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Research Article

The Dominance Degree-Based Heterogeneous Linguistic Decision-Making Technique for Sustainable 3PRLP Selection

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This study develops a novel dominance degree-based heterogeneous linguistic decision-making technique for identifying the most sustainable third-party reverse logistics providers (3PRLPs) under complex input environments. First, qualitative and uncertain inputs that arise from real-world 3PRLP evaluation process are successfully managed by using linguistic terms, hesitant fuzzy linguistic terms, and probabilistic linguistic term sets with different granularities. Then, the dominance degrees of each 3PRLP related to the other 3PRLPs are calculated based on a new ratio index-based probabilistic linguistic ranking method and the dominance matrix is constructed. Furthermore, to represent the closeness of each 3PRLP to the ideal solution, we propose a sort of measures including the dominance-based group utility measure, the dominance-based individual regret measure, and the dominance-based compromise measure. Accordingly, the selection results of 3PRLPs are obtained according to these measures. Finally, the developed method is applied to a case study from car manufacture industry, and the comparison analysis shows that the proposed method is reliable and stable for dealing with the problem of the 3PRLP selection. The main advantage of the developed method is that it cannot only well avoid the potential loss risks but also balance group utility scores and individual regret scores.

1. Introduction

Growing environmental concerns and potential economic profitability have driven more and more corporations to outsource their logistics activities to third-party reverse logistics providers (3PRLPs) [1]. To achieve the goals of cost reduction and environmental protection, it is crucial for manufacturers to select the best available 3PRLP. Considering the qualitative nature of assessed criteria in the selection process of 3PRLPs, linguistic expression forms [2] are quite comfortable and straightforward for evaluators to capture their uncertain preferences. For example, Mavi et al. [3] and Zarbakhshnia et al. [4] employed single linguistic terms (LTs) to express performances of 3PRLPs. With the need of modeling more complexity uncertain information, two new extensions of linguistic variables, hesitant fuzzy linguistic term set (HFLTS) [5–7] and probabilistic linguistic term set (PLTS) [8–11], are recently developed. These new linguistic forms provided more freedom for evaluators to express their uncertain preferences [12–14], especially for the 3PRLP evaluation contexts.

In the practical 3PRLP evaluating process, for example, one evaluator may employ single LT like "good" or "poor" to express performances of 3PRLPs under the quality criterion and utilize comparative linguistic expression (CLE) like "at least good" to model performances of 3PRLPs from the aspect of green technology capability, and use one PLTS $\{\text{fair}(0.6), \text{good}(0.4)\}$ to represent performances of 3PRLPs from the aspect of the employment stability. This PLTS means that the preference for the evaluator is "good" with a degree of 40% and "fair" with a degree of 60%. It is evident that diverse linguistic expression forms of decision information, such as LTs, HFLTSs, and PLTSs, are simultaneously involving with the real-world 3PRLP selection problems under complex assessed contexts. This situation is called a kind of heterogeneous linguistic information-based 3PRLP selection problems. However, the majority of the existing techniques developed for 3PRLP selection problems only consider the situations where the performance scores of 3PRLPs are described in a uniform mathematical format. Therefore, the one challenge need to be addressed imperatively is how to deal with the qualitative and heterogeneous uncertain inputs.

On the other hand, in the real-world 3PRLP selection process, the decision maker (DM) is usually bounded rational and the behavior factor of DM greatly affects the final decision results [15, 16]. A recent study by Li et al. [1] has also been proved that the psychological behavior of DM in 3PRLP selection under environmental pressure weighed heavily with decision solution. But the majority of the current 3PRLP selection techniques that are constructed under a strict hypothesis that DM is completely rational in decision making fail to investigate 3PRLP selection problems with consideration of the psychological behavior of DM. Therefore, one other challenge urgently needed to deal with is how to identify the most preferred 3PRLP with full consideration of DM's psychological behavior.

In order to deal with these two challenges, this study attempts to develop a new dominance degree-based heterogeneous linguistic decision-making method to identify the optimal 3PRLP in case of considering the DM's psychological behavior. The remainder of this paper is organized as follows: Section 2 provides literature review and Section 3 introduces briefly the basic concepts of different linguistic forms and formulates the 3PRLP selection problems. Section 4 develops a dominance degree-based heterogeneous linguistic decision-making method. Section 5 provides an empirical study to demonstrate the usefulness of our proposed method, and Section 6 presents our conclusions.

2. Literature Review

Reverse logistics management has been one of the most heated topics discussed in the supply chain management research domain, which mainly focuses on the backward flow of materials and raw equipment from customers to suppliers [3]. Its biggest advantage is able to provide customers with a chance to return end-of-life products to the manufacturer and to allow this manufacturer to reevaluate them and utilize them again in the production cycle [17]. In other words, reverse logistics can not only bring economic benefits but also protect the resources of raw materials as the environment [18]. The pressure from environmental protection and sustainable development has driven the majority of manufacturers to outsource logistics activities to 3PRLPs. To identify the most sustainable 3PRLP, the manufacturers have to address two key issues in the 3PRLP selection. The first one is to determine the optimal selection criteria. In the early research, the majority of the identified 3PRLP evaluation criteria are from economic, environmental, and social dimensions [19–25], such as the quality or cost factor from the economic aspect and the recycle or disposal factor from the perspective of environment. Recent studies [3, 26] have demonstrated that the risk factors including operational and financial risks play an important role in selecting the most preferred 3PRLPs. The study [4] had further discussed the relationships between the operational risk and the financial risk and provided the sixteen criteria-based evaluation index system. Following the pioneering works of Zarbakhshnia [4, 27], the sixteen evaluation criteria from economic, environmental, social, and risk dimensions are taking into account in this study when evaluating 3PRLPs, and the key criteria for the selection of sustainable 3PRLPs are summarized in Table 1.

The second one is to propose an evaluation and selection method. Multicriteria decision-making (MCDM) methods, which conduct the selection and ranking process by evaluating lots of criteria in different dimensions simultaneously, have been widely used in the 3PRLP selection, such as the TOPSIS method [33], the VIKOR method [34–36], the ELECTRE method [28], and the DEA method [37, 38]. Table 2 summarizes the prevailing approaches to evaluation and selection of 3PRLPs in the existing literature. It is easy to see that the majority of the current 3PRLP selection techniques are constructed under a strict hypothesis that the DM is completely rational in decision making. In other words, few aforementioned techniques have investigated 3PRLP selection problems with consideration of the psychological behavior of DM.

3. Preliminaries

3.1. Basic Concepts. LTs, HFLTSs, and PLTSs are three frequently used linguistic expression forms and are adopted in this study to capture uncertain performances of 3PRLPs. Their basic concepts are introduced as follows.

Definition 1 (see [43]). The label set $L = \{l_i \mid i = 0, 1, \ldots, \tau\}$ is called the ordinal scale-based linguistic variable when $l_i \geq l_j$ if $i \geq j \, (i, j = 0, 1, \ldots, \tau)$ and $N(l_i) = l_j$ if $j = \tau - i (N(\bullet)$ is the negation operator and τ is a positive integer).

Definition 2 (see [7]). HFLTS is defined as one ordered finite subset of consecutive LTs based on the predefined LT set, which is denoted by $H_L = \{l_i, l_{i+1}, \ldots, l_j\}$ and $l_k \in L \, (k = i, i+1, \ldots, j)$.

Definition 3 (see [44]). The PLTS is defined as $L(p) = \{l_\sigma(p_\sigma) \mid l_\sigma \in L, \; p_\sigma \geq 0, \; \sigma \in \Lambda, \; \sum_{\sigma \in \Lambda} p_\sigma \leq 1\}$, where $\Gamma = \{1, 2, \ldots, \tau\}$ be a set of the subscripts of LTs in L and Λ be a subset of Γ.

In the practical operation process, the LT $l_i \in L$ is equivalent to the special PLTS $L(p) = \{l_i(1.0)\}$, and the HFLTS $H_L = \{l_i, l_{i+1}, \ldots, l_j \mid l_k \in L, k = i, i+1, \ldots, j\}$ can be mathematically rewritten the PLTS as follows:

$$L(p) = \left\{ l_i\left((q - g + 1)^{-1} \right) \Big| \, i = g, g+1, \ldots, q \right\}. \tag{1}$$

Definition 4 (see [44]). Given a set of PLTSs $\wp = \{L_1(p), L_2(p), \ldots, L_m(p)\}$, the element $L_i(p) \in \wp$ is

Table 1: Criteria used for the selection of sustainable 3PRLPs.

Dimensions	Criteria	Optimal references											
		[17]	[28]	[19]	[20]	[29]	[30]	[31]	[32]	[26]	[3]	[4]	[27]
Economic	Quality		✓	✓	✓	✓			✓	✓	✓	✓	✓
	Cost	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	Lead time	✓								✓	✓	✓	✓
	Delivery and services	✓		✓	✓	✓			✓		✓	✓	✓
	Transportation					✓			✓	✓	✓	✓	
Environment	Recycle			✓		✓	✓	✓	✓	✓	✓	✓	✓
	Disposal			✓		✓			✓	✓	✓	✓	✓
	Remanufacture and reuse			✓		✓			✓	✓	✓	✓	✓
	Green technology capability		✓	✓				✓	✓			✓	
	Environment protection certification									✓		✓	
	Eco-design production						✓				✓	✓	
Social	Health and safety		✓				✓				✓	✓	✓
	Voice of customer	✓				✓					✓	✓	✓
	Employment stability				✓	✓		✓			✓	✓	
Risk	Operational risk		✓						✓		✓	✓	✓
	Financial risk		✓						✓		✓	✓	✓

Table 2: Summary of the prevailing methods to select the optimal 3PRLPs.

Selection methods	Optimal references															
	[3]	[4]	[27]	[36]	[34]	[35]	[39]	[40]	[41]	[33]	[28]	[20]	[42]	[1]	[37]	[38]
AHP			✓			✓	✓			✓						
ANP								✓	✓							
TOPSIS				✓						✓		✓				
VIKOR				✓	✓	✓										
ELECTRE											✓					
SWARA	✓	✓														
MOORA	✓		✓													
COPRAS		✓														
DEA															✓	✓
Other methods													✓	✓		

denoted by $L_i(p) = \{l_\sigma(p_\sigma^i) \mid \sigma \in \Lambda_i\}$. $L_i(p)$ is called a partial PLTS when $\sum_{\sigma\in\Lambda_i} p_\sigma^i < 1$, and $L_i(p)$ is called a complete PLTS when $\sum_{\sigma\in\Lambda_i} p_\sigma^i = 1$. Then, the normalization process of the set of PLTSs $\wp$ is shown as follows:

(1) If $L_i(p)$ is a partial PLTS, then it should be normalized into the complete PLTS $\widehat{L}_i(p) = \{l_\sigma(p_\sigma^i + \tau^{-1}(1 - \sum_{\sigma\in\ \Lambda_i} p_\sigma^i)), l_\rho(\tau^{-1}(1 - \sum_{\sigma\in\Lambda_i} p_\sigma^i)) \mid \sigma \in \Lambda_i, \rho \in (\Gamma\backslash\Lambda_i)\}$

(2) Let $\Lambda_\wp = \Lambda_1 \cup \Lambda_2 \cup \cdots \cup \Lambda_m$ and $\Lambda^+ = \Lambda_i \cap \Lambda_\wp$, if $\Lambda_i \subset \Lambda_\wp (i = 1, 2, \ldots, m)$, the set of LTs $L^+ = \{\bar{l}_\rho \mid \rho \in \Lambda^+\}$ is added in $\widehat{L}_i(p)$ until $\Lambda_i = \Lambda_\wp$, and probabilities of all added LTs are zero

Definition 5. Considering two complete PLTSs denoted by $L_1(p) = \{l_\sigma(p_\sigma^1) \mid \sigma \in \Lambda_1\}$ and $L_2(p) = \{l_\sigma(p_\sigma^2) \mid \sigma \in \Lambda_2\}$, probabilistic linguistic distance between $L_1(p)$ and $L_2(p)$ is provided as follows:

$$d(L_1(p), L_2(p)) = \frac{1}{\tau}\left|\sum_{\sigma\in\Lambda_1\cap\Lambda_2} \sigma \times \left(p_\sigma^1 - p_\sigma^2\right) + \sum_{(\sigma\in\Lambda\backslash\Lambda_2)} p_\sigma^1 - \sum_{(\sigma\in\Lambda\backslash\Lambda_1)} p_\sigma^2\right|, \quad (2)$$

where $\Lambda = \Lambda_1 \cup \Lambda_2$.

The above probabilistic linguistic distance measure is motivated by the idea of linguistic distribution distance measure reported in [45], and it is easy to prove that this measure possesses the following desirable properties.

Proposition 1. *Let $L_1(p) = \{l_\sigma(p_\sigma^1) \mid \sigma \in \Lambda_1\}$, $L_2(p) = \{l_\upsilon(p_\upsilon^2) \mid \upsilon \in \Lambda_2\}$, and $L_3(p) = \{l_\upsilon(p_\upsilon^3) \mid \upsilon \in \Lambda_3\}$ be three complete PLTSs, and $L_1(p) > L_2(p)$ when $\min_{\sigma\in\Lambda_1}\sigma > \max_{\upsilon\in\Lambda_2}\upsilon$, then we have*

(P1.1) $0 \le d(L_1(p), L_2(p)) \le 1$

(P1.2) $d(L_1(p), L_2(p)) = 0$ *if and only if* $L_1(p) = L_2(p)$

(P1.3) $d(L_1(p), L_2(p)) = d(L_2(p), L_1(p))$

(P1.4) If $L_1(p) > L_2(p) > L_3(p)$, *then* $d(L_1(p), L_2(p)) < d(L_1(p), L_3(p))$ *and* $d(L_2(p), L_3(p)) < d(L_1(p), L_3(p))$

3.2. Formulation of the 3PRLP Selection Problems. The practical 3PRLP selection usually needs to take into account lots of factors from the following four aspects (also called main criteria): economic criterion (mc_1), social criterion (mc_2), environment criterion (mc_3), and risk criterion (mc_4). Every main criterion $\mathrm{mc}_j\,(j \in \{1,2,3,4\})$ is assumed to include $o_j - o_{j-1}$ subcriteria $\{c_{o_{j-1}+1}, c_{o_{j-1}+2}, \ldots, c_{o_j}\}\,(o_0 = 0)$, where o_4 denotes the total number of subcriteria. Let $A = \{a_1, a_2, \ldots, a_m\}$ be a set of feasible 3PRLPs, $C = \{c_1, c_2, \ldots, c_{o_4}\}$ be the set of subcriteria, and r_{if} denote the performance score of $a_i\,(i \in \{1,2,\ldots,m\})$ under the subcriterion $c_f\,(f \in \{1,2,\ldots,o_4\})$. Owing to the fact that the expression form of 3PRLPs performances generally depends on the nature of the criteria in the real-life complex assessed contexts [46, 47], the performance scores under different criteria may be represented by different expression forms of information. In this study, the criterion c_f in the subcriteria set C is assumed to be evaluated using one of three distinct information forms (i.e., LTs, HFLTSs, and PLTSs). The criteria set is divided into three different criteria subsets, i.e., $C = C_1 \cup C_2 \cup C_3$ and $C_1 \cap C_2 \cap C_3 = \varnothing$. Without loss of generality, it is stipulated that

(i) If $c_f \in C_1$, then $r_{if} = l_{if}^{g(f_1)}$ is represented by single LT based on $L^{g(f_1)} = \{l_1, l_2, \ldots, l_{g(f_1)}\}$

(ii) If $c_f \in C_2$, then $r_{if} = (H_L)_{if}^{g(f_2)}$ is represented by a HFLTS based on $L^{g(f_2)} = \{l_1, l_2, \ldots, l_{g(f_2)}\}$

(iii) If $c_f \in C_3$, then $r_{if} = L_{if}^{g(f_3)}(p)$ is represented by a PLTS based on $L^{g(f_3)} = \{l_1, l_2, \ldots, l_{g(f_3)}\}$

where $g(f_k)\,(k = 1,2,3)$ is the granularity of the LT set.

Then, the 3PRLP selection problem is concisely expressed in the form of heterogeneous linguistic decision matrix $\mathrm{R} = (r_{if})_{m \times o_4}$ which is shown in Table 3.

4. The Developed Dominance Degree-Based Heterogeneous Linguistic Decision-Making Technique

To well evaluate and identify the sustainable 3PRLP, this section will develop a new dominance degree-based heterogeneous linguistic decision-making method. There are two influencing factors: the first one is to determine the dominance matrix (which is solved in Section 4.1), and the second one is to identify the group utility and the individual regret (which is dealt with in Section 4.2).

4.1. Determining the Dominance Matrix. Usually, the dominance degree of each 3PRLP under each criterion over the other 3PRLPs is determined by comparing the magnitudes of their performance values. Owing to the fact that all the performance values r_{if} take the form of PLTSs, the first task is to develop a useful ranking method for comparing the magnitudes of performance values. Thus, a new probabilistic linguistic distance-based ratio index is introduced in Definition 6.

Definition 6. Given two complete PLTSs $L_1(p)$ and $L_2(p)$, let $\mathcal{O}^+ = \{l_\tau(1.0)\}$ and $\mathcal{O}^- = \{l_1(1.0)\}$ be the positive ideal PLTS and the negative ideal PLTS, respectively, the ratio index of $L_j(p)\,(j = 1,2)$ is defined as follows:

$$\mathcal{F}\big(L_j(p)\big) = \frac{d\big(L_j(p), \mathcal{O}^-\big)}{1 + \max\{d(L_1(p), \mathcal{O}^-), d(L_2(p), \mathcal{O}^-)\}} - \frac{d\big(L_j(p), \mathcal{O}^+\big)}{1 + \min\{d(L_1(p), \mathcal{O}^+), d(L_2(p), \mathcal{O}^+)\}}, \tag{3}$$

where $d(\bullet, \bullet)$ is probabilistic linguistic distance measure defined in equation (2).

In the practical 3PRLP selecting process under PLTSs context, if the evaluation value of one 3PRLP under a criterion provided by the DM is the PLTS $\{l_\tau(1.0)\}$ based on $L^{(\tau)} = \{l_1, l_2, \ldots, l_\tau\}$, then the 3PRLP is regarded as the best one for the evaluator from the perspective of this criterion and the evaluation value can be regarded as the positive ideal PLTS $\mathcal{O}^+ = \{l_\tau(1.0)\}$. On the contrary, if the assessment value is $\{l_1(1.0)\}$, which means that this preference for the evaluator is the worst and the evaluation value can be regarded as the negative ideal PLTS $\mathcal{O}^- = \{l_1(1.0)\}$. Apparently, if $L_1(p)$ has much shorter distance from $\mathcal{O}^+$ than $L_2(p)$ and has much farther distance from $\mathcal{O}^-$ than $L_2(p)$, then $L_1(p)$ is superior to $L_2(p)$. That is to say, the bigger the $\mathcal{F}(L_j(p))\,(j = 1,2)$ is, the larger the PLTS $L_j(p)$ is, and thus, the comparison law between $L_1(p)$ and $L_2(p)$ is provided as follows:

(i) If $\mathcal{F}(L_1(p)) < \mathcal{F}(L_2(p))$, then $L_1(p) \prec_{\mathcal{F}} L_2(p)$

(ii) If $\mathcal{F}(L_1(p)) = \mathcal{F}(L_2(p))$, then $L_1(p) \sim_{\mathcal{F}} L_2(p)$

(iii) If $\mathcal{F}(L_1(p)) > \mathcal{F}(L_2(p))$, then $L_1(p) \succ_{\mathcal{F}} L_2(p)$

where the symbol $\succ$ means "is superior to," the symbol $\sim$ means "is equivalent to," and the symbol $\prec$ means "is inferior to," respectively.

Proposition 2. *Given two PLTSs $L_1(p)$ and $L_2(p)$, the ratio index of $L_j(p)\,(j = 1,2)$ which is denoted by $\mathcal{F}(L_j(p))$ possesses the following properties:*

(P2.1) $-1 \le \mathcal{F}(L_j(p)) \le 0.5$

(P2.2) $\mathcal{F}(L_j(p)) = 0.5$ *if and only if* $L_j(p) = \mathcal{O}^+$

(P2.3) $\mathcal{F}(L_j(p)) = -1$ *if and only if* $L_j(p) = \mathcal{O}^-$

Table 3: Heterogeneous linguistic decision matrix R for performances of 3PRLPs.

3PRLPs	Main criteria/subcriteria											
	Economic mc_1			Social mc_2			Environment mc_3			Risk mc_4		
	c_1	$\cdots$	c_{o_1}	c_{o_1+1}	$\cdots$	c_{o_2}	c_{o_2+1}	$\cdots$	c_{o_3}	c_{o_3+1}	$\cdots$	c_{o_4}
a_1	r_{11}	$\cdots$	r_{1o_1}	$r_{1(o_1+1)}$	$\cdots$	r_{1o_2}	$r_{1(o_2+1)}$	$\cdots$	r_{1o_3}	$r_{1(o_3+1)}$	$\cdots$	r_{1o_4}
a_2	r_{21}	$\cdots$	r_{2o_1}	$r_{2(o_1+1)}$	$\cdots$	r_{2o_2}	$r_{2(o_2+1)}$	$\cdots$	r_{2o_3}	$r_{2(o_3+1)}$	$\cdots$	r_{2o_4}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
a_m	r_{m1}	$\cdots$	r_{mo_1}	$r_{m(o_1+1)}$	$\cdots$	r_{mo_2}	$r_{m(o_2+1)}$	$\cdots$	r_{mo_3}	$r_{m(o_3+1)}$	$\cdots$	r_{mo_4}

(P2.4) If $d(L_1(p),\mathcal{O}^-) > d(L_2(p),\mathcal{O}^-)$ and $d(L_1(p),\mathcal{O}^+) < d(L_2(p),\mathcal{O}^+)$, namely, $L_1(p)$ is superior to $L_2(p)$, then $\mathcal{F}(L_2(p)) < \mathcal{F}(L_1(p))$

Proof. (P2.1) Owing to $0 \le d(L_j(p),\mathcal{O}^-), d(L_j(p),\mathcal{O}^+) \le 1$, we have

$$0 \le \max_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^-\right)\right\},\qquad \min_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^+\right)\right\} \le 1. \tag{4}$$

It is easy to obtain

$$0 \le \frac{d\left(L_j(p),\mathcal{O}^-\right)}{1+\max_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^-\right)\right\}} \le 0.5,\qquad -1 \le -\frac{d\left(L_j(p),\mathcal{O}^+\right)}{1+\min_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^+\right)\right\}} \le 0. \tag{5}$$

According to the definition of $\mathcal{F}(L_j(p))$, we can conclude $-1 \le \mathcal{F}(L_j(p)) \le 0.5$.

(P2.2) If $\mathcal{F}(L_j(p)) = 0.5$, according to the proof of (1) in Proposition 2, we have

$$\frac{d\left(L_j(p),\mathrm{O}^-\right)}{1+\max_{j=1}^{n}\left\{d\left(L_j(p),\mathrm{O}^-\right)\right\}} = 0.5,\qquad -\frac{d\left(L_j(p),\mathrm{O}^+\right)}{1+\min_{j=1}^{n}\left\{d\left(L_j(p),\mathrm{O}^+\right)\right\}} = 0. \tag{6}$$

Further, we conclude $d(L_j(p),\mathcal{O}^-) = \max_{j=1}^{n}\left\{(L_j(p),\mathcal{O}^-)\right\} = 1$ and $d(L_j(p),\mathcal{O}^+) = 0$. By the definition of probabilistic linguistic distance measure, we have $L_j(p) = \mathcal{O}^+$. On the contrary, if $L_j(p) = \mathcal{O}^+$, then $d(L_j(p),\mathcal{O}^+) = 0$ and $d(L_j(p),\mathcal{O}^-) = 1$, namely, $\mathcal{F}(L_j(p)) = 0.5$.

(P2.3) This proof is similar to the proof of (P2.2) in Proposition 2.

(P2.4) If $d(L_1(p),\mathcal{O}^-) > d(L_2(p),\mathcal{O}^-)$ and $d(L_1(p),\mathcal{O}^+) < d(L_2(p),\mathcal{O}^+)$, then we have

$$\max\{d(L_1(p),\mathcal{O}^-), d(L_2(p),\mathcal{O}^-)\} = d(L_1(p),\mathcal{O}^-),\qquad \min\{d(L_1(p),\mathcal{O}^+), d(L_2(p),\mathcal{O}^+)\} = d(L_1(p),\mathcal{O}^+), \tag{7}$$

and then we conclude

$$\mathcal{F}(L_1(p)) = \frac{d\left(L_1(p),\mathcal{O}^-\right)}{1+d\left(L_1(p),\mathcal{O}^-\right)} - \frac{d\left(L_1(p),\mathcal{O}^+\right)}{1+d\left(L_1(p),\mathcal{O}^+\right)},\qquad \mathcal{F}(L_2(p)) = \frac{d\left(L_2(p),\mathcal{O}^-\right)}{1+d\left(L_1(p),\mathcal{O}^-\right)} - \frac{d\left(L_2(p),\mathcal{O}^+\right)}{1+d\left(L_1(p),\mathcal{O}^+\right)}. \tag{8}$$

Obviously, $\mathcal{F}(L_1(p)) > \mathcal{F}(L_2(p))$.

The proof of Proposition 2 is completed.

Analogously, the ranking law for a set of PLTSs $\Theta = \{L_1(p), L_2(p), \ldots, L_n(p)\}\,(n>2)$ is provided as follows:

(i) If $\mathcal{F}(L_1(p)) < \mathcal{F}(L_2(p)) < \cdots < \mathcal{F}(L_n(p))$, then $L_1(p) \prec_{\mathcal{F}} L_2(p) \prec_{\mathcal{F}} \cdots \prec_{\mathcal{F}} L_n(p)$

(ii) If $\mathcal{F}(L_1(p)) = \mathcal{F}(L_2(p)) = \cdots = \mathcal{F}(L_n(p))$, then $L_1(p) \sim_{\mathcal{F}} L_2(p) \sim_{\mathcal{F}} \cdots \sim_{\mathcal{F}} L_n(p)$

(iii) If $\mathcal{F}(L_1(p)) > \mathcal{F}(L_2(p)) > \cdots > \mathcal{F}(L_n(p))$, then $L_1(p) \succ_{\mathcal{F}} L_2(p) \succ_{\mathcal{F}} \cdots \succ_{\mathcal{F}} L_n(p)$

where $\mathcal{F}(L_j(p))$ is the ratio index of $L_j(p) \in \Theta$ and is defined as follows:

$$\mathcal{F}\left(L_j(p)\right) = \frac{d\left(L_j(p),\mathcal{O}^-\right)}{1+\max_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^-\right)\right\}} - \frac{d\left(L_j(p),\mathcal{O}^+\right)}{1+\min_{j=1}^{n}\left\{d\left(L_j(p),\mathcal{O}^+\right)\right\}}. \tag{9}$$

Based on the developed ratio index of PLTSs, we next present a new defuzzification function of PLTSs to manage probabilistic linguistic assessment-based criteria weights. □

Definition 7. Given a set of PLTSs $\Theta = \{L_1(p), L_2(p), \ldots, L_n(p)\}$, the ratio index-based defuzzification function of $L_j(p)\,(j=1,2,\ldots,n)$ is defined as follows:

$$\mathcal{E}\left(L_j(p)\right) = \frac{1+\mathcal{F}\left(L_j(p)\right)}{\sum_{j=1}^{n}\left(1+\mathcal{F}\left(L_j(p)\right)\right)}. \tag{10}$$

Proposition 3. *Given a set of PLTSs $\Theta = \{L_1(p), L_2(p), \ldots, L_n(p)\}$, the ratio index-based defuzzification function of $L_j(p)$ which is denoted by $\mathcal{E}(L_j(p))\,(j=1,2,\ldots,n)$ possesses the following properties:*

(P3.1) $0 \le \mathcal{E}(L_j(p)) \le 1$

(P3.2) $\sum_{j=1}^{n}\mathcal{E}(L_j(p)) = 1$

(P3.3) If $L_1(p) \prec L_2(p)$, then $\mathscr{E}(L_1(p)) < \mathscr{E}(L_2(p))$

The proof of Proposition 3 is straightforward and is omitted here.

By equation (10), the defuzzification score of the main criterion weight $w(\mathrm{mc}_i)$ can be calculated by the following expression:

$$\mathscr{E}(w(\mathrm{mc}_i)) = (1 + \mathscr{F}(w(\mathrm{mc}_i)))^{-1} \sum_{i=1}^{4} (1 + \mathscr{F}(w(\mathrm{mc}_i))), \quad i = 1, 2, 3, 4, \tag{11}$$

where $\mathscr{F}(w(\mathrm{mc}_i)) = d(w(\mathrm{mc}_i), \mathcal{O}^-)/(1 + \max_{i=1}^{4}\{d(w(\mathrm{mc}_i), \mathcal{O}^-)\}) - d(w(\mathrm{mc}_i), \mathcal{O}^+)/(1 + \min_{i=1}^{4}\{d(w(\mathrm{mc}_i), \mathcal{O}^+)\})$.

Analogously, the defuzzification score of the subcriterion weight $w(c_f)$ is determined by the following expression:

$$\mathscr{E}(w(c_f)) = (1 + \mathscr{F}(w(c_f)))^{-1} \sum_{f=1}^{o_4} (1 + \mathscr{F}(w(c_f))), \quad f = 1, 2, \ldots, o_4, \tag{12}$$

where $\mathscr{F}(w(c_f)) = (dw(c_f), \mathcal{O}^-)/(1 + \max_{f=1}^{o_4}\{d(w(c_f), \mathcal{O}^-)\}) - d\ (w(c_f), \mathcal{O}^+)/(1 + \min_{f=1}^{o_4}\{d(w(c_f), \mathcal{O}^+)\})$.

Then, the final weight score for each subcriterion $w_f\ (f = 1, 2, \ldots, o_4)$ is determined as follows:

$$\begin{aligned}
\begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_{o_1} \end{pmatrix} &= \mathscr{E}(w(\mathrm{mc}_1)) \otimes \begin{pmatrix} \mathscr{E}(w(c_1)) \\ \mathscr{E}(w(c_2)) \\ \vdots \\ \mathscr{E}(w(c_{o_1})) \end{pmatrix}, \\
\begin{pmatrix} w_{o_1+1} \\ w_{o_1+2} \\ \vdots \\ w_{o_2} \end{pmatrix} &= \mathscr{E}(w(\mathrm{mc}_2)) \otimes \begin{pmatrix} \mathscr{E}(w(c_{o_1+1})) \\ \mathscr{E}(w(c_{o_1+2})) \\ \vdots \\ \mathscr{E}(w(c_{o_2})) \end{pmatrix}, \\
\begin{pmatrix} w_{o_2+1} \\ w_{o_2+2} \\ \vdots \\ w_{o_3} \end{pmatrix} &= \mathscr{E}(w(mc_3)) \otimes \begin{pmatrix} \mathscr{E}(w(c_{o_2+1})) \\ \mathscr{E}(w(c_{o_2+2})) \\ \vdots \\ \mathscr{E}(w(c_{o_3})) \end{pmatrix}, \\
\begin{pmatrix} w_{o_3+1} \\ w_{o_3+2} \\ \vdots \\ w_{o_4} \end{pmatrix} &= \mathscr{E}(w(\mathrm{mc}_4)) \otimes \begin{pmatrix} \mathscr{E}(w(c_{o_3+1})) \\ \mathscr{E}(w(c_{o_3+2})) \\ \vdots \\ \mathscr{E}(w(c_{o_4})) \end{pmatrix},
\end{aligned} \tag{13}$$

which is the product of the main criterion weight score and the subcriterion weight score with respect to the corresponding main criterion.

Furthermore, we can calculate the dominance degree of the 3PRLP a_i over the 3PRLP a_k concerning the criterion $c_f\ (f = 1, 2, \ldots, o_4)$ using the following expression:

$$\phi_f(a_i, a_k) = \begin{cases} \tau^{-1}\left|\sum_{\sigma\in\Lambda_{r_{\mathrm{if}}}\cap\Lambda_{r_{kf}}} \sigma \times \left(p_\sigma^{r_{\mathrm{if}}} - p_\sigma^{r_{kf}}\right) + \sum_{\left(\sigma\in\Lambda\backslash\Lambda_{r_{kf}}\right)} p_\sigma^{r_{\mathrm{if}}} - \sum_{\left(\sigma\in\Lambda\backslash\Lambda_{r_{\mathrm{if}}}\right)} p_\sigma^{r_{kf}}\right|, & \text{if } \mathscr{F}(r_{\mathrm{if}}) - \mathscr{F}(r_{kf}) > 0, \\ 0, \quad \text{if } \mathscr{F}(r_{\mathrm{if}}) - \mathscr{F}(r_{kf}) = 0, & \\ -(\theta\tau)^{-1}\left|\sum_{\sigma\in\Lambda_{r_{kf}}\cap\Lambda_{r_{\mathrm{if}}}} \sigma \times \left(p_\sigma^{r_{kf}} - p_\sigma^{r_{\mathrm{if}}}\right) + \sum_{\left(\sigma\in\Lambda\backslash\Lambda_{r_{\mathrm{if}}}\right)} p_\sigma^{r_{kf}} - \sum_{\left(\sigma\in\Lambda\backslash\Lambda_{r_{kf}}\right)} p_\sigma^{r_{\mathrm{if}}}\right|, & \text{if } \mathscr{F}(r_{if}) - \mathscr{F}(r_{kf}) < 0. \end{cases} \tag{14}$$

In equation (14), the parameter θ represents the attenuation factor of the losses.

In the practical decision analysis processes, $\phi_f(a_i, a_k)$ is usually regarded as a gain when $\mathscr{F}(r_{if}) - \mathscr{F}(r_{kf}) > 0$,

$\phi_f(a_i, a_k)$ is deemed to be a nil when $\mathscr{F}(r_{if}) - \mathscr{F}(r_{kf}) = 0$, and $\phi_f(a_i, a_k)$ is counted to be a loss when $\mathscr{F}(r_{if}) - \mathscr{F}(r_{kf}) < 0$.

Then, the dominance matrix for the criterion $c_f\,(f = 1, 2, \ldots, o_4)$ is obtained as follows:

$$D_f = \left[\phi_f(a_i, a_k)\right]_{m\times m} = \begin{bmatrix} & a_1 & a_2 & \cdots & a_m \\ a_1 & 0 & \phi_f(a_1, a_2) & \cdots & \phi_f(a_1, a_m) \\ a_2 & \phi_f(a_2, a_1) & 0 & \cdots & \phi_f(a_2, a_m) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_m & \phi_f(a_m, a_1) & \phi_f(a_m, a_2) & \cdots & 0 \end{bmatrix}. \tag{15}$$

Next, the total dominance degree of the 3PRLP $a_i\,(i = 1, 2, \ldots, m)$ under $c_f\,(f = 1, 2, \ldots, o_4)$ can be calculated by the following form:

$$\vartheta_f(a_i) = \sum_{k=1}^{m} \phi_f(a_i, a_k). \tag{16}$$

Accordingly, the total dominance matrix is determined as below:

$$D = \left[\vartheta_f(a_i)\right]_{m\times o_4} = \begin{bmatrix} & c_1 & c_2 & \cdots & c_{o_4} \\ a_1 & \sum_{k=1}^{m} \phi_1(a_1, a_k) & \sum_{k=1}^{m} \phi_2(a_i, a_k) & \cdots & \sum_{k=1}^{m} \phi_f(a_i, a_k) \\ a_2 & \sum_{k=1}^{m} \phi_1(a_2, a_k) & \sum_{k=1}^{m} \phi_f(a_i, a_k) & \cdots & \sum_{k=1}^{m} \phi_f(a_i, a_k) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_m & \sum_{k=1}^{m} \phi_f(a_i, a_k) & \sum_{k=1}^{m} \phi_f(a_i, a_k) & \cdots & \sum_{k=1}^{m} \phi_f(a_i, a_k) \end{bmatrix}. \tag{17}$$

4.2. Identifying the Group Utility and the Individual Regret. On the basis of the obtained dominance matrix $D = (\vartheta_f(a_i))_{m\times o_4}$, the dominance degree-based positive ideal solutions (PISs) $\vartheta^+ = (\vartheta_1^+, \vartheta_2^+, \ldots, \vartheta_{o_4}^+)$ is determined by the following equation:

$$\begin{aligned} \vartheta^+ &= \left(\vartheta_1^+, \vartheta_2^+, \ldots, \vartheta_{o_4}^+\right) \\ &= \left(\max_{i=1}^{m} \sum_{k=1}^{m} \phi_1(a_i, a_k), \max_{i=1}^{m} \sum_{k=1}^{m} \phi_2(a_i, a_k), \ldots, \max_{i=1}^{m} \sum_{k=1}^{m} \phi_{o_4}(a_i, a_k)\right), \end{aligned} \tag{18}$$

and the dominance degree-based negative ideal solutions (NISs) $\vartheta^- = (\vartheta_1^-, \vartheta_2^-, \ldots, \vartheta_{o_4}^-)$ is calculated according to the following form:

$$\begin{aligned} \vartheta^- &= \left(\vartheta_1^-, \vartheta_2^-, \ldots, \vartheta_{o_4}^-\right) \\ &= \left(\min_{i=1}^{m} \sum_{k=1}^{m} \phi_1(a_i, a_k), \min_{i=1}^{m} \sum_{k=1}^{m} \phi_2(a_i, a_k), \ldots, \min_{i=1}^{m} \sum_{k=1}^{m} \phi_{o_4}(a_i, a_k)\right). \end{aligned} \tag{19}$$

Thus, the dominance degree-based maximum group utility $\text{Dom}\, S_i$ for the 3PRLP $a_i\,(i = 1, 2, \ldots, m)$ is obtained by the following equation:

$$\text{Dom}\, S_i = \sum_{f=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) \bullet \frac{d\left(\vartheta_f^+, \vartheta_{if}\right)}{d\left(\vartheta_f^+, \vartheta_f^-\right)}, \tag{20}$$

and the dominance degree-based minimum individual regret $\text{Dom}\, R_i$ for $a_i\,(i = 1, 2, \ldots, m)$ is determined as follows:

$$\text{Dom}\, R_i = \max_{j=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) \bullet \frac{d\left(\vartheta_f^+, \vartheta_{if}\right)}{d\left(\vartheta_f^+, \vartheta_f^-\right)}, \tag{21}$$

where $d\,(\vartheta_f^+, \vartheta_{if})$ is defined as follows:

$$d\left(\vartheta_f^+, \vartheta_{if}\right) = \max_{i=1}^{m} \sum_{k=1}^{m} \phi_f\,(a_i, a_k) - \sum_{k=1}^{m} \phi_f\,(a_i, a_k), \tag{22}$$

and $d\,(\vartheta_f^+, \vartheta_f^-)$ is defined as follows:

$$d\left(\vartheta_f^+, \vartheta_f^-\right) = \max_{i=1}^{m} \sum_{k=1}^{m} \phi_f\,(a_i, a_k) - \min_{i=1}^{m} \sum_{k=1}^{m} \phi_f\,(a_i, a_k). \tag{23}$$

Accordingly, the compromise solution of the 3PRLP $a_i\,(i = 1, 2, \ldots, m)$ is obtained as follows:

$$\text{Dom}\, Q_i = t\, \frac{\text{Dom}\, S_i - \min_i\{\text{Dom}\, S_i\}}{\max_i\{\text{Dom}\, S_i\} - \min_i\{\text{Dom}\, S_i\}} + (1-t)\, \frac{\text{Dom}\, R_i - \min_i\{\text{Dom}\, R_i\}}{\max_i\{\text{Dom}\, R_i\} - \min_i\{\text{Dom}\, R_i\}}, \tag{24}$$

where the parameter $t\,(t \in [0, 1])$ is used to construct a convex combination of $\text{Dom}\, S_i$ and $\text{Dom}\, R_i$.

At length, we rank the 3PRLPs by sorting the scores of $\text{Dom}\, S_i$, $\text{Dom}\, R_i$, $\text{Dom}\, Q_i\,(i = 1, 2, \ldots, m)$ in a decreasing order, and three ranking lists of 3PRLPs are obtained. Let $a_{\sigma(1)}$ be the 3PRLP with the first position in the ranking list derived by $\text{Dom}\, Q_i\,(i = 1, 2, \ldots, m)$, and it is the compromise solution if the following two conditions (Cd1 and Cd2) are satisfied simultaneously [48, 49]:

(i) Cd1: $\text{Dom}\, Q\,(a_{\sigma(2)}) - \text{Dom}\, Q\,(a_{\sigma(1)}) \geq (m-1)^{-1}$

(ii) Cd2: the 3PRLP $a_{\sigma(1)}$ is also the 3PRLP with the first position in the ranking lists derived by $\text{Dom}\, S_i\,(i = 1, 2, \ldots, m)$ and/or $\text{Dom}\, R_i\,(i = 1, 2, \ldots, m)$

If $Cd1$ is not satisfied, we should identify the maximum value of M according to the following formula: $\text{Dom}\, Q\,(a_{\sigma(M)}) - \text{Dom}\, Q\,(a_{\sigma(1)}) < (1/(m-1))$, and the set of 3PRLPs $\left\{a_{\sigma(1)}, a_{\sigma(2)}, \ldots, a_{\sigma(M)}\right\}$ is the compromise solution for the DM; if $Cd2$ is not satisfied, the set of 3PRLPs $\left\{a_{\sigma(1)}, a_{\sigma(2)}\right\}$ is the set of the compromise solutions.

Based on the above analysis, a brief algorithm of the proposed method is presented in Figure 1.

5. Case Study and Comparison Analysis

With the increasing cost of raw materials and pressure to minimize the environmental impacts of business activities, more and more car manufacturers plan to outsource their logistics activities to a sustainable 3PRLP. We here introduce a car manufacture case study to illustrate the usefulness and application of the developed method to the 3PRLP selection.

5.1. Description of the Selection Problems of 3PRLPs. The car manufacturer X considered for this research mainly produces business cars, home cars, and batteries in China. Its production capacity is more than hundred thousand cars annually. This manufacture follows the development route of independent R&D, production and brand and is determined to create a truly affordable national vehicle. Owing to lack of the available infrastructure and expertise, the management team of the manufacturer X recently plans to outsource the logistics activities to a sustainable 3PRLP. In order to select a most preferred 3PRLP from five potential 3PRLPs {3PRLP1, 3PRLP2, 3PRLP3, 3PRLP4, 3PRLP5} to cooperate with, 16 qualified assessed criteria from economic, environmental, social, and risk aspects are identified and are listed in Table 4 [4]. Considering the complexity and uncertainty of the realistic evaluation contexts, the weights of all evaluating criteria are represented by PLTSs and are provided in Table 4. LTs, HFLTSs, and PLTSs with different granularities are simultaneously provided for assessors to capture the qualitative and uncertain performances of 3PRLPs. The performances of five 3PRLPs in terms of 16 criteria are provided in Table 5.

It is worthy mentioned in Table 5 that (1) the performances of 3PRLPs under *quality criterion*, *disposal criterion*, *eco-design production criterion*, and *operational risk criterion* are represented by single LTs based on LT set with the granularity $g\,(1) = 7$; (2) the performances of 3PRLPs under *cost criterion*, *recycle criterion*, *remanufacture and reuse criterion*, *environment protection certification criterion*, *green technology capability criterion*, and *voice of customer criterion* are represented by PLTSs based on LT set with the granularity $g\,(2) = 5$; (3) the performances of 3PRLPs under *lead time criterion* and *transportation criterion* are represented by single LTs based on LT set with the granularity $g\,(3) = 5$; (4) the performances of 3PRLPs under *delivery and services criterion* and *health and safety criterion* are represented by HFLTSs based on LT set with the granularity $g\,(4) = 7$; (5) the performances of 3PRLPs under *lead time criterion and transportation criterion* are represented by single LTs based on LT set with the granularity $g\,(3) = 5$; and (6) the performances of 3PRLPs under *employment stability criterion* and *financial risk criterion* are represented by PLTSs based on LT set with the granularity $g\,(5) = 7$.

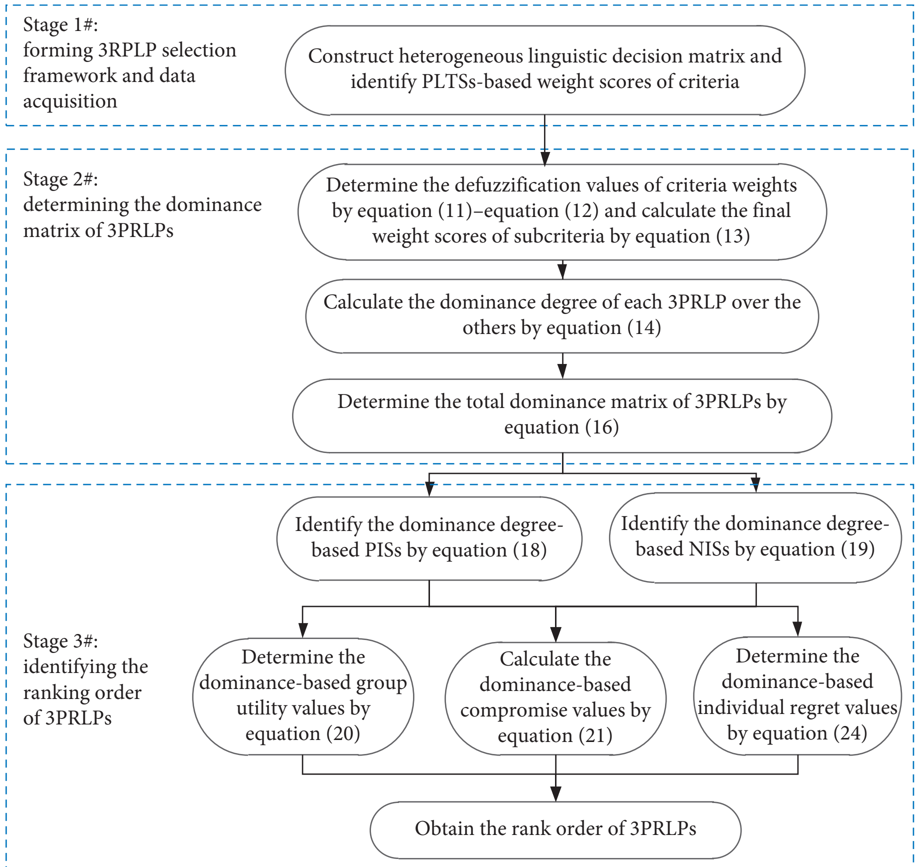

Figure 1: Flowchart of the algorithm of the developed method.

Table 4: The main criteria and subcriteria for 3PRLP selection and criteria weights.

Main criteria	Weights of main criteria	Subcriteria	Weights of subcriteria
C_1	$\{l_4^{(5)}(0.4), l_5^{(5)}(0.6)\}$	c_1	$\{l_3^{(5)}(0.2), l_4^{(5)}(0.4), l_5^{(5)}(0.4)\}$
		c_2	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
		c_3	$\{l_4^{(5)}(1.0)\}$
		c_4	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$
		c_5	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$
C_2	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$	c_6	$\{l_3^{(5)}(1.0)\}$
		c_7	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$
		c_8	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$
		c_9	$\{l_4^{(5)}(1.0)\}$
		c_{10}	$\{l_3^{(5)}(0.7), l_4^{(5)}(0.3)\}$
		c_{11}	$\{l_3^{(5)}(1.0)\}$
C_3	$\{l_3^{(5)}(1.0)\}$	c_{12}	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$
		c_{13}	$\{l_4^{(5)}(1.0)\}$
		c_{14}	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
C_4	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$	c_{15}	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$
		c_{16}	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$

5.2. Selection Results Derived by the Developed Method. With the aid of the dominance degree-based heterogeneous linguistic decision-making technique, the most preferred 3PRLP will be determined for the case company. The detailed calculation and selection processes are introduced as follows. First, all the nonhomogeneous linguistic assessed

Table 5: The performances of five 3PRLPs under 16 criteria.

	Quality	Cost	Lead time	Delivery and services
3PRLP1	$l_5^{(7)}$	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$	$l_3^{(5)}$	$\{l_4^{(7)}, l_5^{(7)}\}$
3PRLP2	$l_3^{(7)}$	$\{l_4^{(5)}(1.0)\}$	$l_4^{(5)}$	$\{l_3^{(7)}\}$
3PRLP3	$l_6^{(7)}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$	$l_3^{(5)}$	$\{l_4^{(7)}\}$
3PRLP4	$l_3^{(7)}$	$\{l_3^{(5)}(1.0)\}$	$l_5^{(5)}$	$\{l_2^{(7)}, l_3^{(7)}\}$
3PRLP5	$l_4^{(7)}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$l_2^{(5)}$	$\{l_3^{(7)}, l_4^{(7)}, l_5^{(7)}\}$
	Transportation	Recycle	Disposal	Remanufacture and reuse
3PRLP1	$l_4^{(5)}$	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$	$l_5^{(7)}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
3PRLP2	$l_2^{(5)}$	$\{l_3^{(5)}(1.0)\}$	$l_3^{(7)}$	$\{l_4^{(5)}(1.0)\}$
3PRLP3	$l_3^{(5)}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$l_6^{(7)}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$
3PRLP4	$l_5^{(5)}$	$\{l_3^{(5)}(0.4), l_4^{(5)}(0.4), l_5^{(5)}(0.2)\}$	$l_4^{(7)}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.3), l_6^{(7)}(0.2)\}$
3PRLP5	$l_3^{(5)}$	$\{l_5^{(5)}(1.0)\}$	$l_6^{(7)}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
	Health and safety	Environment protection certification	Eco-design production	Green technology capability
3PRLP1	$\{l_3^{(7)}, l_4^{(7)}, l_5^{(7)}\}$	$\{l_2^{(5)}(0.6), l_3^{(5)}(0.4)\}$	$l_4^{(7)}$	$\{l_2^{(5)}(1.0)\}$
3PRLP2	$\{l_4^{(7)}, l_5^{(7)}\}$	$\{l_3^{(5)}(0.5), l_4^{(5)}(0.2), l_5^{(5)}(0.3)\}$	$l_3^{(7)}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
3PRLP3	$\{l_6^{(7)}\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$l_4^{(7)}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$
3PRLP4	$\{l_5^{(7)}\}$	$\{l_3^{(5)}(1.0)\}$	$l_6^{(7)}$	$\{l_4^{(5)}(1.0)\}$
3PRLP5	$\{l_6^{(7)}, l_7^{(7)}\}$	$\{l_3^{(5)}(0.2), l_4^{(5)}(0.8)\}$	$l_4^{(7)}$	$\{l_3^{(5)}(0.4), l_4^{(5)}(0.4), l_5^{(5)}(0.2)\}$
	Voice of customer	Employment stability	Operational risk	Financial risk
3PRLP1	$\{l_5^{(5)}(1.0)\}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.3), l_6^{(7)}(0.2)\}$	$\{l_6^{(7)}, l_7^{(7)}\}$	$\{l_4^{(7)}(1.0)\}$
3PRLP2	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$	$\{l_5^{(7)}(0.6), l_6^{(7)}(0.4)\}$	$\{l_5^{(7)}\}$	$\{l_2^{(7)}(0.2), l_3^{(7)}(0.8)\}$
3PRLP3	$\{l_4^{(5)}(1.0)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_4^{(7)}, l_5^{(7)}\}$	$\{l_4^{(7)}(0.4), l_5^{(7)}(0.3), l_6^{(7)}(0.3)\}$
3PRLP4	$(l_4^{(5)}(0.8), l_5^{(5)}(0.2))$	$\{l_6^{(7)}(1.0)\}$	$\{l_5^{(7)}\}$	$\{l_5^{(7)}(1.0)\}$
3PRLP5	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$	$\{l_3^{(7)}(0.3), l_4^{(7)}(0.7)\}$	$\{l_3^{(7)}, l_4^{(7)}, l_5^{(7)}\}$	$\{l_4^{(7)}(0.7), l_5^{(7)}(0.3)\}$

values in Table 5 are unified into the form of PLTSs and are shown in Table 6.

In light of the assessment data in Table 4, the defuzzification scores of the main criteria weights are determined according to equation (11) as follows:

$$\begin{aligned}\mathscr{E}(w(\mathrm{mc}_1)) &= 0.3089,\\ \mathscr{E}(w(\mathrm{mc}_2)) &= 0.2673,\\ \mathscr{E}(w(\mathrm{mc}_3)) &= 0.1981,\\ \mathscr{E}(w(\mathrm{mc}_4)) &= 0.2258.\end{aligned} \tag{25}$$

According to equations (12) and (13), the final weight scores of the subcriteria are obtained in Table 7.

Afterwards, take *voice of customer criterion* for example, we can calculate the dominance degrees of one 3PRLP over another one under this criterion according to equation (14), and the dominance matrix under *voice of customer criterion* is obtained as follows:

$$D_{(\text{voice of customer})} = \begin{bmatrix} & \text{3PRLP}_1 & \text{3PRLP}_2 & \text{3PRLP}_3 & \text{3PRLP}_4 & \text{3PRLP}_5 \\ \text{3PRLP}_1 & 0 & 0.32 & 0.20 & 0.16 & 0.46 \\ \text{3PRLP}_2 & -0.32 & 0 & -0.12 & -0.16 & -0.14 \\ \text{3PRLP}_3 & -0.20 & 0.12 & 0 & -0.04 & 0.26 \\ \text{3PRLP}_4 & -0.16 & 0.16 & 0.04 & 0 & 0.30 \\ \text{3PRLP}_5 & -0.46 & 0.14 & 0.26 & 0.30 & 0 \end{bmatrix}. \tag{26}$$

Table 6: Probabilistic linguistic-based performances of five 3PRLPs under 16 criteria.

	Quality	Cost	Lead time	Delivery and services
3PRLP1	$\{l_5^{(7)}(1.0)\}$	$\{l_3^{(5)}(0.3), l_4^{(5)}(0.4), l_5^{(5)}(0.3)\}$	$\{l_3^{(5)}(1.0)\}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.5)\}$
3PRLP2	$\{l_3^{(7)}(1.0)\}$	$\{l_4^{(5)}(1.0)\}$	$\{l_4^{(5)}(1.0)\}$	$\{l_3^{(7)}(1.0)\}$
3PRLP3	$\{l_6^{(7)}(1.0)\}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$	$\{l_3^{(5)}(1.0)\}$	$\{l_4^{(7)}(1.0)\}$
3PRLP4	$\{l_3^{(7)}(1.0)\}$	$\{l_3^{(5)}(1.0)\}$	$\{l_5^{(5)}(1.0)\}$	$\{l_2^{(7)}(0.5), l_3^{(7)}(0.5)\}$
3PRLP5	$\{l_4^{(7)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$\{l_2^{(5)}(1.0)\}$	$\{l_3^{(7)}(\frac{1}{3}), l_4^{(7)}(\frac{1}{3}), l_5^{(7)}(\frac{1}{3})\}$
	Transportation	**Recycle**	**Disposal**	**Remanufacture and reuse**
3PRLP1	$\{l_4^{(5)}(1.0)\}$	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$	$\{l_5^{(7)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
3PRLP2	$\{l_2^{(5)}(1.0)\}$	$\{l_3^{(5)}(1.0)\}$	$\{l_3^{(7)}(1.0)\}$	$\{l_4^{(5)}(1.0)\}$
3PRLP3	$\{l_3^{(5)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$\{l_6^{(7)}(1.0)\}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$
3PRLP4	$\{l_5^{(5)}(1.0)\}$	$\{l_3^{(5)}(0.4), l_4^{(5)}(0.4), l_5^{(5)}(0.2)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.3), l_6^{(7)}(0.2)\}$
3PRLP5	$\{l_3^{(5)}(1.0)\}$	$\{l_5^{(5)}(1.0)\}$	$\{l_6^{(7)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
	Health and safety	**Environment protection certification**	**Eco-design production**	**Green technology capability**
3PRLP1	$\{l_3^{(7)}(\frac{1}{3}), l_4^{(7)}(\frac{1}{3}), l_5^{(7)}(\frac{1}{3})\}$	$\{l_2^{(5)}(0.6), l_3^{(5)}(0.4)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_2^{(5)}(1.0)\}$
3PRLP2	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.5)\}$	$\{l_3^{(5)}(0.5), l_4^{(5)}(0.2), l_5^{(5)}(0.3)\}$	$\{l_3^{(7)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$
3PRLP3	$\{l_6^{(7)}(1.0)\}$	$\{l_4^{(5)}(0.7), l_5^{(5)}(0.3)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$
3PRLP4	$\{l_5^{(7)}(1.0)\}$	$\{l_3^{(5)}(1.0)\}$	$\{l_6^{(7)}(1.0)\}$	$\{l_4^{(5)}(1.0)\}$
3PRLP5	$\{l_6^{(7)}(0.5), l_7^{(7)}(0.5)\}$	$\{l_3^{(5)}(0.2), l_4^{(5)}(0.8)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_3^{(5)}(0.4), l_4^{(5)}(0.4), l_5^{(5)}(0.2)\}$
	Voice of customer	**Employment stability**	**Operational risk**	**Financial risk**
3PRLP1	$\{l_5^{(5)}(1.0)\}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.3), l_6^{(7)}(0.2)\}$	$\{l_6^{(7)}(0.5), l_7^{(7)}(0.5)\}$	$\{l_4^{(7)}(1.0)\}$
3PRLP2	$\{l_3^{(5)}(0.6), l_4^{(5)}(0.4)\}$	$\{l_5^{(7)}(0.6), l_6^{(7)}(0.4)\}$	$\{l_5^{(7)}(1.0)\}$	$\{l_2^{(7)}(0.2), l_3^{(7)}(0.8)\}$
3PRLP3	$\{l_4^{(5)}(1.0)\}$	$\{l_4^{(7)}(1.0)\}$	$\{l_4^{(7)}(0.5), l_5^{(7)}(0.5)\}$	$\{l_4^{(7)}(0.4), l_5^{(7)}(0.3), l_6^{(7)}(0.3)\}$
3PRLP4	$\{l_4^{(5)}(0.8), l_5^{(5)}(0.2)\}$	$\{l_6^{(7)}(1.0)\}$	$\{l_5^{(7)}(1.0)\}$	$\{l_5^{(7)}(1.0)\}$
3PRLP5	$\{l_2^{(5)}(0.3), l_3^{(5)}(0.7)\}$	$\{l_3^{(7)}(0.3), l_4^{(7)}(0.7)\}$	$\{l_3^{(7)}(\frac{1}{3}), l_4^{(7)}(\frac{1}{3}), l_5^{(7)}(\frac{1}{3})\}$	$\{l_4^{(7)}(0.7), l_5^{(7)}(0.3)\}$

Table 7: The final weight scores of sixteen subcriteria.

Subcriteria	Weight scores	Subcriteria	Weight scores
Quality	0.0851	Transportation	0.0810
Cost	0.0871	Recycle	0.0526
Lead time	0.0810	Disposal	0.0701
Delivery and services	0.0539	Remanufacture and reuse	0.0467
Health and safety	0.0701	Voice of customer	0.0520
Environment protection certification	0.0579	Employment stability	0.0559
Eco-design production	0.0526	Operational risk	0.0592
Green technology capability	0.0442	Financial risk	0.0504

Similarly, the dominance matrix under the other criteria can be calculated. Further, the total dominance degrees of 3PRLPs under different criteria are determined according to equation (16) and are shown in Table 8.

By using equations (18) and (19), the dominance degree-based PISs $\vartheta^+ = (\vartheta_1^+, \vartheta_2^+, \ldots, \vartheta_{16}^+)$ and the dominance degree-based NISs $\vartheta^- = (\vartheta_1^-, \vartheta_2^-, \ldots, \vartheta_{16}^-)$ are determined, respectively, and these calculation results are shown in Table 9.

In light of the obtained data in Tables 7–9, the dominance degree-based maximum group utility scores and the dominance degree-based minimum individual regret scores are calculated according to equations (20) and (21),

Table 8: The total dominance degrees of 3PRLPs over different criteria.

	Quality	Cost	Lead time	Delivery and services
3PRLP1	0.5714	0.42	−0.4	0.6714
3PRLP2	−0.8571	0.22	0.6	−0.4
3PRLP3	1.2857	−0.38	−0.4	0.3143
3PRLP4	−0.8571	−0.78	1.6	−0.9
3PRLP5	−0.1429	0.52	−1.4	0.3143
	Transportation	Recycle	Disposal	Remanufacture and reuse
3PRLP1	0.6	−1.06	0.1429	0.16
3PRLP2	−1.4	−0.76	−1.2857	−0.14
3PRLP3	−0.4	0.54	0.8571	−0.74
3PRLP4	1.6	0.04	−0.5714	0.56
3PRLP5	−0.4	1.24	0.8571	0.16
	Health and safety	Environment protection certification	Eco-design production	Green technology capability
3PRLP1	−0.8571	−1.06	−0.1429	−1.5
3PRLP2	−0.5	0.34	−0.8571	0.8
3PRLP3	0.5714	0.84	−0.1429	−0.1
3PRLP4	−0.1429	−0.46	1.2857	0.5
3PRLP5	0.9286	0.34	−0.1429	0.3
	Voice of customer	Employment stability	Operational risk	Financial risk
3PRLP1	1.14	−0.0429	1.0714	−0.1429
3PRLP2	−0.74	0.4571	0	−1
3PRLP3	0.14	0.5429	−0.3571	0.5
3PRLP4	0.34	0.8857	0	0.5714
3PRLP5	−0.88	−0.7571	−0.7143	0.0714

respectively. These calculation results are shown in Table 10. Let the value of t be 0.5 from an equilibrium point of view, the dominance degree-based compromise scores of $3PRLP_i\,(i = 1, 2, 3, 4, 5)$ are calculated according to equation (24) and are also shown in Table 10.

From the calculation results in Table 10, we can see that 3PRLP3 is the best in the ranking lists according to the values of $\mathrm{Dom}\,S_i$, $\mathrm{Dom}\,R_i$, and $\mathrm{Dom}\,Q_i$, respectively. Obviously, 3PRLP3 is the best choice for the car manufacturer X and this selection result simultaneously satisfies the conditions of $Cd1$ and $Cd2$. Clearly, the proposed approach provides informative insights to managers/DMs of car manufacturers for selecting an appropriate 3PRLP to corporate with. First, this developed method offers DMs an insight of cognitive contribution of 3PRLP criteria and provides a good way for DMs to evaluate 3PRLPs under heterogeneous linguistic environments. Second, the developed method gives a better understanding of the influence of DM's psychology in the 3PRLP selection. The results indicate that the developed method not only well avoids the potential loss risks but also balances group utility scores and individual regret scores. The authenticity of 3PRLP selection results can be greatly enhanced.

5.3. Sensitivity Analysis. In our developed method, a parameter t is introduced to coordinate the group utility and the individual regret. One of the advantages of the developed method is that it allows DM to modify the value of t according to his/her individual preferences. For example, when one DM highlights the maximization of group utility, the value of t will become larger, and $0.5 \leq t \leq 1$, conversely, the value of t will become smaller when DM has emphasized on the minimization of individual regret, and $0 \leq t \leq 0.5$ [50]. We next analyze the effects of the parameter t on ranking orders of 3PRLPs. We calculate the ranking results of 3PRLPs by modifying the value of t from 1.0 to 0. The corresponding ranking results of 3PRLPs with the different values of $t\,(t = 1.0, 0.8, 0.6, 0.4, 0.2, 0.0)$ are obtained. These calculation results are shown in Table 11 and are depicted in Figure 2.

It is easily observed from Table 11 and Figure 2 that the compromise scores of 3PRLP2 are increasing as the value of the parameter t changes from 0.0 to 1.0, the compromise scores of 3PRLP3 are constant, while the compromise scores of 3PRLP1, 3PRLP4 and 3PRLP5 are decreasing. In particular, when the value of the parameter t is provided as 1.0, then the ranking order of 3PRLPs is $3PRLP3 \succ 3PRLP4 \succ 3PRLP5 \succ 3PRLP1 \succ 3PRLP2$ which means that the developed method only takes the maximization of group utility into account, and while the value of the parameter t is assigned as 0.0, then the ranking order of 3PRLPs is $3PRLP3 \succ 3PRLP1 \succ 3PRLP5 \succ 3PRLP2 \succ 3PRLP4$, and in this situation, the developed method only takes the minimization of individual regret into account. When $t = 0.8, 0.6, 0.4, 0.2$, the ranking orders of 3PRLPs are consistent $(3PRLP3 \succ 3PRLP1 \succ 3PRLP5 \succ 3PRLP4 \succ 3PRLP2)$ although the ranking scores of 3PRLPs are different, which trade-offs the group utility and the individual regret. Clearly, all of these ranking orders of 3PRLPs show that 3PRLP3 is the best choice for this manufacture although the DM has different preferences between group utility and individual regret. In other words, the ranking result of 3PRLPs is insensitive to the values of t when using our developed method in the above case study.

Table 9: The dominance-based PISs and dominance-based NISs under various criteria.

	Quality	Cost	Lead time	Delivery and services
PIS	1.2857	0.52	1.6	0.6714
NIS	−0.8571	−0.78	−1.4	−0.9
	Transportation	Recycle	Disposal	Remanufacture and reuse
PIS	1.6	1.24	0.8571	0.56
NIS	−1.4	−1.06	−1.2857	−0.74
	Health and safety	Environment protection certification	Eco-design production	Green technology capability
PIS	0.9286	0.84	1.2857	0.8
NIS	−0.8571	−1.06	−0.8571	−1.5
	Voice of customer	Employment stability	Operational risk	Financial risk
PIS	1.14	0.8857	1.0714	0.5714
NIS	−0.88	−0.7571	−0.7143	−1

Table 10: The scores of Dom S_i, Dom R_i, and Dom Q_i of each 3PRLP and the corresponding rank.

	Dom S_i	Ranking order	Dom R_i	Ranking order	Dom Q_i	Ranking order
3PRLP1	0.4683	4	0.0701	2	0.3172	2
3PRLP2	0.6639	5	0.0851	4	0.9623	5
3PRLP3	0.3968	1	0.0603	1	0.0000	1
3PRLP4	0.4439	2	0.0871	5	0.5882	4
3PRLP5	0.4615	3	0.0810	3	0.5078	3

Table 11: The compromise scores of 3PRLPs with different values of t.

	3PRLP1	3PRLP2	3PRLP3	3PRLP4	3PRLP5
$t = 1.0$	0.2676	1.0000	0.0000	0.1765	0.2420
$t = 0.8$	0.3172	0.9623	0.0000	0.5882	0.5078
$t = 0.6$	0.3073	0.9698	0.0000	0.5059	0.4547
$t = 0.4$	0.3272	0.9547	0.0000	0.6706	0.5610
$t = 0.2$	0.3470	0.9396	0.0000	0.8353	0.6673
$t = 0.0$	0.3669	0.9246	0.0000	1.0000	0.7737

5.4. Comparison Analysis. The aforementioned 3PRLP selection methods including TOPSIS selection method [33], VIKOR selection method [34], and VIKOR-TOPSIS selection method [36], which ranked and selected 3PRLPs based on the relative closeness to the ideal solution without considering the psychological factors of DM, are closest to our developed method. It is worth mentioning that these three methods are only suitable to deal with the data represented by real numbers, single LTs, and/or neighborhood rough set but are not able to manage the assessed data represented by HFLTSs and/or PLTSs as the above-mentioned case study. To deal with this issue, these three methods are next modified. Firstly, probabilistic linguistic PISs and NISs are determined by the following equations:

$$\begin{aligned}
3\text{PRLP}^{+} &= \left\{ < c_f, \max_i \mathscr{F}\left(L_{if}(p)\right) > \mid f \in \{1, 2, \ldots, o_4\} \right\} \\
&= \left\{ \langle c_1, L_1^{+}(p) \rangle, \langle c_2, L_2^{+}(p) \rangle, \ldots, \langle c_{o_4}, L_{o_4}^{+}(p) \rangle \right\}, \\
3\text{PRLP}^{-} &= \left\{ < c_f, \min_i \mathscr{F}\left(L_{if}(p)\right) > \mid f \in \{1, 2, \ldots, o_4\} \right\} \\
&= \left\{ \langle c_1, L_1^{-}(p) \rangle, \langle c_2, L_2^{-}(p) \rangle, \ldots, \langle c_{o_4}, L_{o_4}^{-}(p) \rangle \right\},
\end{aligned} \tag{27}$$

where $\mathscr{F}(\bullet)$ is the probabilistic linguistic ranking function proposed in Definition 6.

In terms of the modified TOPSIS method [33], the relative closeness index Id_i of the 3PRLP a_i $(i = 1, 2, \ldots, m)$ to the ideal solution can be calculated by using the following formula:

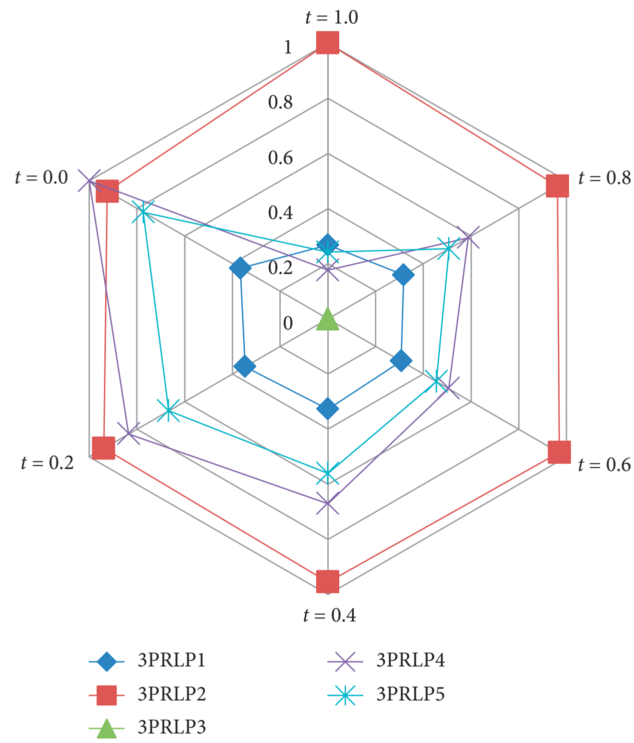

FIGURE 2: The diagrammatic presentation of the 3PRLP compromise scores.

$$Id_i = \frac{\sum_{f=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)}{\sum_{f=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^+(p)\right) + \sum_{f=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)}, \tag{28}$$

where $\mathscr{E}(\bullet)$ is the ratio index-based probabilistic linguistic defuzzification function proposed in Definition 7 and $d(\bullet, \bullet)$ is probabilistic linguistic distance measure introduced in Definition 5.

By equation (28), the ranking order of 3PRLPs in the abovementioned case study is obtained based on the modified TOPSIS method and is shown in Table 12.

In terms of the modified VIKOR method [34], the maximum group utility S_i of the 3PRLP $a_i\,(i = 1, 2, \ldots, m)$ is obtained as follows:

$$S_i = \sum_{f=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) \bullet d\left(L_{if}(p), L_f^+(p)\right) d\left(L_f^+(p), L_f^-(p)\right)^{-1}. \tag{29}$$

And the minimum individual regret R_i of $a_i\,(i = 1, 2, \ldots, m)$ is calculated by the following equation:

$$R_i = \max_{j=1}^{o_4} \mathscr{E}\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^+(p)\right) d\left(L_f^+(p), L_f^-(p)\right)^{-1}. \tag{30}$$

Then, the compromise solution Q_i of $a_i\,(i = 1, 2, \ldots, m)$ is obtained as follows:

$$Q_i = \chi \frac{S_i - \min_i\{S_i\}}{\max_i\{S_i\} - \min_i\{S_i\}} + (1 - \chi) \frac{R_i - \min_i\{R_i\}}{\max_i\{R_i\} - \min_i\{R_i\}}, \quad 0 \le \chi \le 1. \tag{31}$$

By equation (31) with $\chi = 0.5$, the ranking order of these five 3PRLPs is obtained based on the modified VIKOR method and is shown in Table 12.

Table 12: Ranking orders of 3PRLPs obtained by different 3PRLP selection methods.

3PRLP selection methods	Ranking orders of 3PRLPs
The modified TOPSIS method [33]	3PRLP4 ≻ 3PRLP5 ≻ 3PRLP1 ≻ 3PRLP3 ≻ 3PRLP2
The modified VIKOR method [34]	3PRLP4 ≻ 3PRLP5 ≻ 3PRLP3 ≻ 3PRLP1 ≻ 3PRLP2
The modified TOPSIS-VIKOR method [36]	3PRLP4 ≻ 3PRLP3 ≻ 3PRLP5≻3PRLP2 ≻ 3PRLP1
Our proposed method	3PRLP3 ≻ 3PRLP1 ≻ 3PRLP5 ≻ 3PRLP4 ≻ 3PRLP2

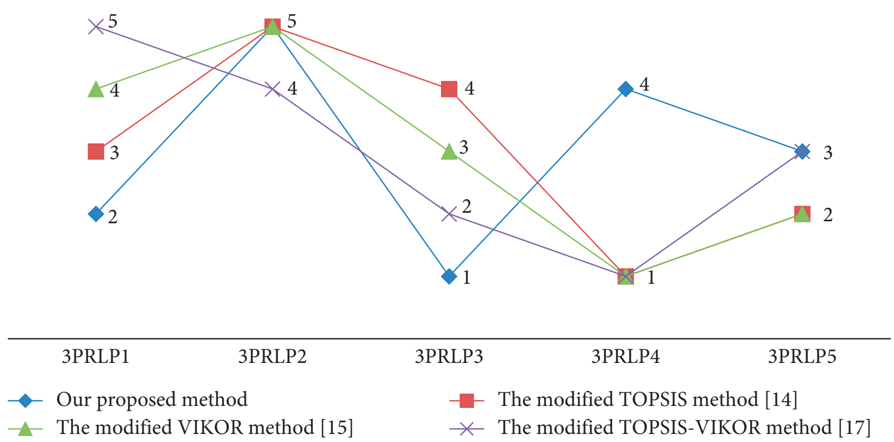

Figure 3: The pictorial representation of ranking orders of 3PRLPs.

In terms of the modified TOPSIS-VIKOR method [36], the relative closeness index Rd_i of each 3PRLP to the ideal solution is determined as follows:

$$Rd_i = \eta \times \frac{\sum_{f=1}^{o_4} E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)}{\sum_{f=1}^{o_4} E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^+(p)\right) + \sum_{f=1}^{o_4} E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)} + (1-\eta) \times \frac{\min_i\left(E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)\right)}{\max_i\left(E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^+(p)\right)\right) + \min_i\left(E\left(w\left(c_f\right)\right) d\left(L_{if}(p), L_f^-(p)\right)\right)}. \tag{32}$$

Accordingly, by equation (32) with $\eta = 0.5$, the ranking order of these five 3PRLPs is obtained based on the modified TOPSIS-VIKOR method and is shown in Table 12. All the above comparison results in Table 12 are depicted in Figure 3.

The comparison results in Table 12 and in Figure 3 indicate that the ranking order of 3PRLPs obtained by the developed method is completely different from that obtained by the modified 3PRLP selection methods [33, 34, 36]. Specifically, 3PRLP3 was regarded as the most preferred alternative by the proposed dominance-based heterogeneous linguistic decision-making method, while the modified TOPSIS [33], the modified VIKOR [34], and the modified TOPSIS-VIKOR [36] all preferred 3PRLP4. The main reason for these differences lies in that the assumptions of DM's rationality between our developed method and the modified methods were distinct. The modified methods [33, 34, 36] ranked the 3PRLPs under the strict assumption that the DM is complete rationality. In contrast, the proposed dominance-based heterogeneous linguistic MCDM method is under the assumption that the DM is bounded rationality and taking fully into account psychology behavior of DM. Therefore, it is not hard to see that the biggest advantage of our proposed method, compared with the modified 3PRLP selection methods [33, 34, 36], is that it took fully into consideration the bounded rationality of DM and the selection result with the most preferred 3PRLP was more consistent with the reality.

6. Conclusions

Selecting an appropriate 3PRLP to cooperate with is a key step for manufacturers to achieve the goals of sustainable development and environmental protection. In this paper, we have developed a dominance degree-based heterogeneous linguistic decision-making method for aiding manufacturers to identify a sustainable 3PRLP. The first advantage of the developed method is that it successfully manages qualitative and heterogeneous uncertain inputs that usually arise from real-world 3PRLP evaluation process. Heterogeneous linguistic expression forms with different granularities give great freedom for evaluators to provide their preferences on 3PRLPs and can well improve the accuracy of evaluation data. The second advantage is that the dominance degrees of each 3PRLP under various criteria related to the others are taken fully into account. It can consider the psychological factor of DM in the 3PRLP selection process and well avoid the potential loss risks. The third advantage is that it carefully balances the maximum group utility and the minimum individual regret. The sensitivity analysis and the comparison analysis with similar 3PRLP selection methods [33, 34, 36] indicated that the developed dominance-based heterogeneous linguistic MCDM method can obtain more precise and reliable selection results. On the other hand, we have developed a new ratio index-based probabilistic linguistic ranking method for comparing the magnitude of PLTSs and have proved its desirable properties. We have also proposed a useful ratio-based defuzzification function of PLTSs, which can well model probabilistic linguistic-based weights of criteria. Despite its advantage, this study has several limitations which may sever as suggestions for further research. First of all, the relationships among the assessed criteria of 3PRLPs are assumed in the developed method to be independent. How to deal with various types of relationships which exist among criteria is an interesting research issue with challenges, especially for the selection of 3PRLPs. Moreover, in order to deal automatically with complex 3PRLP selection problems, how to construct an appropriate decision support system on the basis of the developed technique is also an interesting research idea.

Data Availability

All data used in our study are provided in this manuscript. The reviewers and readers can access the data by Tables 4–11 in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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