



Article Outsourcing Reverse Logistics for E-Commerce Retailers: A Two-Stage Fuzzy Optimization Approach

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Abstract: On the heels of the online shopping boom during the Covid-19 pandemic, the electronic commerce (e-commerce) surge has many businesses facing an influx in product returns. Thus, relevant companies must implement robust reverse logistics strategies to reflect the increased importance of the capability. Reverse logistics also plays a radical role in any business's sustainable development as a process of reusing, remanufacturing, and redistributing products. Within this context, outsourcing to a third-party reverse logistics provider (3PRLP) has been identified as one of the most important management strategies for today's organizations, especially e-commerce players. The objective of this study is to develop a decision support system to assist businesses in the selection and evaluation of different 3PRLPs by a hybrid fuzzy multicriteria decision-making (MCDM) approach. Relevant criteria concerning the economic, environmental, social, and risk factors are incorporated and taken into the models. For obtaining more scientific and accurate ranking results, linguistic terms are adopted to reduce fuzziness and uncertainties of criteria weights in the natural decision-making process. The fuzzy analytic hierarchy process (FAHP) is applied to measure the criteria's relative significance over the evaluation process. The fuzzy technique for order preference by similarity to an ideal solution (FTOPSIS) is then used to rank the alternatives. The prescribed method was adopted for solving a case study on the 3PRLP selection for an online merchant in Vietnam. As a result, the most compatible 3PRLP was determined. The study also indicated that "lead time," "customer's voice," "cost," "delivery and service," and "quality" are the most dominant drivers when selecting 3PLRLs. This study aims to provide a more complete and robust evaluation process to e-commerce businesses and any organization that deals with supply chain management in determining the optimized reverse logistics partners.

Keywords: reverse logistics; recycling; outsource; e-commerce; triangular fuzzy number; FAHP; FTOPSIS; decision making; sustainability

MSC: 90B50; 03E72; 74P05; 74P20; 90B06

1. Introduction

In recent years, reverse logistics has become a key component of any successful streamlined supply chain. Today's global value chains require greater resilience and efficiencies in the flow of goods between and within countries. Sustainability in the supply chain has become a strategic intent for almost all businesses, and reverse logistics practice is key to the effort. In maximizing the value recovery and safe disposal of waste, reverse logistics expands products at the end of their life cycles through some activities such as resell, refurbish, remanufacture, and recycle, to name a few [1]. Besides optimizing value and sustainability for businesses, the reverse logistics issue that directly impacts supply chains the most is to manage the return of products from the end consumer back to the



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). manufacturer. With online shopping becoming increasingly prevalent, the reverse loop has never been so prominent in global supply chains. In an e-commerce-focused era in which customers are returning products at an increasing rate in various industry sectors, e-merchants and other retailers are at a critical juncture, as any continued lack of focus on reverse logistics will be unsustainable. Online purchases are being returned three times more often than store purchases [2]. This statistic means reverse logistics supply chain management has become a necessity for online merchants to maintain a balanced inventory turn and operating expenses. Additionally, the unprecedented crisis by the Covid-19 pandemic has brought inexorable growth to the e-commerce sector, which is expected to lead to an even higher volume of returned goods. Undoubtedly, this trend will endure in a post-Covid-19 world. Accordingly, reverse logistics has a significant effect on customer relationships and, most significantly, leads to sustainability and long-term profitability of business operations.

Expected to reach 603.9 billion USD by 2025 [3], reverse logistics, when optimized, can increase customer satisfaction and return on investment (ROI). Simply put, reverse logistics in e-commerce refers to the return process, which is the collection of all activities of goods that move in the reverse direction, i.e., from their point of consumption back to the business. The most critical processes are customer support, physical movement of goods, warehousing, triage, repairs, and after-sales support [4]. An easy and hasslefree return process can gain customer engagement and loyalty. As a result, functional and efficient reverse logistics has become a pivotal element for e-commerce businesses. However, most companies are not able to manage their reverse logistics networks. Due to the complicated process and resource constraints, more and more businesses choose to outsource third-party companies to handle their reverse e-commerce services and optimize the return process. Third-party reverse logistics providers (3PRLP) are delegated to help companies productively manage returned currents of products at optimal cost. Hence, evaluating and selecting the best 3PRLP is an imperative and complicated task that must be undertaken prudently [5] for businesses, especially e-commerce merchants and other retailers, to facilitate an effective reverse logistics process and retain customers.

Given the abovementioned importance of reverse logistics outsourcing to the industries, the relevant literature on potential sectors in developing countries is sparse, taking the e-commerce sector in Vietnam as a good example. This gap has formed our research motivation. The current study aims to address this gap by investigating reverse logistics outsourcing practices in Vietnam. According to Google, Vietnam is ranked the secondfastest-growing e-commerce market in Southeast Asia, following Indonesia [6]. Vietnam's e-commerce has been growing from about 28 percent in 2017 to nearly half of the population in 2020 [7]. It is also forecast that the country's e-commerce market will hit 15 billion USD by 2025 [8]. While e-commerce giants in Vietnam such as Tiki, Lazada, and Grab have already developed their own logistics sector (warehousing, packing, shipping, and reverse logistics), most other online merchants (including some major players like Shopee and Sendo) are not able to operate an in-house logistics, therefore opt to delegate these activities to third-party logistics providers. Thus, it creates great opportunities and a promising market for e-commerce logistics. According to the 2017 logistics report of the Ministry of Industry and Trade, Vietnam has about 50 enterprises providing e-logistics services [9]. With the need for fast, immediate, and on-demand delivery from customers who shop online, more and more e-logistics startups have entered this market. Providing the volume of e-commerce transactions increasing, logistics providers have to handle large volumes of returned goods. In Vietnam, wrong shipping addresses (especially in rural areas) and unsuccessful orders are daunting challenges faced by both e-commerce retailers and e-logistics businesses. Moreover, competition in terms of delivery speed and costs are factors that can distinguish the best third-party logistics providers.

Moreover, the literature on outsourcing 3PRLP is still limited because of its recent emergence and demand from stakeholders. This lack, therefore, attracted our attention. In this paper, the authors aim to efficiently assist the decision-makers in evaluating and selecting the most sustainable 3PRLP by proposing a robust hybrid multicriteria decisionmaking (MCDM) approach. Among MCDM methods, the analytic hierarchy process (AHP) and the technique for order preference by similarity to an ideal solution (TOPSIS) are two classical and most commonly used techniques. Conventional AHP and TOPSIS have been combined in different ways and investigated in many studies. In these methods, the criteria weights are often determined by AHP, and TOPSIS ranks the alternatives. Some exemplary studies are as follows. In the basic combination of the AHP-TOPSIS approach, the evaluations about criteria and alternatives are all supposed to be deterministic numbers [10]. In the integration of AHP and the fuzzy TOPSIS method applied in [11], the criteria weights determined by AHP are real numbers, and the evaluations of alternatives with respect to different criteria are in linguistic terms. Meanwhile, linguistic terms are adopted to evaluate criteria, and real numbers are used to assess alternatives in [12]. As a further improvement to the existing literature of reverse logistics outsourcing in terms of methodologies, this paper combines fuzzy AHP (FAHP) and fuzzy TOPSIS (FTOPSIS), by which linguistic terms in evaluations of both criteria and alternatives are adopted. This adoption's motive is that experts are often reluctant or unable to assign accurate values during the decision-making process. Thus, they prefer to provide their evaluations in linguistic terms, reflecting their uncertain, ambiguous, and vague judgment. In light of this, fuzzy set theory is a useful method for dealing with uncertainty. The decision model may include unknown, incomplete, and inaccessible information and partially ignorant data. During the whole evaluation process, the linguistic terms are converted into triangular fuzzy numbers.

The research procedure is described as follows. In the first stage, FAHP is applied for determining the fuzzy preference weights of the criteria. The evaluation process's criteria concern economic factors (quality, cost, lead time, delivery and service, R&D capability), environmental factors (recycle, disposal, reproduction, and reuse, green technology, CO_2 emissions), social factors (health and safety, customer's voice, reputation), and risk factors (operation risk, financial risk). In the next stage, FTOPSIS is used to rank all alternatives, offering the optimized 3PRLPs. An application of selecting 3PRLPS for an e-commerce business in Vietnam is presented, simultaneously demonstrating the suggested method. In doing so, this study makes novel contributions to the field by providing a complete and robust evaluation process for 3PRLP selection in the e-commerce sector for a developing country in Asia which is almost neglected in the literature. As a result, this paper provides a holistic framework for businesses with theoretical and managerial implications as a robust decision support system in solving the reverse logistics outsourcing problem.

The paper unfolds as follows. In the next section, a literature review on reverse logistics outsourcing is reviewed. Section 3 summarizes the materials and methods of FAHP and FTOPSIS used in the paper. Result analysis of a case study in Vietnam is shown in Section 4. Finally, Section 5 offers the managerial insights and conclusions of the paper.

2. Literature Review

Concerning the well-developed status of research on outsourcing 3PRLP, multiple criteria decision-making (MCDM) techniques that simultaneously consider various desired selection criteria in different dimensions have appeared to be promising for this task. Literature and practice show that economic, environmental, and social factors are dominant decision-making variables in selecting a sustainable provider of reverse logistics services [13–15]. Sustainable development (economic, environmental, and social aspects) lead organizations to reverse logistics practices (Figure 1) [16]. To determine a qualified provider in the outsourcing process, the proposed evaluation approach and the set of criteria are two quintessential parts [17]. Many notable studies have applied various MCDM techniques that consider different criteria to evaluate and select the best 3PRLP. For example, Tavana et al. [18] proposed an integrated intuitionistic fuzzy AHP and SWOT method

for solving the reverse logistics outsourcing problem faced by a company. Their findings indicated that when delegating reverse logistics activities to 3PRLPs, it is the most significant priority for a firm to focus on its core business; meanwhile, reducing costs constitutes one of its least important priorities. In the study of Zarbakhshnia et al. [5], a multiple attribute decision making (MADM) model to rank and select the sustainable third-party reverse logistics providers in the presence of risk factors was proposed, and a realistic case study in the automotive industry was applied to demonstrate the model's effectiveness. Bai and Sarkis [19] first introduced the use of neighborhood rough set, TOPSIS, and VIKOR as a proper and realistic modeling approach for 3PRLPs evaluation and selection using economic/business, environmental, and social (sustainability) factors.



Figure 1. Three pillars of sustainable development [16].

In the management science and decision-making literature, discussing reverse logistics outsourcing issues has become an increasingly important topic. Various criteria and approaches have been considered in the literature. In terms of criteria, businesses traditionally examine cost, quality, and flexibility [19]. For organizations that seek longterm resilience of reverse supply chains, social and environmental concerns are considered sustainability factors [20–22]. Regarding methodologies, numerous evaluation models based on MCDM techniques for outsourcing 3PRLP have been introduced ranging from analytical hierarchy process (AHP) [23-27], fuzzy AHP [28,29], analytic network process (ANP) [30–32], fuzzy ANP [33], technique for order preference by similarity to ideal solution (TOPSIS) [19,27,34,35], fuzzy TOPSIS [36], visekriterijumska optimizacija i kompromisno resenje (VIKOR) method [19,31,33,37], step-wise weight assessment ratio analysis (SWARA) [38,39], quality function deployment (QFD) model [28,40], data envelopment analysis (DEA) [26,35,41,42], other MCDM methods [30–34,38,39,43], exact methods (mathematical programming) [26,37,43–45], and statistical approaches [40,46–48]. Table 1 presents a summary of the literature review on proposed approaches for 3PRLP selection and evaluation problems.

							Method	lologie	s				P	roblem	IS
No.	Authors [Citation]	Year	AHP	ANP	TOPSIS	VIKOR	SWARA	QFD	Other MCDM	DEA	Mathematical Model	Statistical Approach	Deterministic	Uncertain	Reverse Logistics
1	Korpela and Tuominen [23]	1996	х										x		
2	Moberg and Speh [46]	2004										х	x		
3	Sinkovics and Roath [47]	2004										х	x		
4	Thakkar et al. [30]	2005		х					х				х		х
5	So et al. [24]	2006	x										х		
6	Bottani and Rizzi [36]	2006			х									х	
7	Sahay et al. [44]	2006									х		х		
8	Göl and Çatay [25]	2007	х										x		
9	Yang et al. [48]	2008										x	x		
10	Zhou et al. [41]	2008								x			x		
11	Hamdan and Rogers [42]	2008								х			x		
12	Kannan et al. [34]	2009			х				х				x		
13	Liu and Wang [45]	2009									x			х	
14	Liou et al. [31]	2010		x		x			x				x		
15	Sasikumar and Haq [37]	2011				x					x		x		х
16	Ho et al. [28]	2012	х					x						х	
17	Falsini et al. [26]	2012	х							х	x		x		
18	Hsu et al. [32]	2013		x					x				x		
19	Perçin and Min [40]	2013						x				х		x	
20	Jayant et al. [27]	2014	х		х								x		х
21	Tadić et al. [33]	2014		x		x			x					х	
22	Ilgin [29]	2017	х											х	х
23	Zarbakhshnia et al. [38]	2018					x		x				х		
24	Bai and Sarkis [19]	2019			x	x							x		х
25	Govindan et al. [43]	2019							x		x		x		x
26	Wang et al. [35]	2019			x					x			x		x
27	Agarwal et al. [39]	2020					x		x					x	x
28	This paper	2021	x		x									x	x

Table 1. Summary of method approaches in reverse logistics provider's selection.

Note: analytical hierarchy process (AHP), analytical network process (ANP), technique for order of preference by similarity to ideal solution (TOPSIS), visekriterijumska optimizacija i kompromisno resenje (VIKOR), step-wise weight assessment ratio analysis (SWARA), quality function deployment (QFD), multi-criteria decision making (MCDM), data envelopment analysis (DEA).

Given several methodologies used in the evaluation and selection of 3PRLPs, it can be observed that AHP and TOPSIS methods are the two typical and most commonly used due to their applicability. The foundation of the AHP is a set of axioms that carefully delimits the scope of the problem environment [49]. Among mathematical weighting methods, the pairwise comparison method in the AHP is an effective procedure to determine the importance of different attributes to the objective. Its understandability in theory, simplicity in application, and robustness of its outcomes have been proven in practice and validated by a diverse range of decision-making problems. The TOPSIS method, first introduced in [50], is one of the most well-known classical MCDM methods. Simply stated, in a geometrical sense, the TOPSIS method simultaneously considers the distance to the ideal

solution and negative-ideal solution of each alternative and choosing the closest relative to the ideal solution as the best alternative [27]. In this paper, the authors aim to solve the fuzzy information during the whole evaluation and selection process by considering linguistic terms in both criteria and alternatives, which thereby are converted into triangular fuzzy numbers using the fuzzy set theory. Thus, the gaps in the existing literature are addressed in this paper as follows: (1) methodologically, this is the first study to suggest a hybrid fuzzy decision support system that combines the fuzzy AHP (FAHP) and the fuzzy TOPSIS (FTOPSIS) for the field of reverse logistics outsourcing; (2) in terms of applications, the prescribed approach is used for a case study in Vietnam to support an e-commerce business determining their compatible and sustainable partners for reverse logistics among eight candidates; (3) the managerial implications of this paper provide a comprehensive insight that enables decision analysts to better understand the complete evaluation and selection process of 3PRLPs considering well-rounded aspects. From a broader standpoint, this study can assist e-commerce businesses or any organization to expedite their reverse logistics strategies in this era.

3. Materials and Methods

3.1. Research Process

Decision-making in real-world problems, especially in the evaluation and selection of third-party reverse logistics providers (3PRLP), involves not only quantitative criteria (i.e., cost, lead time) but also quantitative criteria (i.e., the voice of customers, reputation). Fuzzy set theory is useful for handling complex decision-making problems with numerous associated factors. In this paper, among many MCDM models, FAHP and FTOSPS are chosen to select the most efficient providers among alternatives because they are available in decision-making software and allow decision-makers to practice effectively. The process of the paper includes two stages, as can be seen in Figure 2.



Figure 2. Research process.

In the first stage, FAHP is applied to identify fuzzy preference weights of criteria in the outsourcing reverse logistics problem. The list of criteria used in this paper is selected from the relevant literature review (Table 2) and industrial experts' survey. There are four main criteria and 15 criteria including economic (quality, cost, lead time, delivery and service, R&D capability), environment (recycle, disposal, reproduction and reuse, green technology, CO_2 emissions), social (health and safety, customer's voice, reputation), and risk (operational risk, financial risk). In the second stage, FTOPSIS is applied to rank all alternatives. This paper proposed a hybrid approach by combining two MCDM models that can improve the decision-making process. Besides, the problem of outsourcing reverse logistics for e-commerce retailers is addressed under uncertainty environment using fuzzy theory that can enhance the robust results.

Main Criteria	Criteria	Target	Authors [Citation]
	C11. Quality	Max	Bottani and Rizzi [36], Spencer et al. [51], Tsai et al. [52], Zarbakhshnia et al. [38], Mavi et al. [53], Govindan et al. [43], Sasikumar and Haq [37]
Economic (C1)	C12. Cost	Min	Bottani and Rizzi [36], Spencer et al. [51], Tsai et al. [52], Zarbakhshnia et al. [38], Mavi et al. [53], Govindan et al. [43], Sasikumar and Haq [37], Efendigil et al. [54]
	C13. Lead time	Min	Zarbakhshnia et al. [38], Mavi et al. [53], Govindan et al. [43], Efendigil et al. [54]
	C14. Delivery and service	Max	Bottani and Rizzi [36], Spencer et al. [51], Tsai et al. [52], Zarbakhshnia et al. [38], Mavi et al. [53], Govindan et al. [43], Sasikumar and Haq [37], Efendigil et al. [54]
	C15. R&D capability	Max	Bottani and Rizzi [36], Goebel et al. [55], Ni et al. [56]
	C21. Recycle	Max	Zarbakhshnia et al. [38], Mavi et al. [53], Sasikumar and Haq [37], Guimarães and Salomon [57]
	C22. Disposal	Max	Zarbakhshnia et al. [38], Mavi et al. [53], Sasikumar and Haq [37]
Environment (C2)	C23. Reproduction and reuse	Max	Goebel et al. [55], Zarbakhshnia et al. [38], Mavi et al. [53], Sasikumar and Haq [37]
	C24. Green technology	MinBottani and Rizzi [36], [52], Zarbakhshnia Govindan et al. [43] Efend.MinZarbakhshnia et Govindan et al. [MinZarbakhshnia et Govindan et al. [MaxBottani and Rizzi [36], [52], Zarbakhshnia Govindan et al. [43] Efend.MaxBottani and Rizzi [36], 0MaxBottani and Rizzi [36], 0MaxBottani and Rizzi [36], 0MaxBottani and Rizzi [36], 0MaxBottani and Rizzi [36], 0MaxZarbakhshnia et Sasikumar and Haq [37]MaxZarbakhshnia et Sasikumar and Haq [37]MaxGoebel et al. [55], Mavi et al. [53], 5MaxGoebel et al. [53], 5MaxZarbakhshnia et al. [53], 5MaxZarbakhshnia et al. [43] GuimarãesMinZarbakhshnia et al. [43] GuimarãesMinZarbakhshnia et al. [53], 5MaxSpencer et al. [51], Mav Mav MinMinBottani and Rizzi [36] MavMinBottani and Rizzi [36]	Zarbakhshnia et al. [38], Sasikumar and Haq [37], Guimarães and Salomon [57]
	C25. CO_2 emissions	Min	Zarbakhshnia et al. [38], Govindan et al. [43]
	C31. Health and safety	Max	Zarbakhshnia et al. [38], Govindan et al. [43], Mavi et al. [53]
Social (C3)	C32. Customer's voice	Max	Zarbakhshnia et al. [38], Mavi et al. [53], Efendigil et al. [54]
	C33. Reputation	Max	Spencer et al. [51], Mavi et al. [53], Efendigil et al. [54]
Risk (C4)	C41. Operational risk	Min	Zarbakhshnia et al. [38], Mitra et al. [58], Mavi et al. [53]
	C42. Financial risk	Min	Bottani and Rizzi [36], Tsai et al. [52], Ni et al. [56], Mavi et al. [53]

Table 2. List of criteria used in reverse logistics provider's selection.

Note: identified by the researchers.

Fuzzy set theory was introduced by Zadeh [59] to deal with uncertainty problems. A triangular fuzzy number (TFN) is defined as (a, b, c) which denotes pessimistic, most likely, and optimistic values, as shown in Equation (1), and as can be seen in Figure 3.

$$\mu\left(\frac{x}{\widetilde{F}}\right) = \begin{cases} (x-a)/(b-a), & a \le x \le b\\ (c-x)/(c-b), & b \le x \le c\\ 0, & otherwise \end{cases}$$
(1)





The representative of each level of membership function is denoted, as can be seen in Equation (2).

$$\widetilde{F} = (F^{l(y)}, F^{r(y)}) = [a + (b - a)y, c + (b - c)y], y \in [0, 1]$$
(2)

where $F^{l(y)}$, $F^{r(y)}$ denote two sides of the fuzzy number.

3.3. Fuzzy Analytical Hierarchy Process (FAHP)

FAHP is an extension of AHP, which overcomes the drawbacks of AHP, and solves such problems under fuzzy environment. The linguistic expression for fuzzy scale and allocated TFN is shown in Table 3. The procedure of FAHP includes six steps as follows [60].

	Table 3. I	Linguistic	rating le	vel and	allocated	TFN in	the fuzzy	AHP	(FAHP)) model
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Fuzzy Number	Linguistics Rating Level	Allocated TFN
1	Equal importance	(1, 1, 1)
2	Weak importance	(1, 2, 3)
3	Notbad	(2, 3, 4)
4	Preferable	(3, 4, 5)
5	Importance	(4, 5, 6)
6	Fairly importance	(5, 6, 7)
7	Very important	(6, 7, 8)
8	Absolute	(7, 8, 9)
9	Perfect	(8, 9, 10)

Step 1: Build a fuzzy pairwise comparison matrix, as can be seen in Equation (3).

$$\widetilde{M^{k}} = \begin{pmatrix} \widetilde{e_{11}^{k}} & \widetilde{e_{12}^{k}} & \cdots & \widetilde{e_{1n}^{k}} \\ \widetilde{e_{21}^{k}} & \cdots & \cdots & \widetilde{e_{2n}^{k}} \\ \cdots & \cdots & \cdots & \cdots \\ \widetilde{e_{n1}^{k}} & \widetilde{e_{n2}^{k}} & \cdots & \widetilde{e_{nn}^{k}} \end{pmatrix}$$
(3)

where e_{ij}^{k} denotes the important level from *k*th decision-maker with respect to the *i*th criterion over the *j*th criterion using TFN membership function.

Step 2: Assume that a decision group has *K* experts. An integrated fuzzy pairwise comparison matrix can be calculated as Equation (4).

$$\widetilde{M^{k}} = \begin{pmatrix} \widetilde{e_{11}} & \widetilde{e_{12}} & \cdots & \widetilde{e_{1n}} \\ \widetilde{e_{21}} & \cdots & \cdots & \widetilde{e_{2n}} \\ \cdots & \cdots & \cdots & \cdots \\ \widetilde{e_{n1}} & \widetilde{e_{n2}} & \cdots & \widetilde{e_{nn}} \end{pmatrix} \text{ such that } \widetilde{e_{ij}} = \frac{\sum_{k=1}^{K} \widetilde{e_{ij}^{k}}}{K}$$
(4)

Step 3: The fuzzy geometric mean of each criterion is calculated as Equation (5), as follows.

$$\widetilde{r}_i = \left(\prod_{j=1}^n \widetilde{e}_{ij}\right)^{1/n} \text{ such that } i = 1, 2, \dots, n$$
(5)

where $\tilde{r_i}$ denotes the fuzzy geometric mean and $\tilde{e_{ij}}$ denotes the important level from group of decision-maker with respect to the *i*th criterion over the *j*th criterion.

Step 4: Calculate the fuzzy weights of each criterion using Equation (6).

$$\widetilde{w}_i = \widetilde{r}_i (\times) (\widetilde{r}_1 (+) \widetilde{r}_2 (+) \dots (+) \widetilde{r}_n)^{-1}$$
(6)

Step 5: Defuzzify the fuzzy weight using the average weight criteria M_i , as can be seen in Equation (7).

$$M_{i} = \frac{\widetilde{w_{1}}(+)\widetilde{w_{2}}(+)\dots(+)\widetilde{w_{n}}}{n}$$
(7)

Step 6: Calculate the normalized weight criteria N_i as Equation (8).

$$N_i = \frac{M_i}{\sum_{i=1}^n M_i} \tag{8}$$

3.4. Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS)

FTOPSIS is a very useful MCDM model, which is applied to rank different alternatives based on the distance between the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). The process of FTOPSIS includes seven steps below [61].

Step 1: Identify the fuzzy weights of criteria.

In FTOPSIS model, the fuzzy weights of criteria are obtained from FAHP model.

Step 2: Based on the linguistic rating value in Table 4, develop the fuzzy decision matrix, as can be seen in Equations (9) and (10).

$$\widetilde{M} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{11} & \cdots & \widetilde{x}_{11} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \cdots & \widetilde{x}_{mn} \end{bmatrix} \text{ such that } i = 1, 2, \dots, m; \ j = 1, 2, \dots, n \quad (9)$$

$$\widetilde{x}_{ij} = \frac{1}{k} \left(\widetilde{x}_{ij}^1 \left(+ \right) \widetilde{x}_{ij}^2 \left(+ \right) \dots \left(+ \right) \widetilde{x}_{ij}^k \right)$$
(10)

where \tilde{x}_{ij}^k denotes the fuzzy rating of alternative A_i with respect to criteria C_j by *k*th expert, and $\tilde{x}_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k)$.

Step 3: In this step, the fuzzy decision matrix is normalized, as shown in Equations (11)–(13).

$$\widetilde{S} = \left[\widetilde{s}_{ij}\right]_{m \times n} \text{ such that } i = 1, 2, \dots, m; j = 1, 2, \dots, n$$
(11)

$$\widetilde{s}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), c_j^* = max_i \{c_{ij} | i = 1, 2, \dots, m\} \text{ for benefit criteria}$$
(12)

$$\widetilde{s}_{ij} = \left(\frac{a'_j}{c_{ij}}, \frac{a'_j}{b_{ij}}, \frac{a'_j}{a_{ij}}\right), a'_j = \min_i \{a_{ij} | i = 1, 2, \dots, m\} \text{ for cost criteria}$$
(13)

Step 4: Construct the weighted normalized fuzzy decision matrix \tilde{u}_{ij} , Equations (14) and (15).

$$\widetilde{U} = \left[\widetilde{u}_{ij}\right]_{m \times n} \text{ such that } i = 1, 2, \dots, m; j = 1, 2, \dots, n$$
(14)

$$\widetilde{u}_{ij} = \widetilde{s}_{ij} (\times) \widetilde{w}_j \tag{15}$$

Step 5: Determine fuzzy positive ideal solution (FPIS) Q^* and fuzzy negative ideal solution (FNIS) Q' based on Equations (16) and (17).

$$Q^* = \left(\widetilde{u}_1^*, \dots, \widetilde{u}_j^*, \dots, \widetilde{u}_n^*\right)$$
(16)

$$Q' = \left(\widetilde{u}'_1, \dots, \widetilde{u}'_j, \dots, \widetilde{u}'_n\right)$$
(17)

where $\widetilde{u}_{i}^{*} = (1, 1, 1), \, \widetilde{u}_{i}^{\prime} = (0, 0, 0), \, j = 1, 2, \dots, n.$

Step 6: Calculate the distance $(D_i^* \text{ and } D_i')$ of each alternative from FPIS and FNIS, as can be seen in Equations (18) and (19).

$$\widetilde{D}_i^* = \sum_{j=1}^n d\left(\widetilde{u}_{ij}, \widetilde{u}_j^*\right), i = 1, 2, \dots, m$$
(18)

$$\widetilde{D}'_i = \sum_{j=1}^n d\left(\widetilde{u}_{ij}, \widetilde{u}'_j\right), i = 1, 2, \dots, m$$
(19)

Step 7: Calculate the closeness coefficient (i.e., relative gaps-degree) of each alternative, Equation (20). The optimal alternative is closer to the FPIS and farther from the FNIS as \widetilde{CC}_i approaches to 1.

$$\widetilde{CC}_{i} = \frac{\widetilde{D}'_{i}}{\widetilde{D}^{*}_{i} + \widetilde{D}'_{i}} = 1 - \frac{\widetilde{D}^{*}_{i}}{\widetilde{D}^{*}_{i} + \widetilde{D}'_{i}}, i = 1, 2, \dots, m$$
(20)

where $\frac{\tilde{D}'_i}{\tilde{D}^*_i + \tilde{D}'_i}$ is fuzzy satisfaction degree, $\frac{\tilde{D}^*_i}{\tilde{D}^*_i + \tilde{D}'_i}$ is fuzzy gap degree which presents how fuzzy gaps can be improved to obtain the aspiration levels of decision-makers.

Table 4. Linguistics rating level of alternatives in the fuzzy TOPSIS (FTOPSIS) model.

Linguistics Rating Level	Allocated TFN
Very poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very good (VG)	(9, 10, 10)

4. Numerical Application and Results Analysis

4.1. Problem Description

Amid the Covid-19 online sales boom, the e-commerce industry has accelerated in every corner of the world [62], including in Vietnam. For this country, the e-commerce industry is rapidly expanding, thanks to increasing foreign investments, a favorable regula-

tory environment, and enhanced internet access. Investment and development of logistics are among the premises for the expansion and resilience of e-commerce. Among key strategies, outsourcing logistics has been the first choice. Selecting the most suitable partner is the most convenient and economical solution for any e-commerce merchant in Vietnam.

In this paper, a numerical application of an e-commerce business in Vietnam is used to test the effectiveness of the proposed fuzzy MCDM model. After preliminary evaluation, eight potential third-party reverse logistics providers (3PRLP) were selected based on the requirements of the company in order to select a compatible 3PRLP and to ensure a long-term healthy relationship between the two firms. The list of criteria was selected from the relevant literature review and industrial experts' survey. In the numerical application, a to-tal of 10 experts (head of logistics and relevant departments in this e-commerce business) were consulted by interviews to assess the effect of these criteria on the 3PRLP selection. All experts had more than 10 years' working experiences in the area of logistics and supply chain. Figure 4 presents the decision hierarchy for outsourcing reverse logistics including all criteria and the list of eight potential 3PRLP. There are four main criteria and 15 criteria including economic (quality, cost, lead time, delivery and service, R&D capability), environment (recycle, disposal, reproduction and reuse, green technology, CO₂ emissions), social (health and safety, customer's voice, reputation), and risk (operational risk, financial risk).



Figure 4. The decision hierarchy for outsourcing reverse logistics.

4.2. Results of Fuzzy AHP

The following FAHP procedure shows an example of the calculation of the four main criteria (economic, environment, social, risk). Other criteria are calculated using the same procedures. The initial and integrated fuzzy comparison matrix of the main criteria are presented in Tables 5 and 6, respectively.

							Li	nguis	tics Ra	ating I	Level							
Criteria	(8, 9, 10)	(7, 8, 9)	(6, 7, 8)	(5, 6, 7)	(4, 5, 6)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)	(5, 6, 7)	(6, 7, 8)	(2, 8, 9)	(8, 9, 10)	Criteria
C1							x											C2
C1						х												C3
C1							х											C4
C2								х										C3
C2										х								C4
C3											х							C4

Table 5. Initial comparison matrix of the main criteria.

Note: economic (C1), environment (C2), social (C3), risk (C4).

 Table 6. Integrated fuzzy comparison matrix of the main criteria.

Criteria	Economic (C1)	Environment (C2)	Social (C3)	Risk (C4)
Economic (C1)	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(2, 3, 4)
Environment (C2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)	(1/3, 1/2, 1)
Social (C3)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(1, 1, 1)	(1/4, 1/3, 1/2)
Risk (C4)	(1/4, 1/3, 1/2)	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)
	1			

Note: identified by the researchers.

In order to check the consistency ratio (*CR*) of the rating score, the fuzzy number is converted to a real number using lower bound (pessimistic value) and upper bound (optimistic value) values of the fuzzy comparison matrix [60,63,64]. Table 7 shows the non-fuzzy comparison matrix of the main criteria.

Table 7. Non-fuzzy comparison matrix of the main criteria.

Criteria	Economic (C1)	Environment (C2)	Social (C3)	Risk (C4)
Economic (C1)	1	2.8284	3.8730	2.8284
Environment (C2)	0.3536	1	1.7321	0.5774
Social (C3)	0.2582	0.5774	1	0.3536
Risk (C4)	0.3536	1.7321	2.8284	1
Sum	1.9653	6.1378	9.4335	4.7593

Note: calculated by the researchers.

To get the priority vector of the main criteria, the normalized matrix of pairwise comparison is calculated by dividing each number in a column of the comparison matrix by its column sum. In addition, the priority vector is determined by averaging the row entries in the normalized matrix, which are shown in Table 8.

Table 8. Normalized comparison matrix of the main criteria.										
Economic (C1)	Environment (C2)	Social (C3)	Risk (C4)	Priority Vector						

Criteria	Economic (C1)	Environment (C2)	Social (C3)	Risk (C4)	Priority Vector
Economic (C1)	0.5088	0.4608	0.4106	0.5943	0.4936
Environment (C2)	0.1799	0.1629	0.1836	0.1213	0.1619
Social (C3)	0.1314	0.0941	0.1060	0.0743	0.1014
Risk (C4)	0.1799	0.2822	0.2998	0.2101	0.2430
Sum	1	1	1	1	1

Note: calculated by the researchers.

In this step, the largest eigenvector (λ_{max}) is calculated to determine the consistency index (*CI*), the random index (*RI*), and the consistency ratio (*CR*), as follows.

Γ	0.5088	0.4608	0.4106	0.5943	1	0.4936	2.0318
	0.1799	0.1629	0.1836	0.1213		0.1619	0.6524
	0.1314	0.0941	0.1060	0.0743		0.1014	0.4083
L	0.1799	0.2822	0.2998	0.2101		0.2430	0.9849
		$ \begin{bmatrix} 2.0 \\ 0.0 \\ 0.4 \\ 0.5 \end{bmatrix} $	0318 6524 4083 9849	0.4936 0.1619 0.1014 0.2430] = [4.1161 4.0291 4.0253 4.0530	

This paper considers four main criteria. Hence, we get n = 4. Consequently, λ_{max} and *CI* are calculated as follows.

$$\lambda_{max} = \frac{4.1161 + 4.0291 + 4.0253 + 4.0530}{4} = 4.0559$$
$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.0559 - 4}{4 - 1} = 0.0186$$

where n = 4, we get RI = 0.9, and the consistency ratio (*CR*) is calculated as follows:

$$CR = \frac{CI}{RI} = \frac{0.0186}{0.9} = 0.0207$$

From the result, CR = 0.0207 < 0.1, therefore, the pairwise comparison matrix is consistent, and the results are satisfactory. Consequently, other criteria are calculated using the same methodology. The integrated fuzzy comparison matrix of 15 criteria is presented in Table A1 (Appendix A).

The results of the fuzzy weights of all criteria from the FAHP model are calculated based on the fuzzy geometric mean concept, shown in Table 9. Each fuzzy weight includes three values, which are pessimistic value (the lowest weight), most likely value (the middle weight), and optimistic value (the highest weight). For example, the fuzzy weight of criteria quality (C11), has the pessimistic weight at 0.0357, the most likely weight of 0.0750, and the most optimistic weight of 0.1545. The remaining criteria have the same demonstration. These fuzzy preference weights will be used in the next stage of the FTOPSIS model.

Main Criteria	Main CriteriaCriteriaTargetFuzzy Geometric Mean						uzzy Weigł	nts
	C11. Quality	Max	0.7654	1.1409	1.6597	0.0357	0.0750	0.1545
Economia	C12. Cost	Min	0.8479	1.2247	1.7031	0.0395	0.0805	0.1585
Economic	C13. Lead time	Min	0.8834	1.2901	1.8245	0.0412	0.0848	0.1698
(CI)	C14. Delivery and service	Max	0.7785	1.1502	1.6611	0.0363	0.0756	0.1546
	C15. R&D capability	Max	0.6999	j 1.1502 1.6611 0.0363 j 0.9744 1.3549 0.0326	0.0640	0.1261		
	C21. Recycle	Max	0.6329	0.8985	1.2983	0.0295	0.0591	0.1208
Engline and tal	C22. Disposal	Max	0.5795	0.8318	1.2241	0.0270	0.0547	0.1139
Environmental	C23. Reproduction and reuse	Max	0.7801	1.0897	1.4672	0.0364	0.0716	0.1366
(C2)	C24. Green technology	Max	0.7869	1.0865	1.4525	0.0367	0.0714	0.1352
	C25. CO_2 emissions	Min	0.6196	0.8559	1.2218	0.0289	0.0563	0.1137
Carial	C31. Health and safety	Max	0.5680	0.7661	1.0838	0.0265	0.0504	0.1009
Social	C32. Customer's voice	Max	0.9029	1.2784	1.7677	0.0421	0.0840	0.1645
(C3)	C33. Reputation	Max	0.6239	0.8631	1.2284	0.0291	0.0567	0.1143
Risk	C41. Operational risk	Min	0.5917	0.8153	1.1728	0.0276	0.0536	0.1092
(C4)	C42. Financial risk	Min	0.6831	0.9483	1.3387	0.0318	0.0623	0.1246

Table 9. Results of fuzzy weights from the FAHP model.

Note: calculated by the researchers.

Figure 5 depicts the influence levels of criteria. As can be seen, "lead time", "customer's voice", "cost", "delivery and service", and "quality" criteria have the most influence percentages, at 8.4559%, 8.3087%, and 7.9628%, 7.6185%, and 7.58%, respectively. Regarding economic factors in choosing 3PRLPs in the e-commerce sector, the results recommend that "lead time" is more critical in experts' evaluation than other cost and quality issues. For e-commerce businesses, lead times are a significant measure when figuring out inventory management strategy, which is the primary estimator for when the managers reorder stock. It is also an especially concerning factor when adding new product lines to the online store. The new products will have their lead times that may be separate from regularly scheduled deliveries. "Customer's voice" (as a social criterion) is also positioned second in the expert ranking. This result shows that information sharing, and customer engagement are key determinants of reverse logistics in the e-commerce industry [5]. In the booming e-commerce market of Vietnam, e-commerce businesses are attempting to survive and thrive by focusing more on economic aspects. However, green and resilient strategies towards sustainable development have come into focus. In order to enhance the competitiveness of Vietnamese businesses, the government encourages enterprises to participate effectively in the global value chain by embracing and integrating sustainable business strategies [65]. Thus, the criteria ranking results indicate that economic criteria were ranked high, but the other criteria from the three pillars of sustainable development (social and environmental factors) were also noteworthy. Among environmental factors, "reproduction and reuse" and "green technology" ranked sixth (6.9908%) and seventh (6.9550%) among 15 criteria. These figures elaborate that social and environmental drivers are of tremendous importance in reverse logistics systems besides economic aspects.



Figure 5. Influence level of criteria from FAHP model.

4.3. Results of Fuzzy TOPSIS

In FTOPSIS model, the fuzzy preference weights of criteria are obtained from FAHP model. According to the FTOPSIS process in Section 3.4, fuzzy normalized decision matrix and fuzzy weighted normalized decision matrix are shown in Tables A2 and A3 (Appendix A). Table 10 and Figure 6 show the top three potential third-party reverse logistics providers, which are 3PRLP-05, 3PRLP-07, and 3PRLP-01, ranked first, second, and third with scores of 0.0590, 0.0506, and 0.0513, respectively.

Table 10. Closeness coefficient of each alternative.

3PRLP	D_i^*	$D_{i}^{'}$	Gap Degree	Satisfaction Degree	Rank
3PRLP-01	14.3560	0.7756	0.9487	0.0513	3
3PRLP-02	14.5155	0.6184	0.9591	0.0409	6
3PRLP-03	14.4158	0.7260	0.9521	0.0479	4
3PRLP-04	14.5380	0.5851	0.9613	0.0387	8
3PRLP-05	14.2550	0.8943	0.9410	0.0590	1
3PRLP-06	14.5211	0.6152	0.9594	0.0406	7
3PRLP-07	14.3579	0.8446	0.9444	0.0556	2
3PRLP-08	14.5020	0.6222	0.9589	0.0411	5

Note: calculated by the researchers.



Figure 6. Final ranking of the FTOPSIS model.

5. Discussion and Conclusions

As online shopping volumes grow, so do return volumes. Product return rates are rising in the e-commerce industry. The cost of doing e-commerce business is facilitating a simple and seamless return processes as part of the increase in customer expectations. This is where reverse logistics comes into its unique role, which is to handle many inevitable situations regarding e-commerce transactions, including deliveries of incorrect products, customer behaviors, damaged products, delays in order fulfillment, to name just a few [66]. It cannot be failed to mention that reverse logistics systems, in essence, provide businesses with numerous opportunities to integrate the three drivers of sustainable development, such as remanufacturing, repair, recycle, and disposal. There is no question that proficient reverse logistics not only handles the e-commerce returns problem but also enables any business to gain customer retention, reduced costs, and higher achievement of sustainability goals. However, managing reverse logistics in-house means the supply chain of moving goods must be amplified, which leads companies to significant issues. For this reason, more and more e-commerce retailers consider reverse logistics outsourcing as an inevitable part of their business. Thus, the evaluation and selection problem of 3PRLP has never been so prominent in this era.

Methodologically, the authors elaborate that in using the proposed hybrid MCDM approach (combining FAHP and FTOPSIS), this has so far been the first study to fill the gap of the existing literature that lacks 3PRLP evaluation and selection practices for several industries within a developing countries context, and especially to address the increased demand of reverse logistics outsourcing in the e-commerce sector. The use of linguistic expressions for the whole evaluation process will mitigate the risk of fuzzy and uncertain judgment when weighing criteria, as well as improving the robustness of the ranking results and the overall computation efficiency. Proper transformations of linguistic terms also ensures that the approach has a broad range of applications.

E-commerce has been on the rise in Vietnam. By 2025, e-commerce purchases are projected to be used by over 70 percent of the 100 million population. Regarding the e-commerce logistics sector, it has contributed to approximately 20–25% of the GDP of Vietnam, according to Vietnam Logistics Business Association [67]. This industry is also predicted to grow by roughly 12 percent every year. Thus, more and more logistics companies and investors are flooding into this untapped potential market. On the other hand, the dilemma of outsourcing logistics services and the decision to select a provider based on quality management and financial performance criteria are sure to be a headache facing e-commerce retailers. Within this context, our paper aims to provide significant insights for online merchants on the methods of evaluation and selection of 3PRLP. In doing so, the proposed approach is applied to illustrate a case study of the reverse logistics outsourcing problem in Vietnam. From the FAHP stage, results show that "lead time," "cost," "delivery and service," and "quality" (economic factors) and "customer's voice" (social factor) are

the most impactful criteria according to expert evaluation. Environmental drivers such as "reproduction and reuse" and "green technology" were also ranked high, indicating the other aspect from the three pillars of sustainable development were noteworthy in reverse logistics outsourcing of e-commerce in Vietnam. In the next stage, FTOPSIS indicates that 3PRLP-05 was the optimized partner with the final ranking score of 0.059. For practical implications, these findings can help e-commerce businesses or any firms to gain a better understanding of the 3PRLP selection process. Thus, the companies can devise their strategies accordingly to better control their reverse logistics activities.

For future studies involving qualitative and quantitative criteria, new factors concerning today's situation (i.e., post-Covid-19 world) should be upgraded to obtain well-rounded results. Regarding theoretical limitations, this paper calculated the consistency ratio using lower bound (pessimistic value) and upper bound (optimistic value) values of the fuzzy comparison matrix, hence, future studies should approach the procedure of defuzzification according to the derivate fuzzy AHP [68]. Moreover, future studies should target other MCDM techniques (i.e., VIKOR, PROMETHEE II) for ranking alternatives and compare the results using ranking similarity reference coefficients [69], and/or combine with the exact methods [70]. In terms of applications, further studies might therefore investigate reverse logistics outsourcing practices in other countries than Vietnam to improve the findings' external validity. Moreover, the procedure and criteria presented in this paper can also be considered in other related industries, such as supplier selection or any decision-making problems.

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Appendix A

Criteria		C11			C12			C13			C14	
C11	1	1	1	1.0592	1.6632	2.4208	0.7192	1.0414	1.5337	0.5234	0.7800	1.2457
C12	0.4131	0.6012	0.9441	1	1	1	0.9883	1.4902	2.1074	0.9221	1.4310	2.0477
C13	0.6520	0.9603	1.3904	0.4745	0.6711	1.0118	1	1	1	1.2671	1.9896	2.7808
C14	0.8027	1.2821	1.9105	0.4884	0.6988	1.0845	0.3596	0.5026	0.7892	1	1	1
C15	0.5086	0.7490	1.1623	0.4745	0.6711	1.0118	0.5086	0.7490	1.1623	0.2928	0.4131	0.6520
C21	0.4131	0.6012	0.9441	0.4131	0.5610	0.8459	0.4131	0.6012	0.9441	0.4131	0.6012	0.9441
C22	0.4131	0.6012	0.9441	0.4131	0.5610	0.8459	0.4131	0.6012	0.9441	0.4131	0.6012	0.9441
C23	0.5086	0.7490	1.1623	0.4745	0.6711	1.0118	0.9221	1.4310	2.1550	1.7617	2.6531	3.4783
C24	0.9221	1.4310	2.1550	0.7892	1.0592	1.3653	0.2131	0.2732	0.3854	0.5086	0.7490	1.1623
C25	0.5086	0.7490	1.1623	0.8262	1.2457	1.8346	0.2928	0.4131	0.6520	0.5086	0.7490	1.1623

Table A1. Integrated fuzzy comparison matrix of 15 criteria (FAHP).

Criteria		C11			C12			C13			C14	
C31	0 9221	1 4310	2 1550	0.3596	0 4690	0 7071	0 2378	0 2928	0.3854	0.5086	0 7490	1 1623
C32	0.5086	0.7490	1.1623	0.8262	1.2457	1.8346	0.9221	1.4310	2.1550	0.9221	1.4310	2.1550
C33	0.5086	0.7490	1.1623	0.8262	1.2457	1.8346	0.9221	1.4310	2.1550	0.5086	0.7490	1.1623
C41	0.5086	0.7490	1.1623	0.4745	0.6711	1.0118	0.9221	1.4310	2.1550	0.5086	0.7490	1.1623
C42	0.9221	1.4310	2.1550	0.4745	0.6711	1.0118	0.5086	0.7490	1.1623	0.2928	0.4131	0.6520
Criteria		C15			C21			C22			C23	
C11	0.8604	1.3351	1.9663	1.0592	1.6632	2.4208	1.0592	1.6632	2.4208	0.8604	1.3351	1.9663
C12	0.9883	1.4902	2.1074	1.1822	1.7826	2.4208	1.1822	1.7826	2.4208	0.9883	1.4902	2.1074
C13	0.8604	1.3351	1.9663	1.0592	1.6632	2.4208	1.0592	1.6632	2.4208	0.4640	0.6988	1.0845
C14	1.5337	2.4208	3.4154	1.0592	1.6632	2.4208	1.0592	1.6632	2.4208	0.2875	0.3769	0.5676
C15	1	1	1	0.6988	1.0718	1.5971	0.6988	1.0718	1.5971	2.1074	2.7922	3.4154
C21	0.6261	0.9330	1.4310	1	1	1	0.9221	1.3351	1.8346	0.2875	0.3769	0.5676
C22	0.6261	0.9330	1.4310	0.5451	0.7490	1.0845	1	1	1	1.5337	2.4208	3.4154
C23	0.2928	0.3581	0.4745	1.7617	2.6531	3.4783	0.2928	0.4131	0.6520	1	1	1
C24	0.2928	0.3581	0.4745	1.7617	2.6531	3.4783	1.7617	2.6531	3.4783	0.5086	0.6520	0.9330
C25	0.6261	0.8706	1.2821	0.4973	0.7277	1.1161	0.9221	1.4310	2.1550	0.9221	1.2457	1.7299
C31	0.6261	0.8706	1.2821	0.4884	0.7117	1.0845	0.5086	0.7490	1.1623	0.5086	0.6520	0.9330
C32	1.6917	2.4307	3.0837	0.5234	0.7800	1.2457	0.5086	0.7490	1.1623	0.9221	1.2457	1.7299
C33	0.6261	0.8706	1.2821	0.6335	0.8604	1.1623	0.5086	0.7490	1.1623	0.2928	0.3854	0.5842
C41	0.6261	0.8706	1.2821	0.2928	0.4131	0.6520	0.9221	1.4310	2.1550	0.5086	0.6520	0.9330
C42	1.0718	1.4727	1.9744	0.5086	0.7490	1.1623	0.9221	1.4310	2.1550	0.9221	1.2457	1.7299
Criteria		C24			C25			C31			C32	
C11	0.4640	0.6988	1.0845	0.8604	1.3351	1.9663	0.4640	0.6988	1.0845	0.8604	1.3351	1.9663
C12	0.7325	0.9441	1.2671	0.5451	0.8027	1.2104	1.4142	2.1324	2.7808	0.5451	0.8027	1.2104
C13	2.5946	3.6606	4.6932	1.5337	2.4208	3.4154	2.5946	3.4154	4.2049	0.4640	0.6988	1.0845
C14	0.8604	1.3351	1.9663	0.8604	1.3351	1.9663	0.8604	1.3351	1.9663	0.4640	0.6988	1.0845
C15	2.1074	2.7922	3.4154	0.7800	1.1487	1.5971	0.7800	1.1487	1.5971	0.3243	0.4114	0.5911
C21	0.2875	0.3769	0.5676	0.8960	1.3741	2.0107	0.9221	1.4051	2.0477	0.8027	1.2821	1.9105
C22	0.2875	0.3769	0.5676	0.4640	0.6988	1.0845	0.8604	1.3351	1.9663	0.8604	1.3351	1.9663
C23	1.0718	1.5337	1.9663	0.5781	0.8027	1.0845	1.0718	1.5337	1.9663	0.5781	0.8027	1.0845
C24	1	1	1	1.0718	1.5337	1.9663	0.5781	0.8027	1.0845	1.0718	1.5337	1.9663
C25	0.5086	0.6520	0.9330	1	1	1	0.7490	1.0718	1.4902	0.4640	0.6084	0.8706
C31	0.9221	1.2457	1.7299	0.6711	0.9330	1.3351	1 0741	1		0.4040	0.5086	0.7277
C32	0.5086	0.6520	0.9330	1.1487	1.6438	2.1550	1.3741	1.9663	2.4754	I 0 (711	1	1 1 2251
C33	0.4040	0.5451	0.8123	0.6711	0.9550	1.3331	1.148/	1.0438	2.1550	0.6711	0.9330	1.3351
C41 C42	0.4040	0.5451	0.0125	0.0711 1 1487	0.9550	2 1550	0.6711	0.9330	1.3351	0.4040 0.2732	0.3431	0.6125
Criteria	0.0711	C33	1.0001	1.1407	C41	2.1000	0.0711	C42	1.0001	0.2732	0.3317	0.5000
C11	0.8604	1 3351	1 9663	0 8604	1 3351	1 9663	0 4640	0.6988	1 0845			
C12	0.0004 0 5451	0.8027	1.7005	0.0004	1.3351	2 1074	0.4040	1 4902	2 1074			
C12	0.4640	0.6988	1.2101	0.9660	0.6988	1 0845	0.9603	1.3351	1 9663			
C14	0.8604	1.3351	1.0010	0.1010	1.3351	1 9663	1 5337	2 4208	3 4154			
C15	0.7800	1.1487	1.5971	0.7800	1.1487	1.5971	0.5065	0.6790	0.9330			
C21	0.8604	1.1623	1.5784	1.5337	2.4208	3.4154	0.8604	1.3351	1.9663			
C22	0.8604	1.3351	1.9663	0.4640	0.6988	1.0845	0.4640	0.6988	1.0845			
C23	1.7118	2.5946	3.4154	1.0718	1.5337	1.9663	0.5781	0.8027	1.0845			
C24	1.2311	1.8346	2.4754	1.2311	1.8346	2.4754	0.7490	1.0718	1.4902			
C25	0.7490	1.0718	1.4902	0.7490	1.0718	1.4902	0.4640	0.6084	0.8706			
C31	0.4640	0.6084	0.8706	0.7490	1.0718	1.4902	0.7490	1.0718	1.4902			
C32	0.7490	1.0718	1.4902	1.2311	1.8346	2.4754	1.9663	2.8435	3.6606			
C33	1	1	1	0.4640	0.6084	0.8706	0.7490	1.0718	1.4902			
C41	1.1487	1.6438	2.1550	1	1	1	0.4640	0.6084	0.8706			
C42	0.6711	0.9330	1.3351	1.1487	1.6438	2.1550	1	1	1			

Table A1. Cont.

Note: calculated by the researchers.

 Table A2. Fuzzy normalized decision matrix of all alternatives (FTOPSIS).

3PRLP		Quality		Cost			Lead Time			Delivery and Service			
3PRLP-01	0.5054	0.6882	0.8280	0.0800	0.0952	0.1277	0.0779	0.0938	0.1277	0.4409	0.6237	0.7957	
3PRLP-02	0.1505	0.2796	0.4731	0.1500	0.2500	0.4286	0.1579	0.3000	0.7500	0.1720	0.3011	0.4839	
3PRLP-03	0.3441	0.5376	0.7419	0.0923	0.1250	0.1875	0.1017	0.1500	0.2727	0.3656	0.5591	0.7527	
3PRLP-04	0.1505	0.2796	0.4516	0.1429	0.2308	0.4286	0.1429	0.2308	0.4286	0.1505	0.2796	0.4516	
3PRLP-05	0.6237	0.8387	1.0000	0.0645	0.0769	0.1034	0.0645	0.0769	0.1034	0.6237	0.8387	1.0000	
3PRLP-06	0.0645	0.1613	0.3441	0.1875	0.4000	1.0000	0.1875	0.4000	1.0000	0.0645	0.1613	0.3441	
3PRLP-07	0.5161	0.7097	0.8817	0.0732	0.0909	0.1250	0.0732	0.0909	0.1250	0.5161	0.7097	0.8817	
3PRLP-08	0.2688	0.4409	0.6452	0.1000	0.1463	0.2400	0.1000	0.1463	0.2400	0.2688	0.4409	0.6452	
3PRLP	R&	D Capabi	ility		Recycle			Disposal		Reprod	uction an	d Reuse	
3PRLP-01	0.5269	0.6989	0.8280	0.5054	0.6882	0.8280	0.5054	0.6882	0.8280	0.5165	0.7033	0.8462	
3PRLP-02	0.1505	0.2796	0.4731	0.1505	0.2796	0.4731	0.1505	0.2796	0.4731	0.1538	0.2857	0.4835	
3PRLP-03	0.3656	0.5484	0.7419	0.3441	0.5376	0.7419	0.3441	0.5376	0.7419	0.3516	0.5495	0.7582	
3PRLP-04	0.1505	0.2796	0.4516	0.1505	0.2796	0.4516	0.1505	0.2796	0.4516	0.1538	0.2857	0.4615	
3PRLP-05	0.6237	0.8387	1.0000	0.6237	0.8387	1.0000	0.6237	0.8387	1.0000	0.6154	0.8352	1.0000	
3PRLP-06	0.0645	0.1613	0.3441	0.0645	0.1398	0.3011	0.0645	0.1398	0.3011	0.0220	0.1209	0.3077	
3PRLP-07	0.5161	0.7097	0.8817	0.5161	0.7097	0.8817	0.5161	0.7097	0.8817	0.4835	0.6813	0.8571	
3PRLP-08	0.2688	0.4409	0.6452	0.2688	0.4301	0.6237	0.2688	0.4301	0.6237	0.1648	0.3407	0.5495	
3PRLP	Gree	n Techno	ology	C	D ₂ Emissions He			Health and Safety			Customer's Voice		
3PRLP-01	0.5402	0.7356	0.8851	0.0779	0.0938	0.1277	0.5281	0.7191	0.8652	0.5949	0.8101	0.9747	
3PRLP-02	0.1609	0.2989	0.5057	0.1364	0.2308	0.4286	0.1573	0.2921	0.4944	0.1772	0.3291	0.5570	
3PRLP-03	0.3678	0.5747	0.7931	0.0870	0.1200	0.1875	0.3596	0.5618	0.7753	0.4051	0.6329	0.8734	
3PRLP-04	0.1839	0.3218	0.5057	0.1429	0.2308	0.4286	0.1011	0.2360	0.4270	0.3797	0.5316	0.7089	
3PRLP-05	0.5977	0.8276	1.0000	0.0645	0.0723	0.0882	0.6180	0.8315	1.0000	0.3291	0.5823	0.8228	
3PRLP-06	0.1149	0.2184	0.4138	0.1875	0.4000	1.0000	0.2022	0.4045	0.6292	0.1772	0.2911	0.4810	
3PRLP-07	0.5287	0.7356	0.9195	0.0732	0.0938	0.1364	0.4270	0.5730	0.7416	0.6076	0.8354	1.0000	
3PRLP-08	0.3563	0.5402	0.7586	0.1000	0.1463	0.2400	0.1910	0.3596	0.5843	0.4684	0.6709	0.8481	
3PRLP	R	Reputatio	n	Op	erational	Risk	Fi	nancial Ri	sk				
3PRLP-01	0.5054	0.6882	0.8280	0.1818	0.2188	0.2979	0.1818	0.2188	0.2979				
3PRLP-02	0.1505	0.2796	0.4731	0.3182	0.5385	1.0000	0.2857	0.4118	0.6364				
3PRLP-03	0.3441	0.5376	0.7419	0.2029	0.2800	0.4375	0.1918	0.2414	0.3500				
3PRLP-04	0.1505	0.2796	0.4516	0.3333	0.5385	1.0000	0.2500	0.3333	0.4667				
3PRLP-05	0.6237	0.8387	1.0000	0.2414	0.3684	0.6087	0.2154	0.3043	0.5385				
3PRLP-06	0.1613	0.2903	0.4731	0.2090	0.2545	0.3415	0.3684	0.6087	1.0000				
3PRLP-07	0.2903	0.4516	0.6237	0.1707	0.2121	0.2917	0.1772	0.2121	0.2917				
3PRLP-08	0.0860	0.2258	0.4301	0.1892	0.2456	0.3590	0.2090	0.2642	0.3784				

Note: calculated by the researchers.

Table A3. Fuzzy weighted normalized decision matrix (FTOPSIS).

3PRLP	Quality			Cost			Lead Time			Delivery and Service		
3PRLP-01	0.0180	0.0516	0.1279	0.0032	0.0077	0.0202	0.0032	0.0079	0.0217	0.0160	0.0471	0.1230
3PRLP-02	0.0054	0.0210	0.0731	0.0059	0.0201	0.0679	0.0065	0.0254	0.1274	0.0062	0.0228	0.0748
3PRLP-03	0.0123	0.0403	0.1146	0.0036	0.0101	0.0297	0.0042	0.0127	0.0463	0.0133	0.0423	0.1164
3PRLP-04	0.0054	0.0210	0.0698	0.0056	0.0186	0.0679	0.0059	0.0196	0.0728	0.0055	0.0211	0.0698
3PRLP-05	0.0222	0.0629	0.1545	0.0025	0.0062	0.0164	0.0027	0.0065	0.0176	0.0226	0.0634	0.1546
3PRLP-06	0.0023	0.0121	0.0532	0.0074	0.0322	0.1585	0.0077	0.0339	0.1698	0.0023	0.0122	0.0532
3PRLP-07	0.0184	0.0532	0.1362	0.0029	0.0073	0.0198	0.0030	0.0077	0.0212	0.0187	0.0537	0.1363
3PRLP-08	0.0096	0.0331	0.0997	0.0040	0.0118	0.0380	0.0041	0.0124	0.0408	0.0098	0.0333	0.0997
3PRLP	R&D Capability Recycle					Disposal		Reproduction and Reuse				
3PRLP-01	0.0172	0.0448	0.1044	0.0149	0.0406	0.1001	0.0136	0.0376	0.0943	0.0188	0.0504	0.1156
3PRLP-02	0.0049	0.0179	0.0597	0.0044	0.0165	0.0572	0.0041	0.0153	0.0539	0.0056	0.0205	0.0660
3PRLP-03	0.0119	0.0351	0.0936	0.0101	0.0317	0.0897	0.0093	0.0294	0.0845	0.0128	0.0394	0.1035
3PRLP-04	0.0049	0.0179	0.0570	0.0044	0.0165	0.0546	0.0041	0.0153	0.0515	0.0056	0.0205	0.0630

3PRLP	R&	D Capabi	ility		Recycle	2	Disposal			Reproduction and Reuse			
3PRLP-05	0.0203	0.0537	0.1261	0.0184	0.0495	0.1208	0.0168	0.0459	0.1139	0.0224	0.0598	0.1366	
3PRLP-06	0.0021	0.0103	0.0434	0.0019	0.0083	0.0364	0.0017	0.0076	0.0343	0.0008	0.0087	0.0420	
3PRLP-07	0.0168	0.0455	0.1112	0.0152	0.0419	0.1066	0.0139	0.0388	0.1005	0.0176	0.0488	0.1171	
3PRLP-08	0.0088	0.0282	0.0814	0.0079	0.0254	0.0754	0.0073	0.0235	0.0711	0.0060	0.0244	0.0750	
3PRLP	Gree	n Techno	ology	C	O ₂ Emissi	ions	Hea	lth and Sa	ıfety	Customer's Voice			
3PRLP-01	0.0198	0.0525	0.1197	0.0023	0.0053	0.0145	0.0140	0.0362	0.0873	0.0250	0.0681	0.1604	
3PRLP-02	0.0059	0.0213	0.0684	0.0039	0.0130	0.0487	0.0042	0.0147	0.0499	0.0075	0.0277	0.0916	
3PRLP-03	0.0135	0.0410	0.1072	0.0025	0.0068	0.0213	0.0095	0.0283	0.0782	0.0170	0.0532	0.1437	
3PRLP-04	0.0067	0.0230	0.0684	0.0041	0.0130	0.0487	0.0027	0.0119	0.0431	0.0160	0.0447	0.1166	
3PRLP-05	0.0219	0.0591	0.1352	0.0019	0.0041	0.0100	0.0164	0.0419	0.1009	0.0138	0.0489	0.1354	
3PRLP-06	0.0042	0.0156	0.0559	0.0054	0.0225	0.1137	0.0054	0.0204	0.0635	0.0075	0.0245	0.0791	
3PRLP-07	0.0194	0.0525	0.1243	0.0021	0.0053	0.0155	0.0113	0.0289	0.0748	0.0256	0.0702	0.1645	
3PRLP-08	0.0131	0.0386	0.1026	0.0029	0.0082	0.0273	0.0051	0.0181	0.0589	0.0197	0.0564	0.1395	
3PRLP	R	leputatio	n	Op	erational	Risk	Fi	nancial Ri	sk				
3PRLP-01	0.0147	0.0390	0.0947	0.0050	0.0117	0.0325	0.0058	0.0136	0.0371				
3PRLP-02	0.0044	0.0159	0.0541	0.0088	0.0289	0.1092	0.0091	0.0257	0.0793				
3PRLP-03	0.0100	0.0305	0.0848	0.0056	0.0150	0.0478	0.0061	0.0150	0.0436				
3PRLP-04	0.0044	0.0159	0.0516	0.0092	0.0289	0.1092	0.0080	0.0208	0.0581				
3PRLP-05	0.0181	0.0476	0.1143	0.0067	0.0197	0.0664	0.0069	0.0190	0.0671				
3PRLP-06	0.0047	0.0165	0.0541	0.0058	0.0136	0.0373	0.0117	0.0379	0.1246				
3PRLP-07	0.0084	0.0256	0.0713	0.0047	0.0114	0.0318	0.0056	0.0132	0.0363				
3PRLP-08	0.0025	0.0128	0.0492	0.0052	0.0132	0.0392	0.0067	0.0165	0.0471				

Table A3. Cont.

Note: calculated by the researchers.

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