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The decision-making for selecting cold chain logistics providers in the food industry

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Abstract

The issue of selecting a third-party logistics (3PL) provider is becoming more important for businesses that want to reduce costs and improve customer service. This is especially true in cold chain logistics (CCL), which has challenges in shipping perishable products. The objectives of this study are to: (1) compile and validate the criteria used to select CCL providers using the index of item-objective congruence (IOC) and expert interviews; (2) determine the importance of the criteria (the weights) based on the rank-order centroid (ROC) method; and (3) apply the fuzzy technique for order preference by similarity to an ideal solution (fuzzy TOPSIS) method to choose the appropriate provider in real life. The food industry is used as a case study. As a result, after validation, there are 11 main criteria broken down into 26 sub-criteria. The five most important criteria are found to be on-time delivery, transportation system standard, transportation cost, trust, and accessibility of contact persons in urgency, respectively. A sensitivity analysis was also undertaken to assess the robustness of selection result. The integration of the fuzzy TOPSIS and ROC methods is able to facilitate a logical selection of a CCL provider and allows the decision-making process depends less on the subjectivity of the decision maker.

Keywords: Cold chain logistics, Logistics service provider, Multiple criteria decision-making, Index of item-objective congruence (IOC), Fuzzy TOPSIS

1. Introduction

Nowadays, business competition is more intense due to many factors, such as economic, social, political, and technological conditions. Therefore, manufacturing companies should focus more on strategic decision-making to minimize costs, meet customer needs, and gain a sustainable competitive advantage. According to the 2020 Annual Logistics Report [1], Thailand has total logistics costs of around $63.3 billion with an expansion rate of 14.1% of GDP. Around 46.5% of the total costs fall into the inventory costs, followed closely by transportation and administrative costs, respectively. This is because of the disruption to domestic economic activities and the contraction of exports from the COVID-19 epidemic situation.

Cold chain logistics (CCL) is gaining importance day by day. The term “cold chain” refers to a specific supply chain whose activities and methods assure the preservation of perishable goods at an appropriate temperature [2]. Thus, CCL is used to maintain temperature throughout the logistics process, as well as food quality and safety [3]. The CCL market in Thailand was valued in 2018 at $743 million and is likely to expand continuously by 8% from 2019 to 2022 [4]. CCL includes two main activities: cold chain warehouses and cold chain transportation. Examples of cold chain products are medicines and pharmaceuticals, medical equipment, beverages, vegetables, fruits, and food. The cold chain industry is one of the major contributors to the growth of global economies because the demand for value-added food has increased significantly worldwide over the last decade [5].

Many businesses are attempting to abandon own-account transportation in favor of third-party transportation or outsourcing [6]. A third-party logistics (3PL) provider is a company that provides outsourced logistics services to manufacturers for some or all of their supply activities [7]. It is an expert in transporting goods and providing services efficiently while the organization itself may not [8]. Thus, key benefits of using 3PL providers for any activity are to get more flexibility, efficiency, and customer service levels [9]. Currently, there are many 3PL providers in the market. Therefore, choosing the right service provider is an important strategic choice for business owners [10]. A company can significantly reduce costs, time, and increase their market edge [11]. On the other hand, improper selection decisions will result in negative consequences for business such as revenue and market share losses [12].

The selection of a 3PL provider is a complex issue due to the numerous criteria that must be considered. For this reason, the theory of multiple-criteria decision making (MCDM) is applied in order to make a reasonable decision. The application of MCDM is the use of computational techniques that include numerous criteria and orders of preference in evaluating and selecting the best alternative among many possibilities [13]. Bianchini [14], for instance, applied the analytical hierarchy process (AHP) method to calculate the weights of criteria and then used the technique for order preference by similarity to ideal solution (TOPSIS) to obtain the final ranking results in the selection of 3PL provider. In the same way, Beikkhakhian et al. [15] applied the fuzzy AHP for weighting the criteria and the fuzzy TOPSIS to rank suppliers. From a review of relevant literature, several studies on selecting appropriate providers have been conducted, and the methodologies for evaluating the weight and the decision-making methods used differ depending on the format of the data considered. However, it is found that there are only a few studies that focused on selecting cold chain providers, and the criteria for consideration might be changed according to changed circumstances, which all affect the decision-makers’ thoughts.

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The objectives of this study are to (1) collect and validate the criteria used to select the appropriate CCL provider for entrepreneurs in the food industry, (2) determine the importance weight of each criterion and (3) demonstrate the service provider selection process using the fuzzy TOPSIS method. To achieve these aims, Section 2 presents a review of relevant literature, including studies that applied MCDM techniques to solving a 3PL provider selection problem. Section 3 describes the methodology in detail. Section 4 presents results and discussions. Conclusions appear in Section 5.

2. A review of literature

2.1 The fuzzy TOPSIS method

The employment of 3PL providers is becoming an increasingly crucial issue for organizations seeking greater customer service and cost reduction [16]. There are many studies using MCDM to solve the problem of selecting the appropriate logistics providers. This section presents the research on the MCDM application published in 2018-2022. Singh et al. [17] applied the fuzzy AHP to rank the criteria for 3PL selection and fuzzy TOPSIS to determine the best performance of 3PL for outsourcing the logistics activities of perishable products. Jovcic et al. [6] introduced TOPSIS for selecting a 3PL service provider in the territories of the Czech Republic and Poland. Reyes and Colmenero [18] used the MCDM model for outsourcing logistics in an uncertain environment by prioritizing the company's policies. Priority and weight were determined using fuzzy stepwise weight assessment ratio analysis, and the rank of alternatives was analyzed using fuzzy TOPSIS. In addition, Yazdani et al. [19] provide a two-stage decision-making process for selecting suppliers in the dairy industry. The main purpose of the fuzzy TOPSIS method is to reduce unclear expert inputs, and it then determines and assigns economic order quantities to each supplier by utilizing TOPSIS scores as inputs to a linear programming (LP) model. According to a review of the relevant literature, the TOPSIS and AHP methods are commonly used in logistics provider selection problems.

TOPSIS is a highly reliable instrument for determining the preferences of 3PL service providers. In this study, the TOPSIS method was chosen to select the appropriate cold chain logistics providers because it is effective for problems with numerous criteria or alternatives. For the AHP method, if the problem has many criteria to consider, the decision makers may become confused with a lot of required pairwise comparisons. Additionally, the TOPSIS method is less judgmental because it selects the best alternative by comparing the evaluation results of all alternatives on each criterion.

When the decision relies on subjective judgments, it has been discovered that in most cases, humans tend to use feelings primarily and perceive the same information with different feelings, which are uncertain. In other words, it might be difficult or ambiguous to specifically state if something is all “good” or “bad” because there is a gap between “good” and “bad”. To model the uncertainty in humans’ subjective judgments, many previous studies used fuzzy logic to solve supplier selection problems. For example, Puška and Stojanović [20] applied fuzzy methodologies to green supplier selection in the agri-food industry. Thus, this study introduced fuzzy logic combined with the TOPSIS method to facilitate the logical selection of CCL providers. The fuzzy TOPSIS method was developed in 2000 by Chen to improve the capabilities of the traditional TOPSIS method, aiming to solve the problem of qualitative criteria that are difficult to measure accurately.

2.2 The Rank-Order Centroid (ROC) method

The weights of the criteria are important to decision-making. Several methods are being developed to account for the criteria prioritization. In this paper, the rank-based weighting methods are presented. They have the advantage of being simple to implement and calculate [21]. They simply allow decision makers to prioritize the existing criteria and calculate the relative weights according to the specified mathematical equations. In the case of group decision-making, where the thoughts of many individual decision makers are considered, it tends to be difficult to reach a consensus on the weight value of each criterion. Asking the decision makers to only rank the criteria might be a better way to receive a consensus. Furthermore, rank-based methods are also applicable in time-constrained situations or when decision makers have limited knowledge of complex weighting methods.

There are several methods for converting the priority of criteria to a weight, such as Ranking sum (RS), Ranking exponent (RE), Ranking reciprocal (RR), Ranking-order centroid (ROC), etc. [22]. Studying the weighting model of the RS, RR, and ROC methods by varying the number of criteria, it was found that ROC tended to weight the difference between the most significant and least significant criterion. According to Ahn and Park [23] and Wang and Zionts [24], ROC is the most accurate, reliable, and relevant for decision-makers’ intuitive feelings.

3. Methods

This section explains the research methodology used to solve the problem of selecting a 3PL service provider. This proposed model is divided into four sections. The first section is the employment of the index of item-objective congruence (IOC) method in validating the list of criteria. The criteria were primarily collected from relevant literature that was not industry specific and then synthesized. The criteria that had the same meaning were grouped to form a single phrase. The IOC method and interviews with industry experts were then used to assess their content validity. Content validity indicates that the measuring instrument has a comprehensive list that actually measures what it is intended to measure [25]. The IOC method has the advantage that it is practical, especially when the opinions of experts influence the validity of an instrument. It also offers quantitative scores to recommend improvement in addition to expert judgments [26].

For this study, content validity was used to ensure that the synthetic criteria were consistent with the context of the selection of cold chain logistics providers in the food industry. Seven experts, consisting of four logistics managers from three large food companies and three academics in the field of logistics and supply chain management, were invited to participate. Both logistics managers and academics have five years or more of work experience. The number of experts that would be appropriate for such an assessment is between five and ten [27].

The IOC method was developed by Rovinelli and Hambleton in 1977 by requiring experts to evaluate each criterion using a rating of “+1” (the criterion is clearly measuring), “0” (the criterion is unclearly measuring), and “-1” (the criterion is clearly not measuring) [27, 28]. Then, criteria with average scores lower than 0.5 were eliminated. In addition, qualitative interviews were conducted. The experts were asked to explain why they rated a criterion as irrelevant or unimportant in order to support the adjustment of the criteria.

The list of criteria was then updated according to the obtained information. Data from experts is collected in a single round because this method provides both quantitative and qualitative data, as described above, which is sufficient to measure the content validity.

The second section is about the process of weighting criteria using the ROC method. In this study, thirty food cold chain entrepreneurs in Thailand were asked to give a ranking of the importance of the main criteria and the sub-criteria belonging to each main criterion. The relative weights of the criteria and the sub-criteria from each person were calculated based on Equation (1), where n is the total number of criteria (or sub-criteria), r_j is the rank of criterion j ($j = 1,2,\dots,n$) [21]. The weights from all decision makers were next averaged, and the new ranking of criteria could be determined based on the averages. From the new ranking, the new relative weights were then recalculated using the ROC method. Finally, the global weight of each sub-criterion is found by multiplying its local weights by the local weight of the main criterion it belongs to.

$$W_j = \frac{1}{n}\sum_{k=j}^{n}\frac{1}{r_k} \quad (1)$$

The third section is the application of the fuzzy TOPSIS method for selecting the appropriate cold chain logistics provider for entrepreneurs in the food industry. There are three alternatives, namely P1, P2, and P3, which provide logistics services in Thailand. In the following, we describe the detailed provider selection process. The triangular fuzzy number is used in the assessment to analyze the best alternative in decision-making, which has the following steps [29].

Step 1. Convert the decision makers' scores of each alternative on each criterion to triangular fuzzy numbers (TFNs) as shown in Table 1.

Table 1 Triangular fuzzy numbers of each linguistic variable [30].

Linguistic Variables	TFNs
Very Poor, VP	(1, 1, 3)
Poor, P	(1, 3, 5)
Fair, F	(3, 5, 7)
Good, G	(5, 7, 9)
Very Good, VG	(7, 9, 9)

Step 2. Compute the aggregated value from all decision makers in the form of a triangular fuzzy number according to Equation (2).

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \quad (2)$$

where a_{ij} is the lowest score of alternative *i* on criterion *j*; c_{ij} is the highest score of alternative *i* on criterion *j*; and b_{ij} is the average score of alternative *i* on criterion *j* from all decision makers.

Step 3. Use the proportional normalization method, Equation (3), to transform the evaluation results for all criteria to be in the same standard.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_i^+}, \frac{b_{ij}}{c_i^+}, \frac{c_{ij}}{c_i^+}\right); \quad c_i^+ = \max_j c_{ij} \quad (3)$$

Step 4. Multiply $\tilde{r}_{ij}$ by the relative weight of criterion *j* according to the following equation.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times \widetilde{w}_j \quad (4)$$

where $\tilde{v}_{ij} = (v_{ij}^1, v_{ij}^2, v_{ij}^3)$.

Step 5. Calculate the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) of all criteria using the following equations.

$$FPIS_j = \max_i v_{ij}^3 \quad (5)$$

$$FNIS_j = \min_i v_{ij}^1 \quad (6)$$

Step 6. Calculate the distance from the positive ideal solution and the negative ideal solution of each alternative from the equation given. Note that $\tilde{A}_1$ and $\tilde{A}_2$ exemplify two TFNs,

$\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$.

$$d_v(\tilde{A}_1, \tilde{A}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (7)$$

Then sum the distance of FPIS and FNIS in each alternative using the following equation.

$$d_{PIS_i} = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, FPIS_j\right) \tag{8}$$

$$d_{NIS_i} = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, FNIS_j\right) \tag{9}$$

Step 7. Calculate the closeness coefficient (CC_i) of each alternative from the equation below. Subsequently, rank the alternatives using the CC_i. The highest CC_i signifies the most appropriate cold chain logistics provider.

$$CC_i = \frac{d_{NIS_i}}{d_{PIS_i}+d_{NIS_i}} \tag{10}$$

The last section is the sensitivity analysis. In this study, all criteria were given equal weights. Since there are 26 sub-criteria, the weight of each criterion is 0.0385. The new set of CC_i were recalculated using the fuzzy TOPSIS method.

4. Results and discussion

4.1 The preliminary list of criteria from the literature

A review of relevant studies, published between 2006 and 2019 [6, 14, 16, 17, 28, 31-35], shows that these articles used different words despite having the same meaning, such as "delivery" [6, 16, 32, 34] and "on-time rate" [33], "cost" [28, 32, 34] and "price" [6, 16, 31], etc. Therefore, the gathered criteria need to be synthesized and classified to simplify further implementations. Finally, relevant criteria acquired from the literature were synthesized into 11 main criteria and 26 sub-criteria, as presented in Table 2.

Table 2 Initial list of criteria

	Criteria	References
Cost	Transportation cost Warehousing cost	[6, 14, 16, 17, 28, 31-34]
Finance	Financial stability Market share	[16, 31, 32]
Flexibility	Billing flexibility Service flexibility	[17, 28, 31-34]
Service	Breadth of service Characterization of service Value-added services Accessibility of contact persons in urgency Customer's satisfactions	[14, 16, 31-33]
Delivery	On-time delivery	[6, 16, 32-34]
Relationship	Trust Compatibility	[31-33]
Company structure	Corporate culture Labor union Human resource policies	[16, 33]
Professionalism	Business experience	[14, 16, 31, 32]
Quality	Certification standard	[16, 28, 31, 32, 34, 35]
Information and equipment system	Information system for data interchange and tracking Data security Physical equipment	[16, 17, 32, 33]
Others	Social responsibility Location of 3PL providers Safe driving Knowledge skills of employee	[6, 14, 16, 17, 31, 32]

4.2 The IOC results

Table 3 presents results from the IOC method. Ten criteria (38.46%) have an average score of 1, indicating that all experts agreed on the consistency of these criteria in the context under consideration. Twelve criteria (46.15%) have an average score between 0.71 and 0.86, and three criteria (11.54%) have an average score of 0.57. Those are "characterization of service", "corporate culture" and "human resource policies". Characterization of service means service providers use their assets, such as trucks and warehouses, to provide services or do not own assets but contract with other companies to provide services. Some experts disagree, arguing that it does not matter whether the service provider uses their assets or not; what matters is that they can serve efficiently. Three experts are not sure about corporate culture and human resource policies because they relate to unity and employee development. So, they might have an effect on an employee's quality of work. Only one criterion (3.85%) that is "labor union" has an average score below 0.50, so it has been removed from the list. Some experts affirm that labor unions do not relate to the selection of a CCL provider, while others are not sure whether it should be considered or not, since having a good labor union may result in employees' willingness to work.

Moreover, the experts recommended adjusting one criterion which is "certification standard" since the wording used seems to be too general. It can represent a variety of standards, such as organizational management, employees, or vehicles. Therefore, it should be revised to "transportation system standard". Including adding "warranties and claim policies" to the list, as it is a perishable product, this criterion should be taken into consideration. At the conclusion of the validity testing, the final list contains 26 sub-criteria, as summarized in Table 4.

Table 3 The IOC results

Initial list of criteria	IOC scores from experts							IOC average
	1	2	3	4	5	6	7	
(1) Transportation cost	1	1	1	1	1	1	1	1.00
(2) Warehousing cost	1	1	1	1	1	1	1	1.00
(3) Financial stability	1	1	1	1	1	-1	1	0.71
(4) Market share	1	1	0	1	1	0	1	0.71
(5) Billing flexibility	0	1	1	1	0	1	1	0.71
(6) Service flexibility	1	1	1	1	1	1	1	1.00
(7) Breadth of service	1	1	0	1	1	1	1	0.86
(8) Characterization of service	1	1	1	0	1	-1	1	0.57
(9) Value-added services	1	0	1	1	0	1	1	0.71
(10) Accessibility of contact persons in urgency	1	1	1	1	1	1	1	1.00
(11) Customer's satisfactions	1	0	1	0	1	1	1	0.71
(12) On-time delivery	1	1	1	1	1	1	1	1.00
(13) Trust	1	1	1	1	1	1	1	1.00
(14) Compatibility	1	1	1	1	0	1	1	0.86
(15) Corporate culture	1	0	1	1	0	0	1	0.57
(16) Labor union	**0**	**0**	**0**	**0**	**-1**	**0**	**-1**	**-0.29**
(17) Human resource policies	1	0	1	1	0	0	1	0.57
(18) Business experience	1	1	0	0	1	1	1	0.71
(19) Certification standard	1	0	1	0	1	1	1	0.71
(20) Information system for data interchange and tracking	1	1	1	1	1	1	1	1.00
(21) Data security	1	1	1	1	1	1	1	1.00
(22) Physical equipment	1	1	1	1	1	1	1	1.00
(23) Social responsibility	1	0	1	1	1	1	1	0.86
(24) Location of 3PL providers	1	1	1	1	1	1	1	1.00
(25) Safe driving	1	0	1	1	1	1	1	0.86
(26) Knowledge skills of employee	1	0	1	1	1	1	1	0.86

Table 4 List of criteria after the content validity test

Criteria after the content validity test	
Cost	(1) Transportation cost (2) Warehousing cost
Finance	(3) Financial stability (4) Market share
Flexibility	(5) Billing flexibility (6) Service flexibility
Service	(7) Breadth of service (8) Characterization of service (9) Value-added services (10) Accessibility of contact persons in urgency (11) Customer's satisfactions **(12) Warranties and claim policies**
Delivery Relationship	(13) On-time delivery (14) Trust (15) Compatibility
Company structure	(16) Corporate culture (17) Human resource policies
Professionalism	(18) Business experience
Quality	**(19) Transportation system standard**
Information and equipment system	(20) Information system for data interchange and tracking (21) Data security (22) Physical equipment
Others	(23) Social responsibility (24) Location of 3PL providers (25) Safe driving (26) Knowledge skills of employee

4.3 The weighting results

Thirty food cold chain industry entrepreneurs were asked to determine the weight of the criteria based on the ROC method from Equation (1). The results reveal that the top five most important criteria are as follows: on-time delivery, transportation system standard, transportation cost, trust, and accessibility of contact persons in urgency, respectively.

Most entrepreneurs placed a high value on on-time delivery because the products delivered are perishable foods that can spoil or deteriorate over time. Therefore, it was considered crucial, and this was consistent with the studies of [16] and [6] which discovered that on-time delivery was the major criterion for selecting a service provider. For the transportation system standard, in order to avoid contamination and maintain food quality, service providers should implement regulations that ensure the transportation system fulfills criteria. Before shipping, drivers can use a checklist to check the temperature and placement area. This is to ensure that the products are kept at the right temperature and in a clean environment throughout the transit route. Transportation cost comes next. It relates to the rates of transportation charges. Service providers should have a marketing plan in place, such as offering special discounts to members or offering a predetermined fee to compete with other service providers in the market. Trust is another criterion that many entrepreneurs addressed. It is an important foundation for conducting business. Therefore, the service provider organization should have a strict procedure for maintaining the products to prevent product loss. Accessibility of contact persons in urgency is another criterion that service company should consider. There should be a call center system to serve customers. If a customer has a problem or has any queries, service providers should be able to quickly solve problems and provide immediate advice to customers. The global weights of all sub-criteria are shown in Table 5.

4.4 The result of cold chain logistics provider selection

The results from Table 6 were obtained after converting the decision makers' scores to TFNs, collecting TFNs from thirty decision makers from Equation (2), normalizing them to the same standard as from Equation (3), and then multiplying the weight from Table 5 with the normalized results according to Equation (4).

Table 5 Weight of criteria

Criteria	Sub-Criteria (*Cj*)	Weight (*Wj*)	Ranking
Delivery	**C1 On-time delivery**	**0.2745**	**1**
Quality	**C2 Transportation system standard**	**0.1836**	**2**
Service	**C3 Accessibility of contact persons in urgency**	**0.0564**	**5**
	C4 Warranties and claim policies	0.0334	9
	C5 Breadth of service	0.0219	11
	C6 Value-added services	0.0142	15
	C7 Customer's satisfactions	0.0084	18
	C8 Characterization of service	0.0038	23
Cost	**C9 Transportation cost**	**0.0809**	**3**
	C10 Warehousing cost	0.0270	10
Relationship	**C11 Trust**	**0.0639**	**4**
	C12 Compatibility	0.0213	12
Information and equipment system	C13 Information system for data interchange and tracking	0.0409	6
	C14 Data security	0.0186	14
	C15 Physical equipment	0.0074	19
Flexibility	C16 Billing flexibility	0.0389	7
	C17 Service flexibility	0.0130	17
Professionalism	C18 Business experience	0.0388	8
Finance	C19 Financial stability	0.0206	13
	C20 Market share	0.0069	20
Company structure	C21 Corporate culture	0.0130	16
	C22 Human resource policies	0.0043	21
Others	C23 Safe driving	0.0043	22
	C24 Social responsibility	0.0022	24
	C25 Location of 3PL providers	0.0012	25
	C26 Knowledge skills of employee	0.0005	26

Table 6 The weighted normalized scores

Criteria	P1	P2	P3
C1	(0.0915, 0.2257, 0.2745)	(0.0915, 0.2501, 0.2745)	(0.0915, 0.2135, 0.2745)
C2	(0.1020, 0.1673, 0.1836)	(0.0612, 0.1510, 0.1836)	(0.1020, 0.1632, 0.1836)
C3	(0.0188, 0.0489, 0.0564)	(0.0063, 0.0376, 0.0564)	(0.0188, 0.0439, 0.0564)
C4	(0.0186, 0.0282, 0.0334)	(0.0111, 0.0275, 0.0334)	(0.0186, 0.0304, 0.0334)
C5	(0.0073, 0.0180, 0.0219)	(0.0073, 0.0175, 0.0219)	(0.0073, 0.0170, 0.0219)
C6	(0.0047, 0.0120, 0.0142)	(0.0016, 0.0114, 0.0142)	(0.0047, 0.0107, 0.0142)
C7	(0.0047, 0.0071, 0.0084)	(0.0009, 0.0060, 0.0084)	(0.0028, 0.0069, 0.0084)
C8	(0.0021, 0.0034, 0.0038)	(0.0004, 0.0032, 0.0038)	(0.0021, 0.0030, 0.0038)
C9	(0.0270, 0.0665, 0.0809)	(0.0270, 0.0629, 0.0809)	(0.0270, 0.0611, 0.0809)
C10	(0.0150, 0.0258, 0.0270)	(0.0030, 0.0198, 0.0270)	(0.0090, 0.0222, 0.0270)
C11	(0.0355, 0.0553, 0.0639)	(0.0071, 0.0482, 0.0639)	(0.0355, 0.0553, 0.0639)
C12	(0.0118, 0.0184, 0.0213)	(0.0024, 0.0161, 0.0213)	(0.0071, 0.0175, 0.0213)
C13	(0.0227, 0.0355, 0.0409)	(0.0045, 0.0318, 0.0409)	(0.0136, 0.0300, 0.0409)
C14	(0.0103, 0.0165, 0.0186)	(0.0062, 0.0149, 0.0186)	(0.0103, 0.0157, 0.0186)
C15	(0.0041, 0.0069, 0.0074)	(0.0025, 0.0063, 0.0074)	(0.0041, 0.0063, 0.0074)
C16	(0.0130, 0.0345, 0.0389)	(0.0043, 0.0294, 0.0389)	(0.0130, 0.0328, 0.0389)
C17	(0.0043, 0.0112, 0.0130)	(0.0043, 0.0104, 0.0130)	(0.0072, 0.0109, 0.0130)
C18	(0.0216, 0.0345, 0.0388)	(0.0043, 0.0336, 0.0388)	(0.0216, 0.0328, 0.0388)
C19	(0.0069, 0.0169, 0.0206)	(0.0069, 0.0160, 0.0206)	(0.0069, 0.0151, 0.0206)
C20	(0.0023, 0.0058, 0.0069)	(0.0023, 0.0058, 0.0069)	(0.0023, 0.0053, 0.0069)
C21	(0.0043, 0.0107, 0.0130)	(0.0014, 0.0090, 0.0130)	(0.0043, 0.0098, 0.0130)
C22	(0.0014, 0.0037, 0.0043)	(0.0005, 0.0032, 0.0043)	(0.0024, 0.0035, 0.0043)
C23	(0.0024, 0.0039, 0.0043)	(0.0014, 0.0035, 0.0043)	(0.0014, 0.0033, 0.0043)
C24	(0.0012, 0.0019, 0.0022)	(0.0002, 0.0016, 0.0022)	(0.0007, 0.0017, 0.0022)
C25	(0.0007, 0.0010, 0.0012)	(0.0001, 0.0008, 0.0012)	(0.0007, 0.0010, 0.0012)
C26	(0.0003, 0.0005, 0.0005)	(0.0001, 0.0004, 0.0005)	(0.0003, 0.0005, 0.0005)

FPIS and FNIS for each criterion computed from Equations (5) and (6) are as follows:

FPIS = {0.2745, 0.1836, 0.0564, 0.0334, 0.0219, 0.0142, 0.0084, 0.0038, 0.0809, 0.0270, 0.0639, 0.0213, 0.0409, 0.0186, 0.0074, 0.0389, 0.0130, 0.0388, 0.0206, 0.0069, 0.0130, 0.0043, 0.0043, 0.0022, 0.0012, 0.0005}

FNIS = {0.0915, 0.0612, 0.0063, 0.0111, 0.0073, 0.0016, 0.0009, 0.0004, 0.0270, 0.0030, 0.0071, 0.0024, 0.0045, 0.0062, 0.0025, 0.0043, 0.0043, 0.0043, 0.0069, 0.0023, 0.0014, 0.0005, 0.0014, 0.0002, 0.0001, 0.0001}

The distances from the positive ideal solution and the negative ideal solution of each alternative computed from Equations (7) to (9) are shown in Table 7. The closeness coefficients (CC_i) are shown in Table 8. It was found that "P1" has the highest closeness coefficient, so it should be selected, followed by "P3" and "P2", respectively. When considering the distance from the positive and negative ideal solutions in Table 7, it was discovered that "P1" is closest to the positive ideal solution and farthest from the negative ideal solution.

Table 7 The distance from PIS and NIS

	P1	**P2**	**P3**
d_{PIS_i}	0.3366	0.4418	0.3547
d_{NIS_i}	0.5667	0.5366	0.5475

Table 8 Closeness coefficient

	P1	**P2**	**P3**
CC_i	0.6274	0.5485	0.6068
Rank	1	3	2

4.5 The result of sensitivity analysis

The result of the sensitivity analysis from Table 9 and Table 10 showed that "P1" was still selected as the most appropriate service provider, followed by "P3" and "P2", respectively. The outcome is the same as with the previous provider selection. It demonstrates that the result has strong robustness because changes in the input data did not affect the rank of alternatives. However, the sensitivity analysis of this study is based on the constraint that no additional comments from decision makers be considered.

Table 9 The distance from PIS and NIS of sensitivity analysis

	P1	**P2**	**P3**
d_{PIS_i}	0.3207	0.4774	0.3494
d_{NIS_i}	0.6224	0.5672	0.5963

Table 10 Closeness coefficient of sensitivity analysis

	P1	**P2**	**P3**
CC_i	0.6600	0.5430	0.6305
Rank	1	3	2

5. Conclusions

Outsourcing logistics has become a commercial concern as a result of the increasing globalization of business activities and cost pressure. It is challenging to choose the appropriate logistics service because there are many service providers in the market. In this study, we aim to collect criteria that truly influence the selection of 3PL providers via the IOC method, determine the weight of each criterion using the ROC method, and demonstrate the process of provider selection through the fuzzy TOPSIS method.

After the validity test, the term "labor union" has been eliminated, and the term "certification standard" has been changed to "transportation system standard" including adding "warranties and claim policies" as recommended by most experts. Ultimately, there are 26 sub-criteria remaining for further consideration, which can be classified into 11 main criteria.

On-time delivery, transportation system standard, transportation cost, trust, and accessibility of contact persons in an emergency are the top five most important criteria. Calculating the weight of a criterion using the ROC method is straightforward and quick; the evaluator simply ranks the criterion without assigning a numerical weight. From the calculation for selecting a logistics provider based on fuzzy TOPSIS, in the case presented, it was found that "P1" has the highest closeness coefficient, therefore it is considered to be the most appropriate provider. And when the scores from all the criteria were summed up, it was found that "P1" had the overall performance farthest from the negative ideal. At the same time, it is closest to the positive ideal. As a result, it is regarded as having the best overall performance. The entire selection process is based solely on the importance of criteria and the results of the assessment of each provider given by the evaluators. This is a less subjective decision than many other MCDM methods. When considering the results of the sensitivity analysis, it was found that the rank of alternatives did not change. Therefore, decision-makers can be confident that the results are highly robust. The sensitivity of the analysis is considered to understand the influence of data in decision-making. In the case of multiple decision-makers, it can also reduce dissatisfaction with the results.

A future study may try to compare the results from the methodology provided with other membership functions, e.g., trapezoidal membership function, gaussian membership function, etc. In order to explore how changes in membership functions affect the ranking results.

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