Yeung et al. [35] used analysis of variance (ANOVA) for financial performance measurement of 3PL. Bottani and Rizzi [36] used the fuzzy TOPSIS for third-party LSP selection and ranking. Min and Joo [37] used data envelopment analysis (DEA) for benchmarking the efficiency of third party logistics providers.

Jharkharia and Shankar [6] used analytic network process (ANP) to select logistics service provider in a medium-sized and growth-oriented fast moving-consumer-goods (FMCG) company. Işıklar et al. [38] proposed an intelligent decision support framework-integrating case-based reasoning (CBR), rule-based reasoning (RBR), and compromise programming techniques in fuzzy environment, for effective third-party LSP evaluation and selection. Qureshi et al. [39] used ANP and TOPSIS to evaluate the performance of logistics solution providers. Zhang [40] studied the logistics supplier selection based on the analytic hierarchy process (AHP) and data envelopment analysis (DEA).

Liu and Wang [41] proposed an integrated fuzzy approach for the evaluation and selection of third-party LSPs. Their approach method consists of three different techniques: fuzzy Delphi method, fuzzy inference method, and a fuzzy linear assignment approach. Zhang and Feng [42] used fuzzy AHP to discuss a selection approach of reverse logistics provider through a case study.

Kannan et al. [43] developed a multicriteria group decision making model in fuzzy environment for the selection process of best third party reverse logistics service provider by using two methods: interpretive structural modeling (ISM) and fuzzy technique for order preference by similarity to ideal solution (TOPSIS) in battery manufacturing industry in India. Chen and Wu [20] developed a decision making method combining the Delphi method and analytical network process (ANP) to help the electronic companies that need to evaluate and select the logistics service provider type. Cao et al. [44] developed two-step-model based on borda

Table 1: Summary of methods for 3PL providers selection.

Techniques	References
Analytic hierarchy process (AHP) and fuzzy AHP	Zhang et al., [53]; Göl and Çatay [54]; Zhang and Feng [42]; Çakır et al., [8]; Soh [33]
Analytic network process (ANP)	Meade and Sarkis [30]; Jharkharia and Shankar [6]
Analysis of variance (ANOVA)	Yeung et al., [35]
Technique for order preference by similarity to ideal solution (TOPSIS)	Bottani and Rizzi [36],
Case-based reasoning (CBR)	Yan et al., [1]
Data envelopment analysis (DEA)	Haas et al., [55], Min and Joo [37]; Hamdan and Rogers [47]; Saen [56]
İntegrating interpretive structural model (ISM) and ANP	Thakkar et al., [34]
Integrated methods	
(i) Case-based reasoning (CBR), rule-based reasoning (RBR), and compromise programming techniques in fuzzy environment	Işıklar et al., [38]
(ii) Fuzzy Delphi and fuzzy TOPSIS	Gupta and Bhardwaj [57]
(iii) ANP and TOPSIS	Murray [27]
(iv) Analytic hierarchy process (AHP) and data envelopment analysis (DEA)	Zhang [40]
(v) Fuzzy Delphi method, fuzzy inference method, and a fuzzy linear assignment approach	Liu and Wang [41],
(vi) Interpretive structural modeling (ISM) and fuzzy technique for order preference by similarity to ideal solution (TOPSIS)	Kannan et al., [43]
(vii) Delphi method and analytical network process (ANP),	Chen and Wu [20]
(viii) Borda function theory and gray rational analysis	Cao et al., [44]
(ix) AHP and goal programming	Sheng et al., [45]
(x) Vector machine (SVM) and fuzzy analytic hierarchy process (FAHP)	Liu et al., [51]
(xi) AHP, TOPSIS fuzzy	Kumar [49], Kabir [52] Ravi [58], Perçin [59]

function theory and gray rational analysis to select third-party LSP. Sheng et al. [45] used a method integrating AHP and goal programming to select third-party reverse logistics enterprise. Wong [46] proposed a methodology combining fuzzy AHP and preemptive fuzzy integer goal programming to select third-party LSP in global supply chain. Çakır et al. [8] utilized the fuzzy AHP approach to select third-party LSP selection for a medium-sized and growth-oriented fast-moving-consumer-goods (FMCG) company, which is steadily moving towards IT enablement of its supply chain.

Hamdan and Rogers [47] propose a data envelopment analysis (DEA) to evaluate the efficiency of a group of 3PL warehouse logistics operations. Cheng et al. [48] applied the fuzzy AHP method to calculate the relative importance among individual dimensions and subcriteria on the evaluation of fourth party logistics (4PLs) selection criteria.

Kumar [49] proposed a framework which uses AHP and TOPSIS for performance measurement of third-party LSPs. Soh [33] proposed an evaluation framework and methodology by means of Fuzzy AHP for selecting a suitable third-party LSP through a case study. Li et al. [50] utilized an indicator system and established a compound quantification model based on centralized quantification values, a comparison method based on the synthesis effect, and a third party logistics supplier selection model.

Liu et al. [51] used new integrated model for selecting third-party LSP based on support vector machine (SVM) and fuzzy analytic hierarchy process (FAHP). Kabir [52] proposed FAHP approach based on TOPSIS method for evaluating and selecting an appropriate logistics service provider.

Some of these studies are summarized in Table 1.

3. Methodology

In this study we used an integrated method via analytic hierarchy process (AHP) and (TOPSIS) with fuzzy logic to select the best logistics service provider. The methodology applies the Fuzzy AHP and TOPSIS to help the decision makers for the evaluation of logistics service providers in a fuzzy environment where the vagueness and subjectivity are handled with linguistic values parameterized by triangular fuzzy numbers. Fuzzy AHP is used to determine the weight to criteria for 3PL rating. It has been further used in TOPSIS to determine weights of evaluation criteria. Fuzzy TOPSIS is a good tool to determine the order preferences of 3PLs, and this method has been used for ranking of service providers and to find the difference between alternatives to ideal [60].

Combining fuzzy AHP with fuzzy TOPSIS to evaluate the alternatives according to the decision makers' preference orders is very useful when the performance ratings are vague and imprecise. The usage of fuzzy-AHP weights in TOPSIS makes the decisions more realistic and reliable [61].

Methodology used in this study is shown in Figure 2.

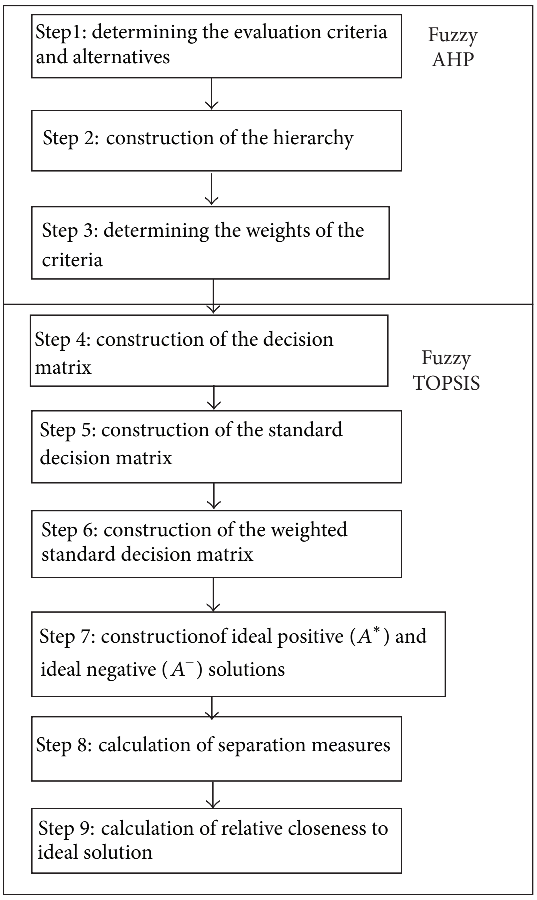

Figure 2: Methodology of the study.

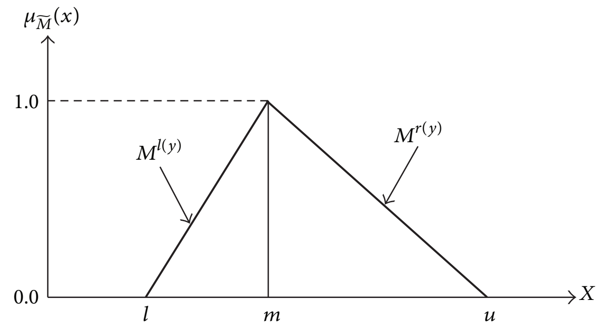

Figure 3: Membership function of triangular fuzzy number.

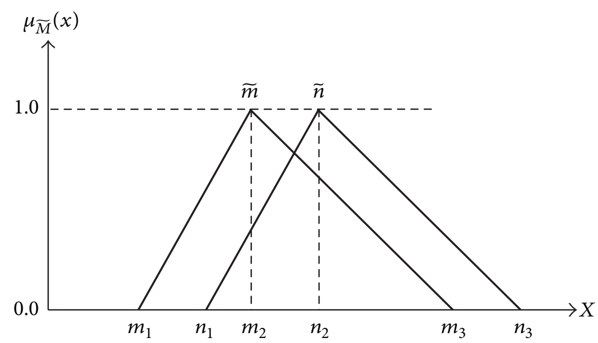

Figure 4: Two triangular fuzzy numbers.

3.1. Selection Criteria. The selection and the evaluation stage of the service provider organization will be important after evaluation of those listed criteria. A systematic approach is necessary to make an effective selection among potential service providers. In this study, the most important eight criteria were used in the evaluation process of the logistics service providers. In order to support objectiveness in selection process, clear definitions of those criteria are listed and defined in Table 2.

3.2. Fuzzy Sets Theory. To deal with vagueness of human thought, Zadeh [66] first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to be applied to the fuzzy domain.

A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. A fuzzy set $\widetilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\widetilde{A}}(x)$ which associates with each element x in X, a real number in the interval [0, 1]. The function value $\mu_{\widetilde{A}}(x)$ is termed the grade of membership of x in $\widetilde{A}$ [66].

A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. A triangular fuzzy number (TFN) is shown in Figure 3. A TFN is denoted simply as $(l/m, m/u)$ or (l, m, u). The parameters l, m and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event [67]. The membership functions for these fuzzy sets will be denoted by (1), respectively. Consider the following:

$$\mu\left(x \mid \widetilde{M}\right) = \begin{cases} 0, & x < l, \\ \dfrac{(x-l)}{(m-l)}, & l \le x \le m, \\ \dfrac{(u-x)}{(u-m)}, & m \le x \le u, \\ 0, & x > u. \end{cases} \tag{1}$$

A linguistic variable is a variable whose values are linguistic terms. Linguistic variables are very useful in relation to situations which are unclear to be described in quantitative expressions. For example, "weight" is a linguistic variable, its values are very low, low, medium, high, very high, and so forth. These linguistic values can also be represented by fuzzy numbers [68].

Suppose that $\widetilde{m} = (m_1, m_2, m_3)$ and $\widetilde{n} = (n_1, n_2, n_3)$ are two triangular fuzzy numbers as presented in Figure 4.

Table 2: Explanation of LSP selection criteria.

Selection criteria	Definition of the criteria	References
On-time delivery	Deliver a product or service that meets customer requirements against a specification for delivery time. On-time delivery is measured as percent achievement within a window of time that brackets the customer-requested date and/or the business' committed date, and is not improved by quoting long lead times and turning down tough business.	Stock et al., [62] Çakır et al., [8]
Price	A key determinate in the purchasing decision. It is the price that a good or service is offered at, or will fetch, in the marketplace	Çakır et al., [8] Özbek and Eren, [63]
Product availability	Reaching or to be able to find a product at the time you need or want it. Retailers and manufacturers across the world are losing out to store and brand switching as consumers substitute products which are unavailable or difficult to find.	Özbek and Eren, [63]
Reliability	This criterion ensures that products or services are reliable and contribute to overall customer satisfaction.	Lynch [64]
Firm background	The achievements of the factory in the past concerning the service or the product that has been provided by now will be evaluated in this criterion.	Çakır et al., [8] Özbek and Eren, [63]
Firm reputation	Considered as a component of the identity as defined by others. Reputation is a fundamental instrument of social order, based upon distributed, spontaneous social control.	Kabir [52]; Çakır et al., [8]
Knowledge sharing	Traditional information sharing referred to one-to-one exchanges of data between a sender and receiver. These information exchanges are implemented via dozens of open and proprietary protocols message and file formats. As criterion, information sharing is a platform that will provide controlled data and information exchange between the customer and the supplier through predefined policies, guidelines, and standards to keep privacy, security, and data quality.	Lynch [64] Stock et al., [62] Bagchi and Virum [65]
Flexibility	The ability of the system to adapt to market demands. In another words, the ability of a system to respond to potential internal or external changes affecting its value delivery, in a timely and cost-effective manner. Thus, flexibility is the ease with which the system can respond to uncertainty in a manner to sustain or increase its value delivery.	Çakır et al., [8] Özbek and Eren [63] Kabir [52]

Distance between two triangular numbers is calculated as follows:

$$d(\widetilde{m},\widetilde{n}) = \sqrt{\frac{1}{3}\left[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2\right]}. \tag{2}$$

Both triangular and trapezoidal fuzzy numbers are used for fuzzy set theory. Using TFNs is preferred because of their computational ease. In this study, it is suitable to work with TFNs because of their computational simplicity and their usefulness in providing representation and information processing in a fuzzy environment. In this study TFNs in the FAHP is adopted. Reason of using TFNs for pairwise comparisons in fuzzy AHP is that a TFN corresponding to the expressed verbal condition in the pairwise comparison process has only one value which has the highest membership degree [69].

3.3. Fuzzy AHP. The analytic hierarchy process (AHP) is one of the extensively used multicriteria decision-making methods. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve cumbersome mathematics. AHP involves the principles of decomposition, pair wise comparisons, and priority vector generation and synthesis. Though the purpose of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the human thinking style. Therefore, fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems. In the fuzzy-AHP procedure, the pairwise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer's emphasis [67].

In the fuzzy AHP, triangular fuzzy numbers are utilized to develop the scaling scheme in the judgement matrices, and interval arithmetic is used to solve the fuzzy eigenvector [70].

The procedure of the fuzzy AHP approach involves four essential steps as follows [71].

Step 1. Define the problem and state clearly the objectives and results.

Step 2. Decompose the complex problem into a hierarchical structure with decision elements (criteria and alternatives).

Step 3. Employ pairwise comparisons among decision elements and form comparison matrices with fuzzy numbers.

Step 4. Use the extent analysis method to estimate the relative weights of the decision elements.

(See [70–72] for further details).

3.4. Fuzzy TOPSIS. In this study, fuzzy TOPSIS method developed by Chen [73] was used. Method is described as follows.

Assume that a decision group contains K persons; then the importance of the criteria and the rating of alternatives according to each criterion are computed as follows:

$$\tilde{w}_j = \frac{1}{K}\left[\tilde{w}_j^1 (+) \tilde{w}_j^2 (+) \cdots (+) \tilde{w}_j^K\right]$$
$$\tilde{x}_j = \frac{1}{K}\left[\tilde{x}_{ij}^1 (+) \tilde{x}_{ij}^2 (+) \cdots (+) \tilde{x}_{ij}^K\right], \quad (3)$$

where $\tilde{x}_{ij}^K$ and $\tilde{w}_j^K$ are the rating and the importance weight of the Kth decision maker.

As mentioned above, a fuzzy multicriteria group decision-making problem can be concisely presented in matrix format as

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & x_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x} & \tilde{x}_{mn} \end{bmatrix}, \qquad \tilde{w}_j = \left[\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n\right], \quad (4)$$

where $\tilde{x}_{ij};$, for all i, j and $\tilde{w}_j; i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$ are linguistic variables. These linguistic variables are described by triangular fuzzy numbers, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (\tilde{w}_{j1}; \tilde{w}_{j2}; \tilde{w}_{j3})$. To avoid the complicated normalization formula used in classical TOPSIS, the linear scale transformation is used to transform the various criteria scales into a comparable scale. Hence, the normalized fuzzy decision matrix is indicated by $\tilde{R}$ as follows:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{mxn}, \quad i = 1, 2, \ldots, m_r; \; j = 1, 2, \ldots, n_r, \quad (5)$$

where B and C are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad j \in B, \; c_j^* = \max_i c_{ij},$$
$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}^*}, \frac{a_j^-}{b_{ij}^*}, \frac{a_j^-}{a_{ij}^*}\right), \quad j \in B, \; a_j^- = \min_i a_{ij}. \quad (6)$$

The normalization method stated above is to protect the property that the ranges of normalized triangular fuzzy numbers belong to [0, 1].

Considering the different importance of each criterion, the weighted normalized fuzzy decision matrix can be constructed as follows:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{mxn}, \quad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \quad (7)$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_j$.

With respect to the weighted normalized fuzzy decision matrix, it is known that the elements $\tilde{v}_{ij}$, for all i, j are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval [0, 1]. Then, the fuzzy positive-ideal solution (FPIS, A^*) and fuzzy negative-ideal solution (FNIS, A^-) can be defined as follows:

$$A^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*\right)$$
$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\right), \quad (8)$$

where $\tilde{v}_j^* = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, \ldots, n$.

The distance of each alternative from A^* and A^- can be currently calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \quad i = 1, 2, \ldots, m, \quad (9)$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \quad i = 1, 2, \ldots, m, \quad (10)$$

where $d(\cdot, \cdot)$ is the distance measurement between two fuzzy numbers.

A closeness coefficient is defined in order to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i $(i = 1, 2, \ldots, m)$ has been computed. The closeness coefficient of each alternative (CC_i) is calculated as follows:

$$\mathrm{CC}_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2, \ldots, m. \quad (11)$$

Obviously, an alternative A_i is closer to the FPIS (A^*) and farther from FNIS (A^-) as CC_i approaches to 1. Therefore, according to the closeness coefficient, the ranking order of all alternatives can be determined and the best one can be selected from among a set of alternatives (see [36, 73, 74] for further details).

4. Case Study

In this section, we presented an illustrative example by using the methodology shown in Figure 2. The example was performed to select logistics service provider for a tire manufacturing company which has more than 1000 employees in Turkey.

Five people working in the logistics department of the company were determined to select evaluation criteria, to make pairwise comparisons for AHP in order to determine weights of criteria, and to evaluate alternatives via TOPSIS method. One of them is the manager of the logistic department and one of them is chief in the logistic department. Three of them are the normal staffs working in the logistics department.

Step 1 (determining the evaluation criteria and alternatives). Seven evaluation criteria are determined. These are on time delivery (OTD), price (P), product availability (PA), reliability (R), firm's background (FB), firm reputation (FR), knowledge sharing (KS), and flexibility (F).

Seven logistics service providers are determined as alternatives. These alternatives are LSP1, LSP2,. . ., and LSP7.

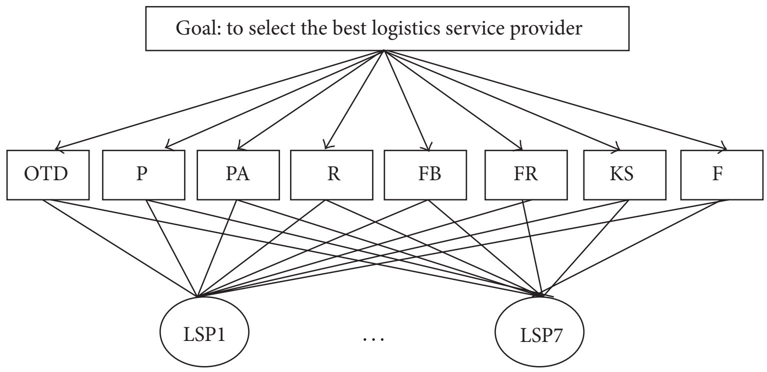

Figure 5: Hierarchical structure of the problem.

Table 3: Fuzzy triangular numbers for pairwise comparison of criteria [75].

Linguistic variables	Triangular fuzzy numbers	Reverse Triangular fuzzy numbers
Equal importance (EI)	(1, 1, 1)	(1/1, 1/1, 1/1)
EI-WI	(1, 2, 3)	(1/3, 1/2, 1)
Weak importance (WI)	(2, 3, 4)	(1/4, 1/3, 1/2)
WI-FSI	(3, 4, 5)	(1/5, 1/4, 1/2)
Fairly strong importance (FSI)	(4, 5, 6)	(1/6, 1/5, 1/4)
FSI-VSI	(5, 6, 7)	(1/7, 1/6, 1/5)
Very strong importance (VSI)	(6, 7, 8)	(1/8, 1/7, 1/6)
VSI-AI	(7, 8, 9)	(1/9, 1/8, 1/7)
Absolute importance (AI)	(8, 9, 9)	(1/9, 1/9, 1/8)

Step 2 (construction of the hierarchy). In this step hierarchical construction of the problem was prepared as shown in Figure 5.

Step 3 (determining the weights of the criteria). In this step, first, linguistic variables for Fuzzy importance level are determined as shown in Table 3 [75]. Then, criteria are compared pairwisely using linguistic variables as shown in Table 4. Then using fuzzy AHP methodology with Chang Algorithm [76], weights of the criteria are calculated as shown in Table 5.

Step 4 (construction of the decision matrix). In this step, first, linguistic variables for fuzzy evaluation of alternatives are determined as shown in Table 6. Then alternatives are evaluated by using these fuzzy linguistic variables as presented in Table 7. Then fuzzy decision matrix of fuzzy TOPSIS ($\widetilde{D}$) is constituted as shown in Table 8.

Step 5 (construction of the normalized decision matrix). In this step, the normalized decision matrix $\widetilde{R} = [\widetilde{r}_{ij}]_{mxn}$ is constituted by (6). Normalized decision matrix for the LSP selection problem is shown in Table 9.

Step 6 (construction of the weighted standard decision matrix). The weighted normalized decision matrix is constituted by multiplying the normalized decision matrix by its associated weights by (7). Weighted normalized matrix for the LSP selection problem is shown in Table 10.

Step 7 (construction of ideal positive (A^*) and ideal negative (A^-) solutions). We determined FPIS and FNIS as

$$\begin{aligned} A^* &= \{(1,1,1),(1,1,1),(1,1,1),(1,1,1),\\ &\quad (1,1,1),(1,1,1),(1,1,1),(1,1,1)\},\\ A^- &= \{(0,0,0),(0,0,0),(0,0,0),(0,0,0),\\ &\quad (0,0,0),(0,0,0),(0,0,0),(0,0,0)\}. \end{aligned} \tag{12}$$

Step 8 (calculation of separation measures). We calculated the distance of each alternative from FPIS and FNIS. The separation measures (d_i^*, d_i^-) are calculated using the m-dimensional Euclidean distance. The separation measure d_i^* of each alternative is calculated from (9). Similarly, the separation measure d_i^- of each alternative is calculated from (10). Separation measures for LSP selection problem are shown in Table 10.

Step 9 (calculation of relative closeness to ideal solution). In this step, the relative closeness to the ideal solution is calculated from (11) and alternatives are ranked in descending order according to CC_i values. *Relative closeness to ideal solution* for LSP selection problem is shown in Table 11. When the index value of $\overline{C}_i$ lies between 0 and 1, the larger the index value, and the better the performance of the alternatives. According to the closeness coefficient, the ranking order of the three candidates is LSP7, LSP5, and LSP3. Obviously, the best selection is candidate LSP7.

Table 4: Pairwise comparison of criteria with linguistic variables.

Criteria	OTD	*P*	PA	*R*	FB	FR	KS	*F*
OTD	EI	EI-WI	WI	WI-FSI	FSI	FSI-VSI	VSI	VSI-AI
P		Eİ	EI-WI	WI	WI-FSI	FSI	FSI-VSI	VSI
PA			Eİ	EI-WI	WI	WI-FSI	FSI	FSI-VSI
R				Eİ	EI-WI	WI	WI-FSI	FSI
FB					Eİ	EI-WI	WI	WI-FSI
FR						Eİ	EI-WI	WI
KS							Eİ	EI-WI
F								Eİ

Table 5: Fuzzy weights of criteria.

Criteria	*l*	*m*	*u*
OTD	0.18	0.28	0.44
P	0.14	0.22	0.36
PA	0.10	0.17	0.28
R	0.07	0.13	0.21
FB	0.05	0.09	0.15
FR	0.03	0.06	0.10
KS	0.02	0.04	0.07
F	0.01	0.02	0.04

Table 6: Linguistic variables used for TOPSIS [49].

Linguistic variables	Triangular fuzzy numbers	Reverse triangular fuzzy numbers
Mostly bad (MB)	0, 1, 1	1/1, 1/1, 0
Bad (B)	0, 1, 3	1/3, 1/1, 0
Moderately Bad (MB)	1, 3, 5	1/5, 1/3, 1/1
Moderate	3, 5, 7	1/7, 1/5, 1/3
Moderately Good (MG)	5, 7, 9	1/9, 1/7, 1/5
Good (G)	7, 9, 10	1/10, 1/9, 1/7
Mostly good (MG)	9, 10, 10	1/10, 1/10, 1/9

Table 7: Evaluation of alternatives with linguistic variables.

	OTD	*P*	PA	*R*	FB	FR	KS	*F*
LSP1	MG	G	M	MG	MG	G	G	MG
LSP2	B	MB	MG	G	G	G	M	G
LSP3	MG	MB	MG	G	MG	MG	G	MG
LSP4	MG	MG	MG	G	MG	G	G	G
LSP5	MG	MG	MG	MG	MG	MG	G	G
LSP6	G	M	MG	G	G	G	G	MG
LSP7	G	MG	MG	MG	MG	M	MG	MB

5. Conclusion

Outsourcing has become a common practice in many industries, specifically in the logistics activities. Because more companies outsource their logistics operations, selecting appropriate and preferable third party LSPs has increasingly become a critical issue and a strategic decision for companies outsourcing their logistics operations.

This study provides a practical approach and methodology for companies to select the best third party LSP meeting their requirements. LSP selection process started the determination of quantitative and qualitative factors to select the best LSP. In this study LSP provider selection via integrating approach of fuzzy AHP and fuzzy TOPSIS method has been presented. Evaluation criteria were determined as on time delivery (OTD), price (P), product availability (PA), reliability (R), firm's background (FB), firm reputation (FR), knowledge sharing (KS), flexibility (F).

This study proposes a methodology to provide a simple approach to evaluate alternative LSP firms and help decision maker to select the best one. By using improved AHP with fuzzy set theory, the qualitative judgment can be qualified to make comparison more intuition and reduce or eliminate assessment bias in pairwise comparison process. Finally this paper defines an approach that integrates fuzzy TOPSIS algorithm with fuzzy AHP to support LSP evaluation and selection decisions. By means of the extent fuzzy approach, the uncertainty in the data could be effectively represented and processed to make a more effective decision.

As a result of this study, alternative LSP7 is determined as the best LSP which has the highest CC_i level. The company management found the application and results to be satisfactory and decided to work with alternative LSP7.

Researchers such as Kabir [52], Kumar [49], Perçin [59], and Ravi [58] utilized integrated approach of fuzzy AHP and fuzzy TOPSIS for evaluation performance of third party LSPs and selection of appropriate third party LSPs. Our findings are consistent with their findings for efficient usage and reliable results of the proposed methodology in this study.

This study has some limitations. One of them is that only qualitative criteria were used to evaluate performance of LSPs. Quantitative criteria can be used together with qualitative data. Another limitation of this study is that any subcriteria are not used as evaluation criteria, only main criteria are used for evaluation. Another limitation of this study is that the focus of the paper is on LSPs of a tire manufacturing company, but the analysis and methodology of 3PL providers' selection can be successfully adopted by other sectors. Because this study used a small sample size and was performed in the tire manufacturing industry, this situation limits the generalization of the results. To generalize

Table 8: Fuzzy decision matrix.

	On time delivery (OTD)			Price (P)			Product availability (PA)			Reliability (R)			Firm's background (FB)			Firm reputation (FR)			Knowledge sharing (KS)			Flexibility (F)		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
LSP1	9	10	10	7	9	10	3	5	7	9	10	10	9	10	10	7	9	10	7	9	10	9	10	10
LSP2	0	1	3	1	3	5	5	7	9	7	9	10	7	9	10	7	9	10	3	5	7	7	9	10
LSP3	9	10	10	1	3	5	9	10	10	7	9	10	9	10	10	9	10	10	7	9	10	9	10	10
LSP4	9	10	10	5	7	9	5	7	9	7	9	10	9	10	10	7	9	10	7	9	10	7	9	10
LSP5	9	10	10	9	10	10	9	10	10	9	10	10	9	10	10	9	10	10	7	9	10	7	9	10
LSP6	7	9	10	3	5	7	5	7	9	7	9	10	7	9	10	7	9	10	7	9	10	9	10	10
LSP7	7	9	10	5	7	9	9	10	10	5	7	9	5	7	9	5	7	5	5	7	9	1	3	5

Table 9: Standardized Decision Matrix.

	On time delivery (OTD)			Price (P)			Product availability (PA)			Reliability (R)			Firm's background (FB)			Firm reputation (FR)			Knowledge sharing (KS)			Flexibility (F)		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
LSP1	0.9	1	1	0.7	0.9	1	0.3	0.5	0.7	0.9	1	1	0.9	1	1	0.7	0.9	1	0.7	0.9	1	0.9	1	1
LSP2	0	0.1	0.3	0.1	0.3	0.5	0.5	0.7	0.9	0.7	0.9	1	0.7	0.9	1	0.7	0.9	1	0.3	0.5	0.7	0.7	0.9	1
LSP3	0.9	1	1	0.1	0.3	0.5	0.9	1	1	0.7	0.9	1	0.9	1	1	0.9	1	1	0.7	0.9	1	0.9	1	1
LSP4	0.9	1	1	0.5	0.7	0.9	0.5	0.7	0.9	0.7	0.9	1	0.9	1	1	0.7	0.9	1	0.7	0.9	1	0.7	0.9	1
LSP5	0.9	1	1	0.9	1	1	0.9	1	1	0.9	1	1	0.9	1	1	0.9	1	1	0.7	0.9	1	0.7	0.9	1
LSP6	0.7	0.9	1	0.3	0.5	0.7	0.5	0.7	0.9	0.7	0.9	1	0.7	0.9	1	0.7	0.9	1	0.7	0.9	1	0.9	1	1
LSP7	0.7	0.9	1	0.5	0.7	0.9	0.9	1	1	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.5	0.5	0.7	0.9	0.1	0.3	0.5

Table 10: Weighted standardized decision matrix.

	On time delivery (OTD)			Price (P)			Product availability (PA)			Reliability (R)			Firm's background (FB)			Firm reputation (FR)			Knowledge sharing (KS)			Flexibility (F)		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
LSP1	0.162	0.280	0.440	0.098	0.198	0.360	0.030	0.085	0.196	0.063	0.130	0.210	0.045	0.090	0.150	0.021	0.054	0.100	0.014	0.036	0.070	0.009	0.020	0.040
LSP2	0.000	0.028	0.132	0.014	0.066	0.180	0.050	0.119	0.252	0.049	0.117	0.000	0.035	0.081	0.150	0.021	0.054	0.100	0.006	0.020	0.049	0.007	0.018	0.040
LSP3	0.162	0.280	0.440	0.014	0.066	0.180	0.090	0.170	0.280	0.049	0.117	0.210	0.045	0.090	0.150	0.027	0.060	0.100	0.014	0.036	0.070	0.009	0.020	0.040
LSP4	0.162	0.280	0.440	0.070	0.154	0.324	0.050	0.119	0.252	0.049	0.117	0.000	0.045	0.090	0.150	0.021	0.054	0.100	0.014	0.036	0.070	0.007	0.018	0.040
LSP5	0.162	0.280	0.440	0.126	0.220	0.360	0.090	0.170	0.280	0.063	0.130	0.210	0.045	0.090	0.150	0.027	0.060	0.100	0.014	0.036	0.070	0.007	0.018	0.040
LSP6	0.126	0.252	0.440	0.042	0.110	0.252	0.050	0.119	0.252	0.049	0.117	0.000	0.035	0.081	0.150	0.021	0.054	0.100	0.014	0.036	0.070	0.009	0.020	0.040
LSP7	0.126	0.252	0.440	0.070	0.154	0.324	0.090	0.170	0.280	0.035	0.091	0.189	0.025	0.063	0.135	0.015	0.042	0.050	0.010	0.028	0.063	0.001	0.006	0.020

Table 11: Separation measures and relative closeness to ideal solution.

Alternatives	d_i^*	d_i^-	Closeness to ideal solution (CC_i)	Ordering
LSP1	7,056233	4,800213	0,404861	4
LSP2	7,482334	2,840077	0,275137	7
LSP3	7,113461	5,90693	0,453668	3
LSP4	7,135847	4,490351	0,386227	5
LSP5	6,960129	13,03951	0,651987	2
LSP6	7,210204	4,154227	0,365546	6
LSP7	7,132629	35,31464	0,831965	1

the results, similar studies can be performed in different industries with a different data set.

The main contribution of this paper includes application of integrated AHP and TOPSIS framework with support of fuzzy approach to measure the relative strength of the third-party LSPs. We hope that results of this research can be used a reference by the tire companies to select the best logistics service provider partner.

The proposed methodology of this study is easy to implement and quite reliable for ranking the alternatives. Applicability of the proposed methodology has been proposed in a tire company for the selection of the third-party LSPs. The approach can also be applied effectively to help any managerial decision-makings. The findings provide valuable insights for logistics practitioners, academicians, and educators. For further research, other multicriteria evaluation methods can be used and the obtained results can be compared with the ones found in this paper. Also, the methodology of third-party LSPs selection can be successfully adapted to other sectors with different data sets.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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