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Decision Support for Business Management Based on Multi-Objective Optimization Algorithm

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Abstract. *With the gradual refinement of social division of labor and the maturation of service outsourcing activities, the decision-making process in the field of business management has become increasingly complex. Many companies choose to entrust their non core businesses to more efficient specialized organizations in order to focus on their core business. Logistics management is a part of the business management category, among which logistics outsourcing is one of the most important business outsourcing. Outsourcing logistics can effectively reduce logistics operating costs and enhance the core competitiveness of enterprises. However, traditional single objective optimization methods are difficult to effectively handle the interrelationships and trade-offs between multiple decision objectives. Therefore, this study adopts a multi-objective optimization algorithm, taking S Company as an example, to construct a multi-objective optimization model with the goals of minimizing logistics costs, minimizing transportation time, maximizing service quality, and maximizing service provider satisfaction. The model is solved by combining actual data from logistics service providers, and the goal optimization situation under the equilibrium of decision-maker preferences is analyzed. The research results indicate that decision support systems based on multi-objective optimization algorithms can effectively help company managers make better decisions in complex environments, improving management efficiency and decision quality.*
Keywords: Multi objective planning; Logistics demand allocation; Logistics service providers; Business management decisions

1. **Introduction.** In the current social environment, customer needs and market products are becoming increasingly diverse and personalized. At the same time, with the advancement of a new round of technological revolution, the cycle of product updates is becoming shorter and shorter. In the face of increasingly fierce market competition, manufacturing enterprises are actively seeking cooperation with professional logistics service providers to achieve the highest investment returns. Due to the fact that logistics outsourcing can help demand enterprises gain competitive advantages in non core businesses and also help them save huge costs of self operated logistics, it is favored by many enterprises in terms of its model. However, logistics outsourcing can bring uncertainty, especially when logistics demand enterprises determine logistics service providers without fully understanding them, which can further amplify this uncertainty. Therefore, how to choose suitable logistics service providers for enterprises and provide reasonable management decisions is currently the focus of research.

1.1. **Related work.** Cost was considered an important reason for the emergence of logistics service providers by early scholars. Rahman [1] investigated the preferences of different industries for logistics outsourcing activities, focusing on the Australian manufacturing industry. The research results showed that the logistics outsourcing proportion in the automotive and pharmaceutical industries was far ahead. Brien and Ghodsypour [2] pointed out five key factors that affect the decision of demand enterprises from the perspective of logistics service provider selection, namely logistics operation knowledge, competitive pressure, labor quality, logistics technology ability and operation mobility, and the comprehensiveness of logistics business.

In the study of logistics service provider selection and evaluation, Chen et al. [3] proposed the MADM framework, which improves information quality and reliability by using semantic analysis techniques. Kulak and Kahraman [4] also found through case studies that the five principles for evaluating and selecting logistics service providers are logistics service cost, logistics information processing ability, logistics on-time delivery rate, goods defect rate, and service response mobility. With the development of information technology since the 21st century, Qureshi et al. [5] proposed to include information sharing in the evaluation index system of logistics service providers, and also proposed to include trust in the index system.

Early research on order allocation mainly focused on traditional supply chains. Ruengsak and Van [6] considered constructing a target model for order allocation with the lowest procurement cost when faced with non unique suppliers, using comprehensive service level and service price as the main parameters. At the same time, they considered the influence of factors such as supplier order quality and order quantity. Ghadimi et al. [7] believe that sustainability is important in procurement and that establishing long-term partnerships is beneficial for procurement. They propose using a multi-agent system approach to promote sustainable supplier selection and order allocation. Kahraman et al. [8] considered the impact of environmental performance in order allocation and incorporated environmental performance into a multi-objective model. Kannan et al. [9] used Analytic Hierarchy Process and TOPSIS method to solve the allocation problem of service providers. Moghaddam [10] used fuzzy objective method to simulate the production capacity of service providers. Kilic [11] constructed a service provider allocation model using the fuzzy analytic hierarchy process. Saputro et al. [12] designed a framework that provides guidance on how to develop and handle supplier selection for different types of projects segmented in Kraljic portfolio matrices and production policies. Luthra et al. [13] used multi criteria optimization and compromise methods to solve the problem of service provider selection.

In the research on order allocation of logistics service providers, most of them focus on the secondary logistics service chain composed of logistics integrators and logistics subcontractors. Liu et al. [14] proposed a multi-objective programming model for emergency order allocation. Liu et al. [15] developed a two-stage order allocation model that takes into account demand updates and FLSP (functional logistics service providers) fairness preferences. The study by Liu et al. [16] shows that the optimal utility of LSI (logistics service integrators) increases with the increase of peer induced fair attention in subsequent FLSP. Kang et al. [17] proposed an auction based LPSS cloud service allocation and sharing method. Liu et al. [18] constructed a multi-objective dynamic programming model with the goals of LSI cost and FLSP order satisfaction. Liu et al. [19] obtained the optimal number of FLSPs by studying the income fairness of LSIs. Yang et al. [20] described a mathematical model for collaborative delivery between two logistics service providers (LSPs). The results indicate that LSP should adopt collaborative distribution to develop the optimal distribution plan, in order to save costs and shorten delivery time, and should choose partners with lower cost parameters, different speeds, and moderate capabilities.

1.2. **Motivation and contribution.** This article takes S Company, a small and medium-sized logistics demand enterprise, as the research object. Based on the actual logistics demand characteristics of S Company and the problems in logistics service provider management, the evaluation index preferences of S Company are obtained through a survey questionnaire. A logistics service provider evaluation index system of S Company is constructed, and based on this, multi-objective optimization methods are used to allocate logistics demand.

In the construction of the objective function for logistics service provider satisfaction, this article redefines the maximum and minimum logistics capacity in the satisfaction function of logistics service providers previously studied by scholars as the agreed price logistics volume and discounted price logistics flow between companies and logistics service providers, based on actual situations, making it suitable for secondary supply chains composed of small and medium-sized companies and logistics service providers.

In the problem-solving process of this article, multiple objectives are involved and there is a certain degree of conflict. In this case, multi-objective programming methods need to be used to optimize multiple objective functions under certain constraint conditions. The Shapley value method is used to assign weights based on the evaluation results, avoiding the influence of decision-makers on the subjective preferences of logistics service providers. The evaluation results of logistics service providers are fully utilized, and the weight of the logistics service provider is used as a parameter in the multi-objective model. Taking logistics cost, transportation time, logistics service quality, and logistics service provider satisfaction as objectives, the regional logistics demand proportion factor, S company's preference for decision-making goals, and logistics service provider weight factor are added. Considering the differences in service quality of logistics service providers in different regions, a multi-objective model is constructed, and fuzzy optimization method is used to solve the model, providing reference for S company's logistics demand allocation. Adjust decision-maker's target preferences, analyze the impact of decision-maker's extreme preferences on allocation results and logistics service provider management.

2. Analysis of relevant principles.

2.1. **The model of logistics outsourcing.** Mello et al. [21] divided the development model of enterprise logistics from complete self operation to complete outsourcing into six types. The first type is complete self operation of enterprise logistics, the second option is to outsource a portion of the logistics demand business, the third option is to establish a logistics subsidiary, the fourth option is to establish a logistics strategic alliance, the fifth option is to take over the logistics system, and the sixth option is to completely outsource the logistics business to the logistics service provider. The current logistics outsourcing model of Company S, the research object of this article, belongs to the logistics business operation outsourcing under the second outsourcing model.

2.2. **Related theories of demand allocation models.** (1) Classic multi-objective mathematical programming model. In reality, there is often more than one standard for measuring the quality of a plan, and multiple goals need to be considered. These goals are sometimes uncoordinated or even contradictory, and it is often difficult to judge the quality of a plan with a single indicator. For example, in enterprise production decision-making, it is often difficult to balance production efficiency and product quality, while also considering costs. In addition, it may be hoped that the production process meets environmental protection requirements and reduces environmental pollution. In investment decision-making, one desires high returns while also controlling risks within a certain range. When choosing a supplier, we hope to obtain high-quality products, low costs, and timely supply at any time. The multi-objective programming model is based on such contradictory situations, considering several conflicting or incompatible indicators of objectives in a given area, and optimizing multiple objective functions. The general form of a multi-objective programming model is:

$$\begin{cases} \min[Z_1(x), Z_2(x), ..., Z_n(x)] \\ \text{s.t. } h_i(x) \le 0,\ i = 1, 2, 3, ..., I \end{cases} \tag{1}$$

Among them, $X = (x_1, x_2, ..., x_n)$ represents n-dimensional decision variables, $[Z_1(x), Z_2(x), ..., Z_n(x)]$ represents various objective functions, and $h_i(x) \le 0, i = 1, 2, 3, ..., I$ is the constraint condition.

(2) Fuzzy multi-objective mathematical programming model. The classical multi-objective programming model has many limitations in its application. Generally speaking, it is difficult to obtain the optimal solution or even impossible to have an optimal solution. However, for decision-makers, sometimes it is not necessary to obtain the optimal solution, only a relative "effective solution" needs to be obtained. In this case, the introduction of fuzzy mathematics can solve this type of problem. Using trigonometric fuzzy numbers in fuzzy mathematics to fuzzify a single objective function to solve the model, although it cannot achieve the optimal value of a single objective function, it can obtain the overall "satisfactory solution".

2.3. **The basic principle of Shapley value method.** The Shapley value method was initially used to evenly distribute the so-called Harsanyi dividend among members of the corresponding alliance. The Harsanyi dividend of an alliance can be seen as the "true value" added by the alliance, that is, the marginal benefits each member brings to the alliance. This method allocates benefits reasonably by considering the "true value" of alliance members to the alliance. Shapley can be specifically described as a set of n members in a large alliance N, $I = \{1, 2, ..., n\}$. For any subset s in I, it corresponds to an interest function $v(i)$; When alliance members form an alliance, the total revenue of the alliance is $Y(I)$, and the benefits shared by each alliance member are $y(i)$.

In addition, the Shapley value method also needs to meet the following conditions:

$$\sum_{i=1}^{n} y(i) = Y(i),\ (i \in I) \tag{2}$$

$$v(i) \le Y(i),\ (i \in I) \tag{3}$$

$$y(i) > v(i),\ (i \in I) \tag{4}$$

Assuming s is any subset of set I, which corresponds to a benefit function $v(s)$, where $|s|$ represents the number of members i in the set, and the benefit of removing member i from the alliance can be expressed as $v(s\backslash i)$. Therefore, the benefit allocated to each member in the alliance is shown as follow:

$$y(i) = \sum_{S \subseteq I} W(|S|)[v(s) - v(s \setminus i)] \tag{5}$$

$$W(|S|) = \frac{(n - |S|)!(|S| - 1)!}{n!} \tag{6}$$

$$d(|S|) = \frac{(n - |S|)!(|S| - 1)!}{n!} \tag{7}$$

$Y(i)$ represents the Shapley value of the i-th member in the combination; S represents a combination containing member i. $|S|$ represents the number of members in the combination; $(s \setminus i)$ indicates excluding member i in the combination; $V(s)$ represents the benefit of set s, and $v(s)$ represents the benefit that can be obtained by removing member i from subset s; $V(s) - v(s \setminus i)$ represents the marginal contribution value of the current combination s, representing the different effects of i on the combination before and after joining the combination; $W(|S|)$ represents the weighting factor, which can represent the marginal contribution achieved by member i in the combination.

3. S Company's Logistics Demand Allocation Model.

3.1. Multi-objective analysis of logistics demand allocation.

In order to solve the distribution problem of logistics demand among protocol logistics service providers, it is necessary to combine the goals that S company, the demand party, attaches importance to in logistics activities, such as reducing costs, improving quality, and reducing transportation time. Based on this goal, a logistics demand distribution model should be established to optimize the configuration of logistics demand among various logistics service providers. The following main factors should be comprehensively considered: (1) logistics cost; (2) Logistics transportation time; (3) Logistics service quality; (4) Satisfaction of logistics service providers.

3.2. Optimization method for logistics demand allocation model.

In the problem-solving process of this article, multiple objectives are involved, leading to certain conflicts. In this case, multi-objective programming methods are needed to optimize multiple objective functions under certain constraints. Generally, it is difficult to obtain the optimal solution for multi-objective problems, and only a relatively optimal result can be obtained. The general manifestation of multi-objective models is:

$$\begin{cases} \min[Z_1(x), Z_2(x), ..., Z_n(x)] \\ h_i(x) \leq 0,\ i = 1, 2, 3, ..., I \end{cases} \tag{8}$$

where $X = (x_1, x_2, ..., x_n)$ represents n-dimensional decision variables, $[Z_1(x), Z_2(x), ..., Z_n(x)]$ represents multiple objective functions, and $h_i(x) \leq 0, i = 1, 2, 3, ..., I$ represents the constraint conditions of the objective function.

The logistics demand allocation problem that this article aims to solve contains the goal of simultaneous compromise, which is itself a multi-objective optimization problem, and there is obvious conflict between these four goals. Therefore, developing the best solution for multi-objective optimization is difficult and requires obtaining a set of "effective solutions". In the solution of the model, various multi-objective optimization methods are considered, commonly including constraint method, membership function method [22], hierarchical sequence method, objective programming method [23], etc. This article adopts the method of membership function, whose function value increases linearly from 0 to 1. The solution process is as follows:

(1) Find the membership function $\mu(Z_i)$ for each single objective function.

Remember Z_i as the objective function. When the four objective functions can achieve the optimal value, the membership degree in this case is 1. First, solve the single objective linear function problem separately to obtain the maximum value $Z_{i,\max}$ and minimum value $Z_{i,\min}$ of the single objective function. Use the following formula to solve the membership function.

The membership function $\mu(Z_i)$ when the optimal value of the objective function is the minimum value:

$$\mu(Z_i) = \begin{cases} 1, & Z_i \geq Z_{i,\max} \\ \frac{Z_{i,\max} - Z_i}{Z_{i,\max} - Z_{i,\min}}, & Z_{i,\min} \leq Z_i \leq Z_{i,\max} \\ 0, & Z_i \leq Z_{i,\min} \end{cases} \tag{9}$$

The membership function $\mu(Z_i)$ when the optimal value of the objective function is the maximum value:

$$\mu(Z_i) = \begin{cases} 1, & Z_i \geq Z_{i,\max} \\ \frac{Z_i - Z_{i,\min}}{Z_{i,\max} - Z_{i,\min}}, & Z_{i,\min} \leq Z_i \leq Z_{i,\max} \\ 0, & Z_i \leq Z_{i,\min} \end{cases} \tag{10}$$

Function $\mu(Z_i)$ determines the membership functions of each objective based on the optimal and worst values.

(2) After obtaining the membership functions of each objective function, weight the objective function and use linear weighted sum to construct the single objective function with the highest comprehensive satisfaction. The weight of the objective function represents the decision-maker's preference for each objective.

(3) Solve the transformed single objective programming model.

3.3. **Weight allocation of logistics service providers based on Shapley value method.** Set the importance level of each logistics service provider as w_i, $\sum_{i=1}^{N} w_i = 1$.

In the weight allocation of logistics service providers, the selected three logistics service providers are considered as a major alliance N, $I = \{1, 2, 3\}$, and the membership degree of logistics service providers evaluated as "good" is $E(i)$. The sum of the membership degrees of the evaluation values of each logistics service provider can be regarded as the total benefit of the overall cooperation in the Shapley value method. Based on the relevant content in Section 2.3 of this article, the way for logistics service providers to use Shapley values for weight allocation is determined as follows:

$$E'(i) = \sum_{s \subseteq I} d(|s|)[E(s) - E(s \setminus i)] \tag{11}$$

where $E'(i)$ represents the Shapley value of the i-th logistics service provider in the combination; s represents a combination that includes logistics service provider i; $|s|$ represents the number of logistics service providers in the combination; $(s \setminus i)$ indicates excluding logistics service provider i from the combination; $E(s) - E(s \setminus i)$ represents the marginal contribution value of combination s, representing the different impact effects on the combination before and after the addition of logistics service provider i; $d(|s|)$ is a weighting factor that represents the marginal contribution that member i needs to bear in the combination. The evaluation values of the selected logistics service provider are shown in Table 1. The membership degree with a good evaluation value is $E'(i)$:

According to the above table, the total evaluation value is $E = (0.926 + 0.653 + 0.620)/3 = 0.733$. A subset of evaluation values for three logistics service providers were constructed, and the results are shown in Table 2:

According to Equation (11), it is calculated that $E'(1) = 0.389$, $E'(2) = 0.184$, $E'(3) = 0.160$, and $E'(1) + E'(2) + E'(3) = 0.733$, indicating that the sum of the sharing values of the three logistics service providers is equal to the total evaluation value. Calculate the weights of each logistics service provider using $w_i = E'(i)/E$, as shown in Table 3:

3.4. **Logistics demand allocation model.**

Table 1. Logistics service provider evaluation value

Logistics service provider ranking	**Alternative logistics service providers**	**Corresponding membership degree E(i)**	**Evaluation results**
1	logistics service provider 3	0.926	good
2	logistics service provider 1	0.653	good
3	logistics service provider 2	0.620	good

Table 2. Subset evaluation values of logistics service providers

Number	**Subset**	**Evaluation value**
1	$E(\{1\})$	0.926
2	$E(\{2\})$	0.653
3	$E(\{3\})$	0.620
4	$E(\{1,2\})$	0.790
5	$E(\{1,3\})$	0.773
6	$E(\{2,3\})$	0.637
7	$E(\{1,2,3\})$	0.733

Table 3. Weight of logistics service providers

Number	**Weight**
logistics service provider 3	0.531
logistics service provider 1	0.251
logistics service provider 2	0.218

3.4.1. *Model assumptions.* (1) Research object: S company, 3 logistics service providers; (2) Enterprises guarantee the minimum logistics demand to logistics service providers; (3) The multi-objective allocation of logistics demand is based on four objectives: logistics cost, logistics transportation time, logistics service quality, and logistics service provider satisfaction; (4) The logistics cost and logistics service quality are only related to the capabilities of logistics service providers; (5) Not considering the limitations of transportation capacity of logistics service providers; (6) Logistics service providers can offer some discounts.

3.4.2. *Symbolic hypothesis.* i - Serial number of logistics service provider, j - The serial number of the logistics transportation destination, c_{ij} - The unit price for the i-th logistics service provider to transport goods to region j. c_{ij}^1 - The agreed unit price for the i-th logistics service provider to transport goods to region j. c_{ij}^2 - The preferential unit price for the i-th logistics service provider to transport goods to region j. t_{ij} - The time when the i-th logistics service provider transports the goods to region j. x_{ij} - The logistics demand allocated by region j to the i-th logistics service provider. R - Total logistics demand. R_j - Logistics demand in logistics service area j. q_{ij} - Logistics service provider i's logistics service quality in region j. w_i - The evaluation results obtained from the evaluation of logistics service providers are re-weighted to determine the decision-maker's preference for logistics service provider i. β_j - The importance of logistics service region j is the proportion of logistics demand in that region to the total logistics demand. θ_j - Minimum demand requirement for obtaining the i-th logistics service provider agreement price. $\overline{\theta}_j$ - The demand for obtaining preferential prices from the i-th logistics service provider. S_i - Satisfaction of logistics service provider i. S_i^0 - Initial satisfaction of logistics service provider i.

3.4.3. *Model building.* The satisfaction expression of logistics service providers is Equation (12).

$$S_i = \begin{cases} \dfrac{x_i}{\theta_i} S_i^0, & x_i \leq \theta_i \\ S_i^0 + \dfrac{x_i - \theta_i}{\overline{\theta}_i - \theta_i}(1 - S_i^0), & \theta_i \leq x_i \leq \overline{\theta}_i \\ \dfrac{\overline{\theta}_i}{x_i}, & x_i > \overline{\theta}_i \end{cases} \tag{12}$$

In order to quantitatively represent the preferences of decision-makers towards different logistics service providers, the results calculated in Section 3.3 are used to represent the preferences of decision-makers, where the satisfaction of logistics service providers is $\sum_{i=1}^{m} w_i S_i$, where $\sum_{i=1}^{m} w_i = 1$.

The construction of this model is based on four indicators: logistics cost, logistics transportation time, logistics service quality, and logistics service provider satisfaction. A multi-objective mixed integer constrained programming model is established as follows:

$$\min Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{13}$$

$$\min Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} x_{ij} \tag{14}$$

$$\max Z_3 = \sum_{i=1}^{m} \sum_{j=1}^{n} \beta_j q_{ij} x_{ij} \tag{15}$$

$$\max Z_4 = \sum_{i=1}^{m} w_i S_i \tag{16}$$

$$R = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \tag{17}$$

$$x_i = \sum_{j=1}^{n} x_{ij},\ i = 1, 2 \tag{18}$$

$$c_{ij} = \begin{cases} c_{ij}^1, & x_i \leq \overline{\theta}_i \\ c_{ij}^2, & x_i > \overline{\theta}_i \end{cases} \tag{19}$$

$$\sum_{j=1}^{n} \beta_j = 1 \tag{20}$$

$$\sum_{i=1}^{m} x_{ij} = R_j,\ j = 1, 2, ..., 7 \tag{21}$$

$$\sum_{i=1}^{m} w_i = 1 \tag{22}$$

The objective function Equation (13) represents the lowest logistics cost; Equation (14) represents the shortest logistics transportation time; Equation (15) indicates the highest quality of logistics services, while Equation (16) indicates the highest satisfaction of logistics service providers.

Constraint Equation (17) represents the total amount of service capacity that all logistics service providers can meet the demand; Equation (18) represents that the total logistics demand allocated by logistics service provider i in each region is equal to the total logistics demand allocated to it; Equation (19) represents the constraint of preferential prices offered by logistics service providers on logistics demand; Equation (20) represents that the sum of weights for each region is 1.

4. Model solving and result analysis.

4.1. Model solving. The model constructed in this article is a multi-objective mixed integer programming model, which is solved using the membership function method. This article uses the optimization software LINGO.18 to solve the membership functions of each objective function. LINGO is a software package developed by LINDO Systems in the United States specifically for solving optimization problems. Using LINGO.18, the membership functions of each single objective function are obtained as follows:

(1) The minimum or optimal value of the logistics cost objective function is 53331, and the maximum or worst value is 69190. The membership function calculated using the triangular fuzzy function is:

$$\mu(Z_1) = \begin{cases} 1, & Z_1 \leq 53331 \\ \frac{69190 - Z_1}{15859}, & 53331 < Z_1 \leq 69190 \\ 0, & Z_1 > 69190 \end{cases} \tag{23}$$

(2) The minimum or optimal value of the objective function for logistics transportation time is 40217, and the maximum or worst value is 32965. The membership function calculated using the triangular fuzzy function is:

$$\mu(Z_2) = \begin{cases} 1, & Z_2 \leq 32965 \\ \frac{40217 - Z_2}{7252}, & 32965 < Z_2 \leq 40217 \\ 0, & Z_2 > 40217 \end{cases} \tag{24}$$

(3) The maximum or optimal value of the logistics service quality function is 8746.96, and the minimum or worst value is 8313.39. The membership function calculated using the triangular fuzzy function is:

$$\mu(Z_3) = \begin{cases} 1, & Z_3 \geq 8746.96 \\ \frac{Z_3 - 8313.39}{433.57}, & 8313.39 \leq Z_3 \leq 8746.96 \\ 0, & Z_3 < 8313.39 \end{cases} \tag{25}$$

(4) The maximum or optimal value of the satisfaction function for logistics service providers is 0.862857, and the minimum or worst value is 0.6026654. The membership function is calculated using the trigonometric fuzzy function as:

$$\mu(Z_4) = \begin{cases} 1, & Z_4 \geq 0.862857 \\ \frac{Z_4 - 0.6026654}{0.2601916}, & 0.6026654 \leq Z_4 \leq 0.862857 \\ 0, & Z_4 < 0.6026654 \end{cases} \tag{26}$$

4.2. Analysis of logistics demand allocation results.

4.2.1. *Objective function preference equilibrium.* When the decision-makers of Company S have a preference weight of λ_k for the four objective functions of logistics cost, logistics transportation time, logistics service quality, and logistics service provider satisfaction, the overall satisfaction of multi-objective programming is defined as $U(x_{ij}) = \sum_{k=1}^{4} \lambda_k * \mu(Z_k(x_{ij}))$ which is transformed into a single objective function and solved using Lingo.18.

When decision-makers have the same preference for each objective function, i.e. $\lambda_k = 0.25, \quad K = 1, 2, 3, 4$, it is transformed into a single objective function $U(x_{ij}) = \sum_{k=1}^{4} \lambda_k * \mu(Z_k(x_{ij}))$ and substituted into Lingo.18 to obtain the objective function values and membership degrees as shown in Table 4.

Table 4. The values and membership results of each objective function

	Logistics service cost	**Logistics transportation time**	**Logistics service quality**	**Satisfaction of logistics service providers**
Z_k	57036.34	35010.56	8595.256	0.8590712
$\mu(Z_k(x_{ij}))$	0.7663575	0.7179309	0.7198206	0.9854499

The distribution results of logistics demand from various logistics service providers are shown in Table 5:

Table 5. Regional distribution results of logistics demand

Logistics service provider	Total	1	2	3	4	5	6	7
1	8000	0	0	0	0	0	820	6650
2	4500	0	0	0	0	0	0	4500
3	9470	1500	3480	1080	680	950	0	7470

The proportion of regional logistics demand allocated by each logistics service provider is shown in Figure 1 and Figure 2:

Figure 1. Distribution chart of logistics demand from different service providers in different regions

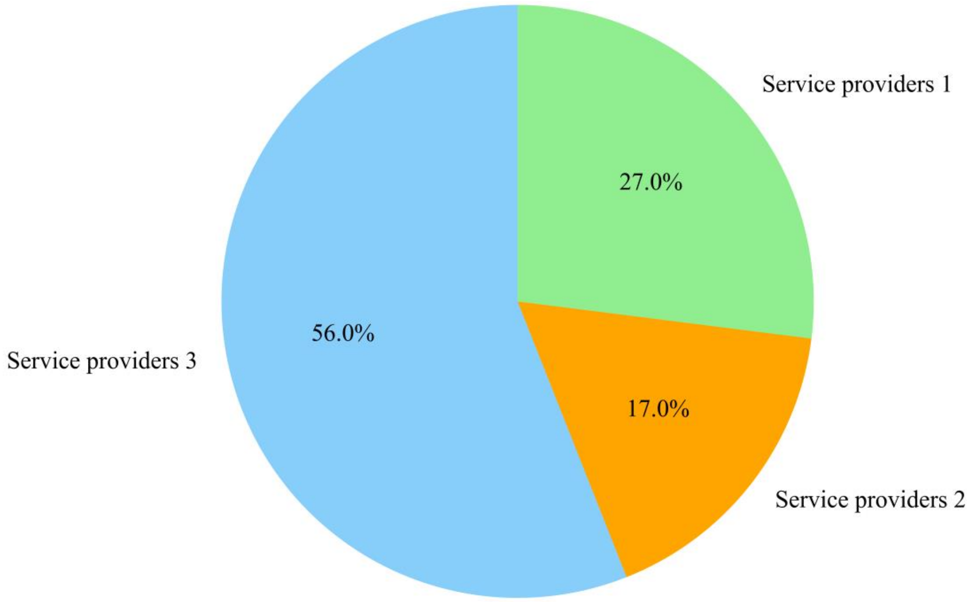

Figure 2. Distribution ratio of logistics demand among logistics service providers

Under the same preference for each objective function, overall, logistics service provider 3 receives the highest logistics demand, accounting for 56%, followed by logistics service provider 1; From the regional allocation results, it can be seen that region 6 tends to be allocated to logistics service provider 1. For region 7 with the largest proportion, it is allocated between logistics service providers 1, 2, and 3. Regions 1, 2, 3, 4, and 5 tend to be allocated to logistics service provider 1. Therefore, when the function preferences are the same, for logistics needs in regions 1, 2, 3, 4, and 5, the shipper can directly choose logistics service provider 1.

Comparing the membership degrees of each function before and after multi-objective optimization in Figure 3, the membership functions of each objective function significantly increased after optimization, resulting in significant optimization effects, reduced logistics costs, and improved service quality. All objectives were optimized to a certain extent.

According to historical data statistics, the logistics demand allocation and membership function before multi-objective optimization are calculated and shown in Table 6.

Table 6. The objective function value and membership degree value of logistics demand allocation before manufacturer optimization

	Logistics service cost	**Logistics transportation time**	**Logistics service quality**	**Satisfaction of logistics service providers**
Z_k	65590	39222.8	8459.15	0.6578
$\mu(Z_k(x_{ij}))$	0.227	0.137	0.409	0.240

Comparing the four objective function values in Tables 4 and 6, i.e. comparing the changes in logistics cost, transportation time, logistics service quality, and logistics service provider satisfaction before and after optimizing logistics demand allocation, we obtain Figure 4:

From the above figure, it can be seen that compared to the original demand allocation, the four objective function values have a certain degree of optimization. Among them, logistics costs have decreased by 13%, logistics transportation time has decreased by

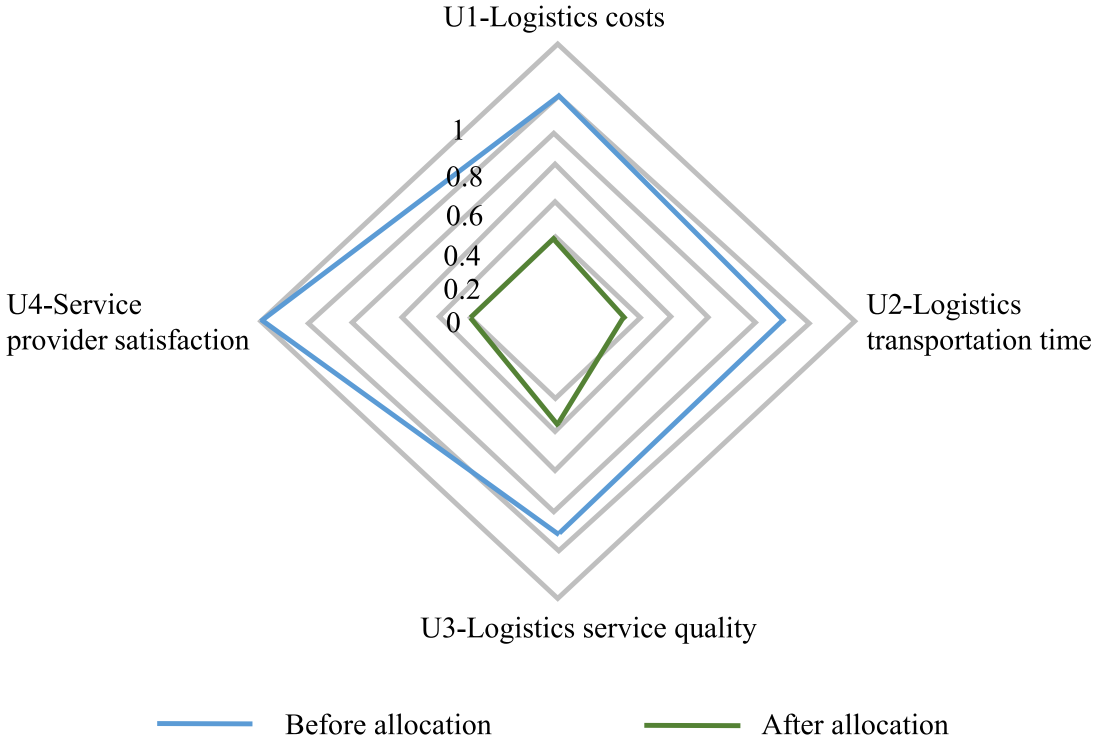

Figure 3. Comparison chart of membership degree of objective function before and after multi-objective optimization

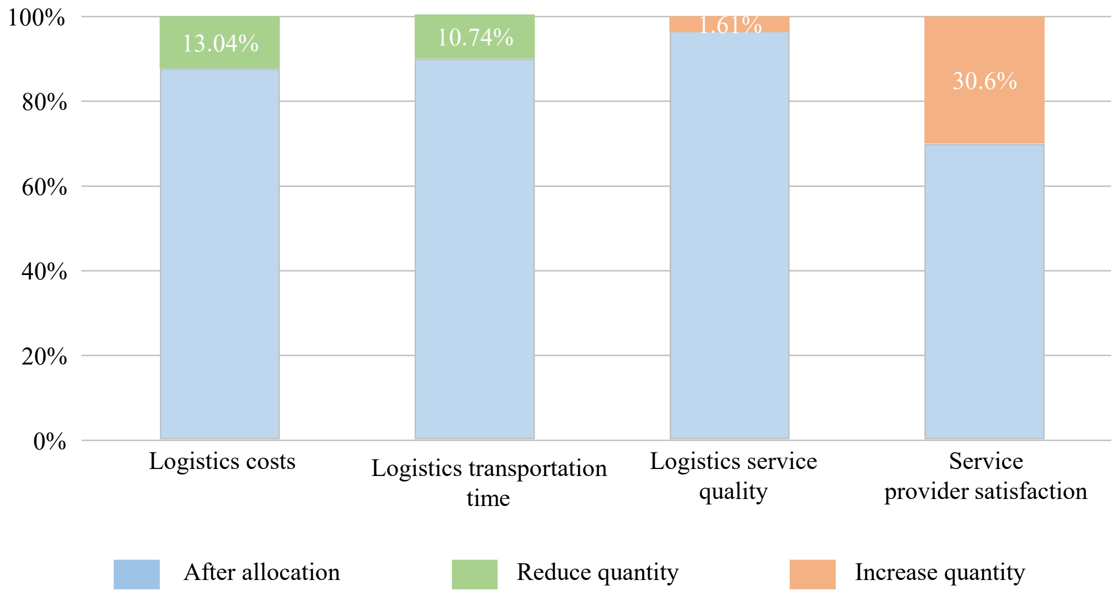

Figure 4. Comparison of objective function values before and after optimization of logistics demand allocation

10.7%, and logistics service quality has increased by 1.6%. Surprisingly, logistics service provider satisfaction has increased by 30.6%, and the optimization effect is obvious. The increase in logistics service provider satisfaction helps to improve the quality of logistics services in subsequent cycles.

4.2.2. *Extreme preference for objective function.* In the allocation of logistics demand, the preferences of decision-makers will change. Therefore, this article further transforms the preference value of the objective function to observe its impact on the results of logistics demand allocation and the membership degree of the objective function. When the decision-makers of Company S attach varying degrees of importance to the four objectives, i.e. assigning different preferences to the four objective functions, different results will be obtained. Adjust the preferences of decision-makers and obtain the allocation results as shown in Table 7:

Table 7. Distribution results of logistics demand under extreme target preferences

(λ_1, λ_2, λ_3, λ_4)	I (1,0,0,0)	II (0,1,0,0)	III (0,0,1,0)	IV (0,0,0,1)
U	1	1	1	1
U_1	1	0.6268996	0.7043542	0.1253567
U_2	0.02068395	1	0.306767	0.5406786
U_3	0.5395923	0.21678687	1	0.3965675
U_4	0.01456753	0.83465769	0	1
Z_1	53331	59248	58033	67202.1
Z_2	40067	32965	37983	36233.95
Z_3	8516.3	8375.86	8781	8453.89
Z_4	0.6067766	0.8276575	0.6255789	0.862857
x_1	5500	8510	11470	8000
x_2	10470	4500	4500	4500
x_3	6000	8960	6000	9470

(Note: I represent extreme preference for logistics costs, II represent extreme preference for logistics transportation time, III represent extreme preference for logistics service quality, and IV represent extreme preference for logistics service provider satisfaction.)

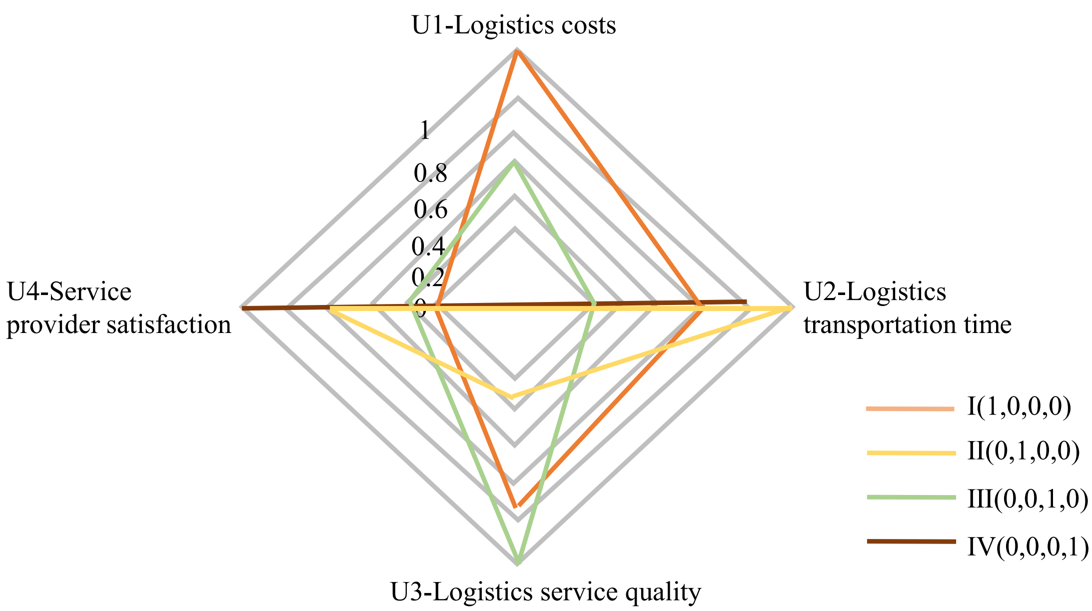

Figure 5. Membership degree of objective function under extreme preferences

In extreme cases, when decision-makers only consider logistics costs, as shown in situation I in Table 7 and Figure 5, logistics costs will reach the optimal state with a membership degree of 1. At this time, the membership degree of the transportation time objective function will become $U_2 = 0.021$, the membership degree of the logistics service quality objective function will become $U_3 = 0.54$, and the membership degree of the service provider satisfaction objective function will be $U_4 = 0.014$. This means that although the final solution greatly meets the requirements for the lowest cost, it also increases the logistics transportation time, reduces the satisfaction of logistics service providers, and at the same time, the quality of logistics service will decrease, which is not conducive to the improvement of logistics service level.

When decision-makers only consider logistics transportation time, the membership degree of the satisfaction objective function of logistics service providers is $U_4 = 0$. Over time, this is not conducive to improving the quality of logistics services. Although transportation time may appear to be reduced to a certain extent, it is not conducive to long-term cooperation between the company and logistics service providers, affects the stability of the logistics supply chain, and is not conducive to the long-term business development of the enterprise. Therefore, decision-makers should fully consider the balance between the two.

When the decision-maker's preference for logistics service quality is 1, the membership values of logistics transportation time, logistics cost, and logistics service provider satisfaction objective functions are relatively low.

Therefore, when making preference decisions, decision-makers of logistics demand enterprises should recognize that if they only pursue cost minimization, it will seriously affect the overall level of logistics services they obtain. In order to obtain high-quality logistics services through scientific and reasonable logistics service provider management and improve customer satisfaction, it is necessary to allocate the preference weights of each objective reasonably.

This article focuses more on the logistics demand allocation of small and medium-sized manufacturing enterprises when facing third-party logistics service providers directly, which can provide decision-making reference for such small and medium-sized manufacturing enterprises.

5. **Conclusions.** This article takes the logistics needs of small and medium-sized manufacturing enterprises as the starting point and constructs a multi-objective optimization-based logistics demand allocation problem to help companies make decisions. In the allocation problem, the objectives are logistics cost, transportation time, logistics service quality, and logistics service provider satisfaction. Factors such as the proportion of regional logistics demand, S company's preference for decision-making goals, and logistics service provider weight are added to consider the differences in service quality among logistics service providers in different regions. A multi-objective model is constructed, and the fuzzy optimization method is used to solve the model, providing reference for S company's logistics demand allocation.

The logistics demand allocation considered in this article is a decision model constructed for a single logistics capacity demand, which has certain limitations and inconveniences in practice. Therefore, further research can be conducted on various logistics capacity demand decision models, such as circulation processing.

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