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Research Article

Scheduling Performance Evaluation of Logistics Service Supply Chain Based on the Dynamic Index Weight

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Scheduling is crucial to the operation of logistics service supply chain (LSSC), so scientific performance evaluation method is required to evaluate the scheduling performance. Different from general project performance evaluation, scheduling activities are usually continuous and multiperiod. Therefore, the weight of scheduling performance evaluation index is not unchanged, but dynamically varied. In this paper, the factors that influence the scheduling performance are analyzed in three levels which are strategic environment, operating process, and scheduling results. Based on these three levels, the scheduling performance evaluation index system of LSSC is established. In all, a new performance evaluation method proposed based on dynamic index weight will have three innovation points. Firstly, a multiphase dynamic interaction method is introduced to improve the quality of quantification. Secondly, due to the large quantity of second-level indexes and the requirements of dynamic weight adjustment, the maximum attribute deviation method is introduced to determine weight of second-level indexes, which can remove the uncertainty of subjective factors. Thirdly, an adjustment coefficient method based on set-valued statistics is introduced to determine the first-level indexes weight. In the end, an application example from a logistics company in China is given to illustrate the effectiveness of the proposed method.

1. Introduction

Service supply chain is a new trend in supply chain research [1], and logistics service supply chain (LSSC) is a type of service supply chain centered on the cooperation of logistics service capacity [2, 3]. The main structure of the LSSC is the mode where the functional logistics service providers (FLSPs) flow to the logistics service integrator (LSI) and then to the manufacturers or retailers [2, 3]. FLSPs consist of traditional functional logistics enterprises, such as transportation and storage enterprises, among others, whose service function is simple and standardized, and the business is limited within a certain area; they are integrated as the suppliers by the LSI when a domestic or international logistics service network is established. For instance, as a LSI, Baogong logistics company in China integrates over 500 warehousing companies and 1200 highway transport companies as their FLSPs to provide personalized logistics services for many world famous companies such as P&G and Unilever. Therefore, managing logistics service operation has become a core content of LSSC management.

Scheduling is an important part of service operations management, which is the activity of allocating and coordinating the enterprise's resources, such as the workforces, machines, vehicles, and material, and stipulates the tasks to be executed by employees within a certain period [4, 5]. Scheduling has an important influence on enterprise performance by determining the order lead time, delivery flexibility, machine and material usage, and staff workload [4, 5]. Reference [6] pointed out that a process can be managed only when its performance can be measured. Therefore, studying the evaluation method of scheduling performance can not only compare the performance within each period, but also identify the problems during scheduling so as to improve the scheduling process. There have already been studies focusing on performance evaluation of LSSC. Reference [7] studied the effect of time scheduling on LSSC scheduling. But existing articles only consider the results evaluation [8], using KPIs, for instance, rather than consider the three phases: before scheduling, during scheduling, and after scheduling.

In terms of scheduling performance evaluation method, much scheduling research concentrates on improving existing methods for specific classes of scheduling situations using techniques from operations research or mathematical programming and, lately, also from artificial intelligence [4, 5, 9, 10]. The majority of these studies pay attention to the performance evaluation of scheduling in a single enterprise or sector. However, different from the scheduling performance evaluation of an individual enterprise, for LSSC, the following problems should be paid more attention to and should be solved.

(1) LSSC is composed of many members (e.g., one LSI and many FLSPs), and the impact of scheduling activities from these members on the performance should be considered. So, how can we give full consideration about the different demands of these members when the LSSC performance indexes are designed?

(2) Different from solid product, service contains the characteristics of customer influence, intangibility, and inseparability; the scheduling indexes of LSSC may include both quantitative index and qualitative index ones. How to consider the qualitative indexes and quantitative indexes as a whole?

(3) Different from general project performance evaluation, scheduling activities are usually continuous and multiperiods. The activities of the previous period will have an impact on those of the next one. For example, along with the increasing of scheduling times, the understanding of decision-maker for each index weight may change [11], which leads to the adjustment of index weight. Therefore, index weight has the feature of dynamic change, so how to select a proper dynamic evaluation method is an important issue.

In this paper, the performance evaluation index system of LSSC scheduling is proposed, and then an evaluation method based on dynamic index weight is adopted. In this method, firstly a multiphase dynamic interaction method is introduced by considering the difficulty of converting qualitative data into quantitative data. As a result, the quantitative results are more objective. Second, as there are many second-level indexes and dynamic variation is required, the maximum attribute deviation method is introduced to determine weight of second-level indexes. Thirdly, as there are few first-level indexes, an adjustment coefficient method based on set-valued statistics is introduced to determine the weight index. An application example from a logistics company in China illustrates that the method proposed is more suitable for scheduling performance evaluation of LSSC.

This paper is organized as follows. In Section 2, the literature review on evaluation methods of scheduling performance is presented. Section 3 proposes the performance evaluation index system of LSSC scheduling. Section 4 gives the evaluation method of dynamic index weight. Section 5 provides the innovations and advantages of the model proposed. The application in a logistics company to prove the effectiveness of this method is provided in Section 6. The last two sections put forward the main conclusions and future insights.

2. The Literature Review

Research about scheduling performance evaluation on LSSC mainly includes two aspects: one is the design of evaluation index system; the other is the evaluation method. Previous studies of supply chain performance mostly focused on manufacturing supply chain, but the research on SSC is an emerging field now. Thus, this section will review the performance evaluation research not only on manufacturing supply chain but also on SSC. The research on performance evaluation methods about scheduling management and supply chain management (SCM) will be discussed as well.

2.1. Performance Evaluation System of Supply Chain. Since the 1990s, the research about manufacturing supply chain performance evaluation has begun and gained many achievements [12]. The authoritative research institute of supply chain, Supply Chain Council (SCC), in 1996 presented 13 indexes about performance evaluation in supply chain operations reference (SCOR). Reference [13] established an evaluation system based on resources, output, and flexibility. Reference [14] studied why and how the SCM influenced the organization's time performance. Reference [15] put forth the performance evaluation system based on four main processes of supply chain, planning, purchasing, assembling, and delivering. On the basis of the SCOR model, [16] proposed the performance evaluation system from the perspective of customers, internal processes, and shareholders. Reference [17] built up the performance evaluation system from the view of financing, customers, operation procedure, organization learning, and growth by adopting the balanced scorecard.

With the development of SSC, more and more studies focus on the performance evaluation of SSC. Reference [18] made the definition of SSC from the perspective of professional services outsourcing and established a comprehensive performance evaluation system. Reference [19] explored the integration SCOR model with service business and developed a reference model of performance evaluation for service organizations. Reference [20] made a review on performance evaluation issues of SSC and constructed the performance evaluation system from the aspects of the strategic, tactical, and operational levels.

In the field of LSSC, based on the characteristics of LSSC, [21] designed the performance evaluation system on the procedure joint process of LSSC and used an ANP method. Reference [7] proposed a time scheduling model and explored the effect of time delay coefficient and cost coefficient on the performance of LSSC.

When considering the evaluation index, the qualitative indexes and quantitative indexes are different. Reference [13] stated that qualitative evaluations were vague and difficult to utilize in any meaningful way. Thus, quantitative performance measures were often preferred over such qualitative evaluations. However, the chosen numerical performance measure may not adequately describe the system's performance [22]. Therefore, many studies use both qualitative and quantitative indicators [23–25]. In these papers, the qualitative indexes are evaluated by questionnaire and they ignore the stability and the consistency of the respondents.

2.2. Scheduling Performance Evaluation Method. Moreover, the methods of scheduling performance evaluation are investigated by many scholars [26–28], but these studies are mostly emphasized by using the method of operation research or optimization algorithm to improve the performance [4, 5, 10] rather than performance evaluation. Reference [29] optimized the performance evaluation method of production scheduling within a workshop, but the method was not extended to supply chain environment. Reference [8] conducted an empirical study about performance evaluation indexes of scheduling with a three-part questionnaire.

Dynamic evaluation method used in this paper is also applied in many fields. References [30, 31] examined air quality model's changes in pollutant concentrations with dynamic evaluation method. Furthermore, the performance evaluation methods of supply chain are enriching with the development of the evaluation theories. Basically, there are several methods including balanced scorecard [17, 32], data envelopment analysis [33, 34], analytic hierarchy process [35, 36], analytic network process [3], and fuzzy evaluation method [37]. Different approaches can be applied to different environments.

From the literature review, it can be found that performance evaluation research of supply chain has gained abundant achievements, but the research on scheduling performance evaluation of LSSC has not been reported before. Therefore, it is necessary to analyze the characteristics of the scheduling performance evaluation in depth and explore the evaluation index system and evaluation methods, which will provide scientific reference for improving the effectiveness and efficiency of LSSC scheduling.

3. The Scheduling Performance Evaluation Index System of LSSC

The goal of LSSC operation management is to provide the customers with the best logistics service through the cooperation of LSI and FLSPs. LSSC scheduling means that LSI manages the logistics service capacities of different FLSPs uniformly and makes various service capacities coordinate with each other so as to meet customers' logistics service demand. LSSC scheduling involves many aspects, including order allocation scheduling, time flexibility scheduling, and process scheduling. In order to complete the scheduling, suitable organization and coordination are required through the information communication, human resource allocation, relationship coordination, and other activities.

To evaluate the scheduling performance of LSSC, the evaluation index system should be given, because it provides significant value to users, which can tell the users how valuable the evaluated objects are [38, 39]. Some scholars have already proposed several performance evaluation systems of manufacturing supply chain, but these systems cannot be completely duplicated into service supply chain [40]. Therefore, the corresponding evaluation index system should be presented based on the characteristics of LSSC scheduling.

First of all, the evaluation index system of LSSC scheduling should take the hierarchy into consideration. Reference [41] pointed out that supply chain management issues covered a wide range of enterprise activities from the strategic through the tactical to the operational levels. Therefore, evaluation index system in this study will be divided into three levels, strategic environment level, operating process level, and scheduling results level, corresponding to strategic level, tactical level, and operational level, respectively.

Second, the index system should reflect the characteristics of supply chain and service. The essence of SCM is integration and coordination among members, while scheduling is the bridge of connecting upstream and downstream in SSC, whose performance evaluation should involve the coordination ability and cooperation effect [42–44]. Additionally, the service characteristics of SSC should be considered. References [45, 46] verified that the dimensions of performance evaluation for manufacturing supply chain are insufficient to evaluate the performance of SSC. Service is intangible and service delivery is quite different from product delivery, which should be considered in the index system design.

Third, the index system should take into account the different members' demand. According to [15], the main reason why few enterprises succeed to maximize the overall supply chain profit through integration and coordination is that they fail to be integrated completely and do not share performance evaluation systems among them. Thus, measurements should be shared and manipulated by all supply chain members. There are three principal members in LSSC, LSI, FLSP, and customers. The LSI and FLSP focus on all the three levels, while the customers pay more attention to scheduling results level.

According to the consideration above, the scheduling performance evaluation index system of LSSC is proposed as in Table 1. It must be noted that for the indexes needed by LSI and FLSP, both LSI and FLSP should be joint during evaluation, and the final index value should be determined by LSI and FLSP jointly.

4. Scheduling Performance Evaluation Method Based on Dynamic Index Weight

In the section of introduction, there are problems in LSSC scheduling performance evaluation that should be solved. The first is how to quantify the qualitative indexes; the second is how to deal with the continuous and multiperiod

Table 1: The scheduling performance evaluation index system of LSSC.

First-level indexes	Evaluation subject	Factors	Second-level indexes	Description
Scheduling environment C_1	LSI FLSP	Environment C_{11}	Organization structure C_{111}	Reasonable setting of scheduler responsibility and power
			Information technology C_{112}	The usage of modern logistics information technology and MIS
			Information collecting ability C_{113}	The availability and accuracy of information
			Cooperation relationship C_{114}	Trust and coordinated operation between LSI and FLSP
Scheduling process C_2	LSI FLSP	Operations C_{21}	Adaptability of scheduling C_{211}	Adaptability for uncertain external environment
			Timeliness of scheduling C_{212}	Timeliness of initial release and schedule adjustment
			Communication quality C_{213}	Understandability and efficiency of communication
			Flexibility of scheduling C_{214}	Time and cost needed to release or change a schedule
Scheduling results C_3	Customer	Customer satisfaction C_{31}	Customer complaints rate C_{311}	Customer complaint about the delivered service
			Fulfillment rate of customer order C_{312}	The rate of order fulfillment
			On-time delivery C_{313}	Orders completed within the prescribed time.
			Response time to demand C_{314}	Speed for response to customer demand
	LSI FLSP	Service quality C_{32}	Wrong scheduling rate C_{321}	The number of schedule errors
			Scheduling cost C_{322}	Cost of all the scheduling process
			FLSP satisfaction C_{323}	Satisfaction of FLSPs
			Resource efficiency C_{324}	Efficiency of resource utilization

characteristics of LSSC scheduling activities; and the third is how to implement the dynamic change of index weight. Thus, the scheduling performance evaluation method of LSSC based on the dynamic index weight is proposed. Section 4.1 proposes an improved method of multiphase dynamic interaction to quantify the qualitative indexes. Section 4.2 uses an improved attribute deviation maximization method to determine the weight of second-level indexes. In Section 4.3, we propose an adjustment coefficient method based on set-valued statistics to adjust the first-level indexes' weight. Section 4.4 shows the main application process of this method.

The notations involved in the method are shown in Table 2.

4.1. Quantify the Qualitative Indexes Using the Method of Multiphase Dynamic Interaction. This method is applicable to quantify the qualitative index by multiphase dynamic interactive expert scoring. The thought is described as in the following: let some experts rate the qualitative indexes with several rounds. Every round can be regarded as a revision for last round till it reaches a relatively stable and consistent level. Suppose that there are m experts scoring for n qualitative indexes, and the higher the score, the better the performance of the index for both cost-type indexes and benefit-type indexes. The index set evaluated is $\mathbf{X} = \{x_1, x_2, \ldots, x_n\}$ and the evaluator group set is $\mathbf{S} = \{s_1, s_2, \ldots, s_m\}$. The interval of scoring is [0,10] and the score matrix is $P = (p_{ij})_{n\times m}$.

4.1.1. Multiphase Dynamic Interaction and the Decision of Interaction Coefficient. The purpose of multiphase dynamic interaction is to give the evaluators a chance of revising their grading according to the group information of last round. P^t $(t = 1, 2, \ldots, l)$ is assumed as the score matrix of the tth round. In the process of multiphase dynamic interaction, the variation of an evaluator's score between two continuous rounds can reflect the influence by the group information of last round. a_j^t can be used to indicate the similarity between the jth evaluator with other group members in the tth round,

$$a_j^t = \frac{1}{m-1} \sum_{k=1, k\neq j}^{m} \left(\cos\theta_{jk}^t - \cos\theta_{jk}^{t-1}\right), \tag{1}$$

where $\cos\theta_{jk}^t = (p_j^t, p_k^t)/|p_j^t||p_k^t| = \sum_{i=1}^n p_{ij}^t p_{ik}^t / \sqrt{\sum_{i=1}^n (p_{ij}^t)^2 \sum_{i=1}^n (p_{ik}^t)^2}$.

During the course of different interaction phases, the influence of a group member is varied with score matrix. Thus, u_j^t is used to indicate the interaction coefficient of the jth evaluator in the tth round as follows:

$$u_j^t = \frac{\left(1 + a_j^t\right)}{\sum_{j=1}^m \left(1 + a_j^t\right)}. \tag{2}$$

The interaction coefficient vector of the tth round is $\mathbf{u^t} = (u_1^t, u_2^t, \ldots, u_m^t)$.

Table 2: Notations used in the method.

Notations	Description
x_i	The ith index
s_j	The jth evaluator
p_{ij}	The score of the ith index evaluated by the jth evaluator
P^t	Score matrix of the tth round
a_j^t	The difference of similarity of the jth evaluator from other group members in the tth round
u_j^t	The interaction coefficient of the jth evaluator in the tth round
p_i^{t*}	The final score of the ith index in the tth round
υ^t	Index stability for the tth round
ω^t	Index consistency for the tth round
ε	Stability threshold of the group information
η	Consistency threshold of the group information
p_i^*	Final score of the ith index
$A(a_{ij})$	Decision matrix
$R(r_{ij})$	Normalized decision matrix
Φ^i	Set of the intervals of second-level indexes' weights under the ith first-level index
w_j^i	The weight of the jth second-level index under the ith first-level index
$[d_{i1}^k, d_{i2}^k]$	The adjustment range of the ith first-level index evaluated by the kth evaluator
d_i	Aggregation point of the ith first-level index
g_i	Ramification degree of the expert scoring for the ith first-level index
e_i	Consistency of experts scoring of the ith first-level index
w_i^t	The weight of the ith first-level index in the tth round

4.1.2. The Aggregation of Scoring Information. The purpose of the aggregation is to obtain the comprehensive score of each index after the tth round scoring. In order to balance every evaluator's opinion, the minimal deviation with the members' scoring is used as the final score. By solving the following programming model, the final score of the ith index in the tth round can be reached as p_i^{t*} $(i = 1, 2, \ldots, n;\ t = 1, 2, \ldots, l)$, where

$$\begin{aligned} \min \quad & \pi\left(p_i^{t*}\right) = \sum_{i=1}^{n}\sum_{j=1}^{m} u_j^t \left(p_{ij}^{t*} - p_{ij}^t\right)^2 \\ \text{s.t.} \quad & \begin{cases} \min_j p_{ij}^t \le p_{ij}^{t*} \le \max_j p_{ij}^t \\ i = 1, 2, \ldots, n, \\ j = 1, 2, \ldots, m. \end{cases} \end{aligned} \tag{3}$$

4.1.3. The Stability and Consistency of Group Information. After several rounds of interscoring, the opinions of group members are known to each other. So the group information tends to be relatively stable and consistent. The stability means the invariance of group information in consecutive rounds and the consistency represents the invariance between different members within the same round. According to the two indexes, the scoring termination condition can be determined.

The indexes stability for the tth round is calculated as follows:

$$\upsilon^t = 1 - \frac{1}{mn}\sqrt{\sum_{i=1}^{n}\sum_{k=1}^{m}\left(p_{ik}^t - p_{ik}^{t-1}\right)^2}. \tag{4}$$

The stability vector is labeled as $\boldsymbol{\upsilon} = (\upsilon^1, \upsilon^2, \ldots, \upsilon^l)$.

The index consistency for the tth round is calculated as follows:

$$\omega^t = 1 - \frac{1}{mn}\sqrt{\sum_{i=1}^{n}\sum_{h=1}^{m}\left(p_{ih}^t - p_i^{-t}\right)^2}, \tag{5}$$

where $p_i^{-t} = (1/m)\sum_{k=1}^{m} p_{ik}^t$ and the consistency vector is labeled as $\boldsymbol{\omega} = (\omega^1, \omega^2, \ldots, \omega^l)$.

In order to determine the termination conditions of interscoring, two thresholds for stability (ε) and consistency (η) are given firstly. If there exists

$$\left|1 - \upsilon^t\right| < \varepsilon, \tag{6}$$

we think that it passes the stability test. Meanwhile, according to the indexes consistency in the tth round, if there exists

$$\left|1 - \omega^t\right| < \eta \tag{7}$$

we believe that it passes the consistency test. When both the stability and the consistency tests are satisfied, the multiphase dynamic interaction can be stopped. In practical application, the stability is more emphasized, so the threshold of consistency can be looser than that of stability.

4.1.4. The Aggregation of the Final Score Result. The comprehensive score of each index in different rounds p_i^{t*} $(i = 1, 2, \ldots, n;\ t = 1, 2, \ldots, l)$ will have an impact on the final score result. For these impacts, the induced ordered weighted averaging (IOWA) [47] operators are adopted to aggregate the index score in different rounds.

Definition 1. Set $\langle v_1, f_1\rangle, \langle v_2, f_2\rangle, \ldots, \langle v_l, f_l\rangle$ as l two-dimensional arrays. Let $h_w(\langle v_1, f_1\rangle, \langle v_2, f_2\rangle, \ldots, \langle v_l, f_l\rangle) = \sum_{i=1}^{l} w_i a_{v-\text{index}(i)}$; then the function h_w is regarded as l dimensional IOWA operator, and v_i is induced component of f_i, where $v - index(i)$ stands for the subscript of the ith large number among $v_1, v_2, \ldots, v_l$ and $\mathbf{w} = (w_1, w_2, \ldots, w_l)$ is weighted vector, which is satisfied with $\sum_{i=1}^{l} w_i = 1$, $w_i \ge 0$, $i = 1, 2, \ldots, l$.

Definition 1 indicates that the value of IOWA is obtained from the ordered weighted average of f_i, which is ranked in order of size of v_i. The values and location of w_i are not associated with those of f_i, but associated with the location of the induced values.

In this paper, because the index stability is more important, it could be used as the induced components of IOWA operator. The final score of each qualitative index is $P^* = p_i^*$ $(i = 1, 2, \ldots, n)$.

4.2. Determining the Weight of Second-Level Indexes. Using the method proposed in Section 4.1, we can convert the qualitative indexes into benefit-type quantitative ones. Now, decision matrix $A = (a_{ij})_{c\times b}$ of whole index system within b period is built up. However, as for the quantitative index a_{ij}, the two types of index, cost-type index and benefit-type index, need to be normalized. The method is described as in the following.

For cost-type index

$$r_{ij} = \frac{\min_j (a_{ij})}{a_{ij}}, \quad j = 1, 2, \dots, b. \tag{8}$$

For benefit-type index

$$r_{ij} = \frac{a_{ij}}{\max_j (a_{ij})}, \quad j = 1, 2, \dots, b. \tag{9}$$

It is important to note that because of the assumption that the higher the score, the better the performance of the index for benefit-type indexes, so all the qualitative indexes are changed into benefit-type index.

With (8) and (9), the normalized decision matrix $R = (r_{ij})_{c\times b}$ of the whole index evaluation system within b period can be obtained. Let Φ be the set of possible weight intervals for known indexes. The single-objective linear programming model can be established by using maximum deviation method based on deviation degree, as shown in

$$\begin{aligned} \max \quad & D(w) = \sum_{i=1}^{b}\sum_{j=1}^{c}\sum_{k=1}^{b} \left(\left|r_{ij} - r_{kj}\right|\right) w_j \\ \text{s.t.} \quad & w_j \in \Phi. \end{aligned} \tag{10}$$

The weight of each index can be achieved by solving the linear programming model.

4.3. Method for Adjusting the Weight of First-Level Indexes. By considering that in practice the decision-makers may have different demands of scheduling performance management in different periods, the first-level indexes of the evaluation system should be adjusted. Since there are only three indexes in the first level, the range of the adjustment will not change frequently. Thus, an adjustment coefficient method based on set-valued statistics is used to adjust the weight. And set-valued statistics have been used in many articles [48–51].

4.3.1. Expert Evaluation. In accordance with the requirements of different performance management, 3 to 5 experts are invited to estimate the proper adjustment ranges of three first-level index weights based on the past data. Because the experts may not hold the specific adjustment range accurately and objectively, they can give their opinions with an interval value $[d_{i1}^k, d_{i2}^k](d_{i1}^k < d_{i2}^k, -1 < d_{i1}^k < 1, -1 < d_{i2}^k < 1)$, where d_{i1}^k and d_{i2}^k should be consistent with positive number or negative number. The values indicate the percentages of increase or decrease in the weight of original index. The matrix of adjustment range is $\mathbf{B}$:

$$\mathbf{B} = \begin{bmatrix} \left(d_{11}^1, d_{12}^1\right) & \left(d_{11}^2, d_{12}^2\right) & \cdots & \left(d_{11}^k, d_{12}^k\right) \\ \left(d_{21}^1, d_{22}^1\right) & \left(d_{21}^2, d_{22}^2\right) & \cdots & \left(d_{21}^k, d_{22}^k\right) \\ \left(d_{31}^1, d_{32}^1\right) & \left(d_{31}^2, d_{32}^2\right) & \cdots & \left(d_{31}^k, d_{32}^k\right) \end{bmatrix}. \tag{11}$$

4.3.2. Processing the Data with Set-Valued Statistics. Set-valued statistics is an extension of classical statistics and fuzzy statistics. In classical statistics, a certain point in the phase space can be obtained in each test, while in set-valued statistics a fuzzy subset can be achieved. Set-valued statistics can deal with uncertain judgment so as to concentrate various opinions conveniently and reduce the random error. In this study, the method is adopted to handle the interval numbers of weight adjustment range, and the detailed algorithm is described as follows.

Let d_i be the aggregation point of the ith index;

$$d_i = \frac{\sum_{k=1}^{n} \left|\left(d_{i2}^k\right)^2 - \left(d_{i1}^k\right)^2\right|}{2\sum_{k=1}^{n}\left(d_{i2}^k - d_{i1}^k\right)}. \tag{12}$$

In order to measure whether the evaluations of experts are uniform, set g_i as the degree of ramification:

$$g_i = \frac{\sum_{k=1}^{n} \left[\left(d_{i2}^k - d_i\right)^3 - \left(d_{i1}^k - d_i\right)^3\right]}{3\sum_{k=1}^{n}\left(d_{i2}^k - d_{i1}^k\right)}. \tag{13}$$

So the consistency of experts' evaluation (e_i) is measured as

$$e_i = \frac{1}{1 + g_i}. \tag{14}$$

The closer the value of e_i to 1 is, the higher the consistency is. A certain threshold is set to testify. If the consistency is too low, the new round evaluation is required.

4.3.3. Weight of Adjusted First-Level Indexes. After the consistency test reaches the acceptable range, we can use the results to adjust the weight and then normalize the adjusted weight with

$$w_i^{\,t} = \frac{w_i^{t\prime}}{\sum_{i=1}^{3} w_i^{t\prime}}, \tag{15}$$

where $w_i^{t\prime} = (1 + d_i)w_i^{t-1}$ and w_i^t is the weight of ith first-level index for the tth period.

4.4. Application Procedure of Performance Evaluation Method Based on the Dynamic Index Weight. The evaluation method of scheduling performance presented here is adopted to evaluate the performance data of the $(b + 1)$th period. The application procedure is described as in the following.

Step 1. Determine the weight of first-level indexes. According to the requirements of dynamic adjustment, the weight can be achieved by the method proposed in Section 4.4.

Step 2. Process the qualitative data. After the data of previous b periods are collected, separate them into qualitative and quantitative data. For each period's qualitative data, quantify them with the multiphase dynamic interactive scoring method. Then the decision matrix $A = (a_{ij})_{c\times b}$ with fixed value can be obtained.

Step 3. Normalize $A = (a_{ij})_{c\times b}$ and obtain the normalized decision matrix $R = (r_{ij})_{c\times b}$ in b periods.

Step 4. Determine the weight of second-level indexes using the maximum deviation method based on deviation degree proposed in Section 4.3.

Step 5. Collect the data of the $(b + 1)$th period and quantify the qualitative data with the multiphase dynamic interactive scoring method proposed in Section 4.2 and then normalize all the data in this period.

Step 6. Obtain the final score with the weight of two-level indexes and the fixed value of data in the $(b + 1)$th period.

The flow diagram is shown in Figure 1.

5. Innovations and Advantages of This New Performance Evaluation Method

5.1. The Main Innovations and Advantages of This New Method. In the implementation of the performance evaluation methods, the most important two aspects are the accuracy of the data and the accuracy of the weight. Compared with other papers, this paper has made much effort on these two aspects.

Firstly, the new evaluation method proposed has advantages in quantifying the qualitative index. In general, there are two types of traditional quantifying methods. One is a simple method which needs one-off scoring and removing the singular points according to some rule [52, 53]; the other is a complex method, such as analytic hierarchy process [35, 36], analytic network process [3], and fuzzy evaluation method [37]. These methods are all one-off scoring and solving with judging criteria [23–25]. The above two types of traditional methods may be faced with the problem that the selected experts have different understanding with the indexes measure and only have once evaluation opportunity, which will lead to inaccurate results. Therefore, this paper uses the multiperiod interaction method. The core idea of this method is through several rounds interacting evaluations to make the group's opinions reach certain stability and consistency so as to reduce the subjectivity and improve the accuracy in expert scoring.

Secondly, in previous evaluation methods, the weight of indexes was given, single-period and constant [7, 8, 15–17] while in this paper we consider the problem of indexes weight dynamic adjustment in the multiperiod context. We draw the multiperiod interaction method presented by [54] and improve it. The method of [54] is suitable for direct evaluation and ranking for several objects, but not for the quantified assessment of a single object. In this paper, the method is improved properly and applied to realize the quantified assessment for LSSC scheduling which is single object.

Thirdly, because there are only three first-level indexes (scheduling environment, scheduling process, and scheduling results) and, in multiperiod dynamic adjustment, their weight will not change frequently in practice, we adopt an adjustment coefficient method based on set-valued statistics to adjust first-level indexes weight. Obviously, set-valued statistics is a group decision and has better effect than general one-off scoring in integrating the opinions of experts group [48–51].

5.2. Other Merits of This New Performance Evaluation Method. Compared with other performance evaluation methods, this method has some other merits of the following aspects.

(1) The evaluation index system used in this new method overcomes the shortcoming of traditional methods that only focus on a single enterprise or sector. From the perspective of supply chain cooperation, the evaluation index system emphasizes the whole scheduling process, namely, before scheduling, during scheduling, and after scheduling.

(2) The maximum attribute deviation method is introduced to determine the weight of the second-level indexes, which can remove the uncertainty of subjective factors. This improves the method proposed by [55].

(3) An adjustment coefficient method based on set-valued statistics is introduced to determine the weight of the first-level indexes, which can make the adjustment range more precise and decrease the difference among experts more significantly.

6. Method Application: A Case from Tianjin Baoyun Logistics Company, China

6.1. Case Description

6.1.1. Company Introduction. In order to verify the usability of the method, the data are collected from Baoyun Logistics Company in Tianjin, China. The company is a professional third-part logistics enterprise and an excellent logistics service integrator listed as the top 100 logistics enterprises of China in three consecutive years from 2005 to 2007. Currently, the company has 28 branches across the country and builds up a good relationship of cooperation with 32 large-scale warehousing enterprises, 20 transportation enterprises, and more than 15 professional logistics enterprises. By integrating these functional logistics service providers, Baoyun has established wide business connection with over 20 multinational customers such as P&G, Siemens, and Delphi Corporation and offered customized logistics service in accordance with logistics demands.

During the cooperation with P&G, Baoyun Logistics Company provides integrated service, including railway transportation service, warehousing service, and road

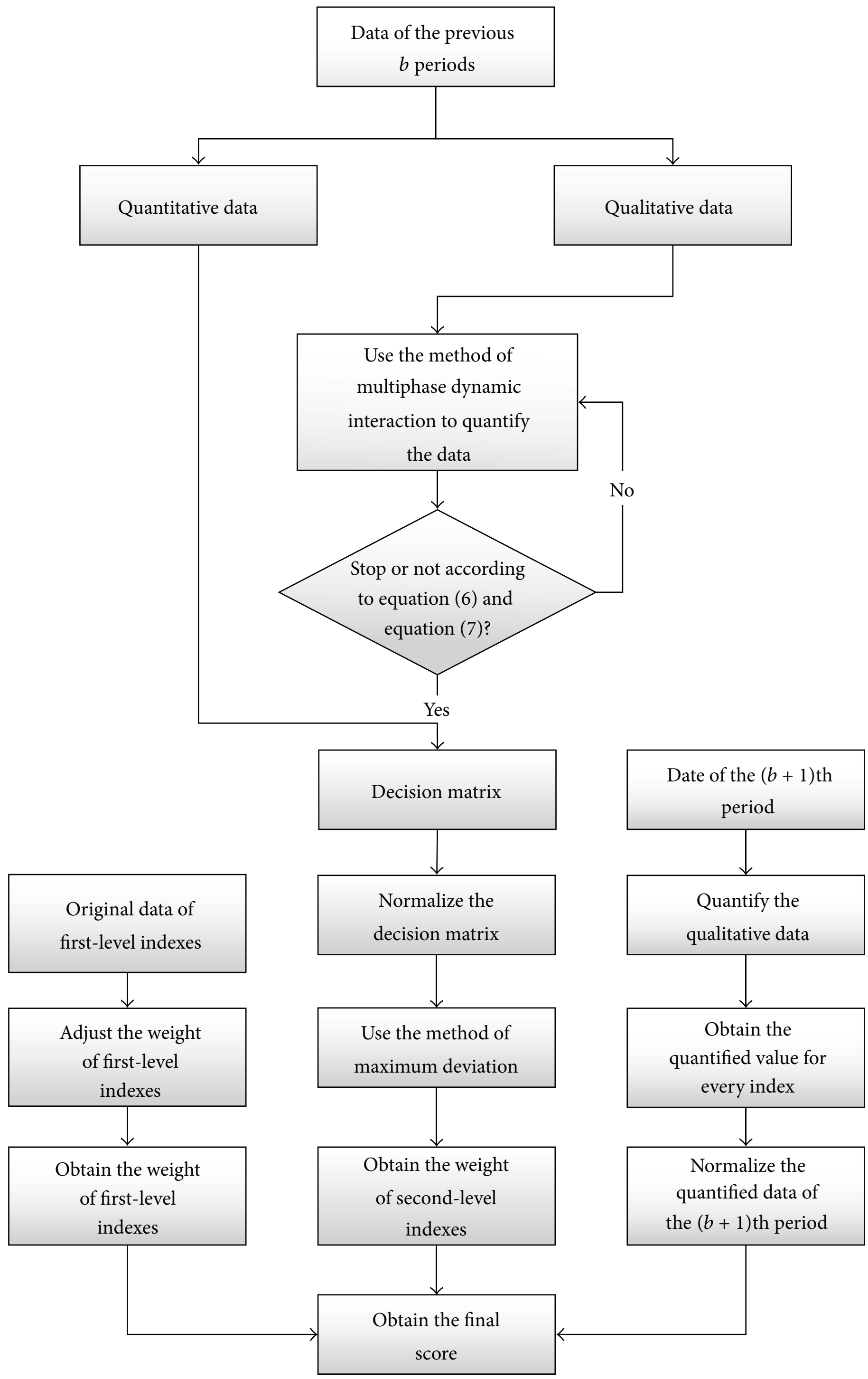

Figure 1: Flow diagram of performance evaluation method based on the dynamic index weight.

distribution and delivery service. Generally speaking, Baoyun evaluates the scheduling performance of these services provided to P&G monthly. When the evaluation is conducted, P&G, logistics service providers, and Baoyun jointly participated, and the indexes are evaluated individually to get the original data. If some indexes involve multiple parts, they need to be negotiated with each other to determine the final values.

In this case, the original data were collected from January 2012 to May 2012. Then the method proposed in the paper is used to evaluate the scheduling performance of June according to the data of the previous 5 months.

6.1.2. Selection of Evaluation Experts. In the scheduling performance evaluation of Baoyun, the biggest challenge is how to quantify the qualitative data. For this, Baoyun selects the managers who directly take charge of scheduling activities as evaluation experts. Usually, the three members which are P&G, Baoyun, and FLSP of LSSC assign their managers to participate in the performance evaluation. The experts group was composed as in Tables 3 and 4.

It is important to note that, according to the task of evaluation subject in Table 1, the first-level indexes are evaluated by all the three evaluation subjects, P&G, Baoyun, and FLSP. There are 5 experts in total shown in Table 3. While for the second-level indexes which are closely related to practical scheduling process, they are evaluated by Baoyun and FLSP shown in Table 4. When evaluating, all experts give their scores independently first and then start multistage interactive grading.

6.1.3. Challenges and Solutions in Evaluation. There are three aspects of challenges. The first is that the experts are from different companies and they may have different preferences. The second is that it is hard for these experts to get together doing evaluation work. The third is that sometimes the divergences among experts are too big to obtain a consistent result. So we need more grading rounds.

To overcome these challenges, P&G, Baoyun, and FLSP cooperate a lot. First, before the evaluating, the experts studied and discussed the indexes to make a consistent understanding. Second, Baoyun Company assigns a secretary to coordinate the time of these experts. She would inform the meeting time ten days before. Third, to reduce the evaluation round, every expert would explain his evaluation in the first round, so that other experts can understand his considerations. This can improve the evaluation efficiency and reach an agreement faster.

6.2. Application of Scheduling Performance Evaluation Method

6.2.1. Step 1: Determine the Weight of First-Level Indexes. According to the evaluation index system, there are three first-level indexes, scheduling environment, scheduling process, and scheduling result. The index of scheduling result is composed of two factors, which are customer satisfaction and service quality. In this paper, it is assumed that the two factors are equally important. The weights of the three indexes for the previous 5 months are 0.3, 0.3, and 0.4, respectively, and need to readjust in the sixth month. The matrix of weight adjustment range obtained from 5 experts is as follows and the consistency test threshold is 0.95:

$$\mathbf{B} = \begin{bmatrix} (0.0, 0.1) & (0.1, 0.2) & (0.1, 0.3) & (0.2, 0.4) & (0.1, 0.2) \\ (0.1, 0.2) & (0.3, 0.4) & (0.2, 0.4) & (0.0, 0.1) & (0.2, 0.3) \\ (-0.3, -0.2) & (-0.2, 0.0) & (-0.2, -0.1) & (-0.2, -0.1) & (-0.3, -0.2) \end{bmatrix}. \tag{16}$$

According to the matrix $\mathbf{B}$, adjustment range d_i could be calculated by (12); then consistency index e_i could be gotten by (13) and (14). Original weight w_i^{t-1} and adjusted weight $w_i^{t'}$ could be obtained by (15). The weight of first-level indexes is calculated as in Table 5.

See from Table 5 that the consistency index values of the experts evaluation are all over 0.95, and the adjustment of index weight is acceptable, so the first-level weights of the 6th period are 0.34, 0.35, and 0.31, respectively.

6.2.2. Step 2: Quantify the Qualitative Indexes Using the Method of Multiphase Dynamic Interaction. According to the original data, by using the method of multiphase dynamic interaction, the qualitative indexes of previous five periods can be converted into benefit-type quantitative ones, and the decision matrix $A = (a_{ij})_{c\times b}$ can be obtained as in Table 6.

6.2.3. Step 3: Normalize Decision Matrix. Customer complaints rate (C_{311}), response time for demand (C_{314}), wrong scheduling rate (C_{321}), and scheduling cost (C_{322}) are cost-type indexes and the rest are benefit-type indexes. After the decision matrix is normalized, the normalized decision matrix can be obtained as in Table 7.

6.2.4. Step 4: Determine the weight of second-level indexes. The maximum deviation method based on deviation degree is applied to calculate the weight of scheduling environment, scheduling process, and scheduling result respectively.

The possible index weight of each index for scheduling environment is $\Phi^1 = \{w^1 = (w_1^1, w_2^1, w_3^1, w_4^1) 0.25 \le w_1^1 \le 0.27, 0.21 \le w_2^1 \le 0.23, 0.24 \le w_3^1 \le 0.28, 0.20 \le w_4^1 \le 0.32\}$.

And that for scheduling process is $\Phi^2 = \{w^2 = (w_1^2, w_2^2, w_3^2, w_4^2) 0.22 \le w_1^2 \le 0.25, 0.24 \le w_2^2 \le 0.31, 0.18 \le w_3^2 \le 0.22, 0.28 \le w_4^2 \le 0.32\}$.

And that for scheduling result is $\Phi^3 = \{w^3 = (w_1^3, w_2^3, w_3^3, w_4^3, w_5^3, w_6^3, w_7^3, w_8^3) \mid 0.120 \le w_1^3 \le 0.135, 0.118 \le w_2^3 \le 0.132, 0.109 \le w_3^3 \le 0.141, 0.101 \le w_4^3 \le 0.141, 0.114 \le w_5^3 \le 0.147, 0.119 \le w_6^3 \le 0.132, 0.106 \le w_7^3 \le 0.134, 0.113 \le w_8^3 \le 0.134\}$.

Three single-objective linear programming models are established as in (17). Software MATLAB 7.0 is adopted and the weight of each index is obtained as shown in Table 8.

Consider

$$\max \quad D(w) = \sum_{i=1}^{5}\sum_{j=1}^{4}\sum_{k=1}^{5}\left(\left|r_{ij} - r_{kj}\right|\right) w_j$$

$$\text{s.t.} \quad w_j \in \Phi^1$$

Table 3: Experts group for evaluating the first-level indexes.

	Number of experts	Composition	Evaluation task
Baoyun (LSI)	2	General manager, operation manager	Weight of C_1, C_2, C_3
FLSP	2	General manager, operation manager	Weight of C_1, C_2, C_3
P&G	1	Logistics manager	Weight of C_1, C_2, C_3

Table 4: Experts group for evaluating the second-level qualitative indexes.

	Number of experts	Composition	Evaluation task
Baoyun (LSI)	2	Marketing manager, operation manager	Giving score for indexes in C_{11} and C_{21}
FLSP	3	General manager, marketing manager, operation manager	Giving score for indexes in C_{11} and C_{21}

Table 5: The results of adjusted weight of first-level indexes.

	Scheduling environment	Scheduling process	Scheduling outcome
Adjustment range d_i	0.193	0.233	−0.167
Consistency index e_i	0.991	0.988	0.990
Original weight w_i^{t-1}	0.3	0.3	0.4
Adjusted weight $w_i^{t'}$	0.358	0.370	0.333
Normalized weight w_i^t	0.34	0.35	0.31

$$\begin{aligned} \max \quad & D(w) = \sum_{i=1}^{5}\sum_{j=1}^{4}\sum_{k=1}^{5}\left(\left|r_{ij} - r_{kj}\right|\right) w_j \\ \text{s.t.} \quad & w_j \in \Phi^2 \\ \max \quad & D(w) = \sum_{i=1}^{5}\sum_{j=1}^{8}\sum_{k=1}^{5}\left(\left|r_{ij} - r_{kj}\right|\right) w_j \\ \text{s.t.} \quad & w_j \in \Phi^3. \end{aligned} \tag{17}$$

6.2.5. Step 5: Process the Data of the Sixth Month Based on Multiphase Dynamic Interaction. In this step, the application example of the method based on multiphase dynamic interaction is given. The original data of the sixth month is shown in Table 9.

According to the original data, 5 experts are invited to score the 8 qualitative indexes. After discussion, 4 times dynamic interaction are conducted. So $m = 5$, $n = 8$, and $l = 4$. The scores are distributed between 0 and 10, and the matrixes are shown as follows:

$$\mathbf{P^0} = \begin{array}{c} C_{111} \\ C_{112} \\ C_{113} \\ C_{114} \\ C_{211} \\ C_{212} \\ C_{213} \\ C_{214} \end{array} \begin{bmatrix} 8 & 4 & 3 & 6 & 5 \\ 5 & 5 & 8 & 3 & 2 \\ 6 & 8 & 2 & 4 & 4 \\ 8 & 2 & 5 & 3 & 7 \\ 6 & 3 & 6 & 5 & 7 \\ 5 & 2 & 8 & 6 & 3 \\ 7 & 7 & 3 & 7 & 4 \\ 7 & 3 & 6 & 6 & 2 \end{bmatrix}$$

Table 6: Decision matrix.

	January	February	March	April	May
C_{11}					
C_{111}	5.6	5.8	6.1	4.5	5.1
C_{112}	7	4.6	4.6	4.6	4.4
C_{113}	6.5	6.6	5.7	6.8	5.2
C_{114}	4.3	6.2	4.5	4.3	5.2
C_{21}					
C_{211}	6.3	6.2	6.3	5.1	4.2
C_{212}	4.5	4.5	6.2	6	6.5
C_{213}	5.1	4.3	6.7	4.5	4.1
C_{214}	6.9	5.1	6.5	6.9	6.8
C_{31}					
C_{311}	0.051	0.038	0.067	0.041	0.045
C_{312}	0.731	0.91	0.909	0.711	0.85
C_{313}	0.727	0.932	0.75	0.903	0.897
C_{314}	1.22	2.16	1.36	1.75	2.83
C_{32}					
C_{321}	0.014	0.048	0.035	0.057	0.024
C_{322}	17400	19100	18700	18000	15700
C_{323}	0.801	0.685	0.829	0.727	0.842
C_{324}	0.927	0.825	0.926	0.72	0.75

Table 7: Normalized decision matrix.

	January	February	March	April	May
C_{11}					
C_{111}	0.92	0.95	1	0.74	0.84
C_{112}	1	0.66	0.66	0.66	0.63
C_{113}	0.96	0.97	0.84	1	0.76
C_{114}	0.69	1	0.73	0.69	0.84
C_{21}					
C_{211}	1	0.98	1	0.81	0.67
C_{212}	0.69	0.69	0.95	0.92	1
C_{213}	0.76	0.64	1	0.67	0.61
C_{214}	1	0.74	0.94	1	0.99
C_{31}					
C_{311}	0.75	1	0.57	0.93	0.84
C_{312}	0.8	1	1	0.78	0.93
C_{313}	0.78	1	0.8	0.97	0.96
C_{314}	1	0.56	0.9	0.7	0.43
C_{32}					
C_{321}	1	0.29	0.4	0.25	0.58
C_{322}	0.9	0.82	0.84	0.87	1
C_{323}	0.95	0.81	0.98	0.86	1
C_{324}	1	0.89	1	0.78	0.81

$$\mathbf{P}^1 = \begin{array}{c} C_{111} \\ C_{112} \\ C_{113} \\ C_{114} \\ C_{211} \\ C_{212} \\ C_{213} \\ C_{214} \end{array} \begin{bmatrix} 8 & 6 & 3 & 6 & 7 \\ 4 & 4 & 3 & 5 & 5 \\ 5 & 4 & 7 & 6 & 3 \\ 7 & 8 & 5 & 3 & 6 \\ 4 & 5 & 9 & 7 & 3 \\ 6 & 9 & 4 & 8 & 8 \\ 9 & 8 & 3 & 7 & 6 \\ 5 & 7 & 6 & 2 & 2 \end{bmatrix}$$

$$\mathbf{P}^2 = \begin{array}{c} C_{111} \\ C_{112} \\ C_{113} \\ C_{114} \\ C_{211} \\ C_{212} \\ C_{213} \\ C_{214} \end{array} \begin{bmatrix} 7 & 5 & 6 & 3 & 4 \\ 2 & 5 & 5 & 4 & 6 \\ 4 & 5 & 8 & 6 & 3 \\ 8 & 3 & 4 & 7 & 2 \\ 5 & 7 & 8 & 3 & 5 \\ 4 & 5 & 4 & 6 & 7 \\ 6 & 4 & 6 & 8 & 4 \\ 8 & 6 & 6 & 2 & 4 \end{bmatrix}$$

$$\mathbf{P}^3 = \begin{array}{c} C_{111} \\ C_{112} \\ C_{113} \\ C_{114} \\ C_{211} \\ C_{212} \\ C_{213} \\ C_{214} \end{array} \begin{bmatrix} 6 & 6 & 6 & 4 & 4 \\ 2 & 6 & 4 & 3 & 5 \\ 6 & 5 & 7 & 5 & 3 \\ 7 & 4 & 5 & 7 & 3 \\ 5 & 6 & 8 & 4 & 6 \\ 2 & 5 & 3 & 6 & 4 \\ 8 & 5 & 5 & 8 & 5 \\ 5 & 7 & 6 & 3 & 6 \end{bmatrix}$$

$$\mathbf{P}^4 = \begin{array}{c} C_{111} \\ C_{112} \\ C_{113} \\ C_{114} \\ C_{211} \\ C_{212} \\ C_{213} \\ C_{214} \end{array} \begin{bmatrix} 6 & 6 & 6 & 4 & 4 \\ 3 & 6 & 4 & 4 & 5 \\ 6 & 5 & 7 & 5 & 4 \\ 7 & 5 & 5 & 7 & 3 \\ 5 & 6 & 7 & 4 & 6 \\ 4 & 5 & 3 & 6 & 4 \\ 8 & 5 & 5 & 8 & 5 \\ 5 & 7 & 6 & 4 & 6 \end{bmatrix}. \quad (18)$$

Calculate the interaction coefficient with (1) and (2) as in the following:

$$\begin{aligned} \mathbf{u}^1 &= (0.194, 0.214, 0.194, 0.196, 0.203) \\ \mathbf{u}^2 &= (0.192, 0.201, 0.219, 0.190, 0.198) \\ \mathbf{u}^3 &= (0.202, 0.196, 0.197, 0.202, 0.202) \\ \mathbf{u}^4 &= (0.202, 0.199, 0.198, 0.201, 0.199). \end{aligned} \quad (19)$$

Aggregate the score of each round with (3):

$$\begin{aligned} \mathbf{P}^{1*} &= (6.009, 4.205, 4.964, 5.840, 5.567, 7.051, 6.623, 4.426) \\ \mathbf{P}^{2*} &= (5.025, 4.432, 5.259, 4.471, 5.679, 5.175, 5.582, 5.228) \\ \mathbf{P}^{3*} &= (5.191, 3.988, 5.192, 5.208, 5.788, 3.999, 6.213, 5.387) \\ \mathbf{P}^{4*} &= (5.199, 4.395, 5.399, 5.408, 5.594, 4.403, 6.210, 5.595). \end{aligned} \quad (20)$$

Set the stability threshold as 0.1 ($\varepsilon = 0.1$) and the consistency threshold as 0.25 ($\eta = 0.25$), and then calculate the stability index and the consistency index of each round as follows:

$$\begin{aligned} \boldsymbol{v} &= (0.56, 0.641, 0.813, 0.921) \\ \boldsymbol{\omega} &= (0.685, 0.7, 0.744, 0.771). \end{aligned} \quad (21)$$

The index stability and index consistency of the fourth round are 0.921 and 0.771, respectively. The test value of stability index is 0.079 less than 0.1, and the test value of consistency index is 0.229 less than 0.25. So it can be

Table 8: Weight of second-level indexes.

Organization structure C_{111}	0.25
Information technology C_{112}	0.21
Information collecting ability C_{113}	0.24
Cooperation relationship C_{114}	0.3
Adaptability of scheduling C_{211}	0.22
Timeliness of scheduling C_{212}	0.28
Communication quality C_{213}	0.22
Flexibility of scheduling C_{214}	0.28
Customer complaints rate C_{311}	0.135
Fulfillment rate C_{312}	0.13
On-time delivery C_{313}	0.109
Response time for demand C_{314}	0.141
Wrong scheduling rate C_{321}	0.147
Scheduling cost C_{322}	0.119
Provider satisfaction C_{323}	0.106
Resource efficiency C_{324}	0.113

Table 9: Original data of the sixth month.

	Index value	Nature
C_{11}		
C_{111}	Fair	Qualitative
C_{112}	Very poor	Qualitative
C_{113}	Fair	Qualitative
C_{114}	Fair	Qualitative
C_{21}		
C_{211}	Good	Qualitative
C_{212}	Poor	Qualitative
C_{213}	Very good	Qualitative
C_{214}	Fair	Qualitative
C_{31}		
C_{311}	0.055	Quantitative
C_{312}	0.849	Quantitative
C_{313}	0.913	Quantitative
C_{314}	1.64	Quantitative
C_{32}		
C_{321}	0.022	Quantitative
C_{322}	16900	Quantitative
C_{323}	0.823	Quantitative
C_{324}	0.896	Quantitative

concluded that the results pass the tests. Finally, the final score of each index with IOWA is aggregated:

$$\mathbf{P}^{*} = (5.243, 4.261, 5.265, 5.258, 5.667, 4.701, 6.127, 5.342). \tag{22}$$

The data of the sixth month are normalized by combining the data in previous 5 months, and the results are shown in Table 10.

Table 10: Normalized value of data in the sixth month.

	Index	Data	Normalized data
Scheduling environment	C_{111}	5.2428	0.86
	C_{112}	4.2613	0.61
	C_{113}	5.2654	0.8
	C_{114}	5.2578	0.85
Scheduling process	C_{211}	5.6665	0.9
	C_{212}	4.701	0.72
	C_{213}	6.1266	0.91
	C_{214}	5.3423	0.77
Scheduling result	C_{311}	0.055	0.69
	C_{312}	0.849	0.93
	C_{313}	0.913	0.98
	C_{314}	1.64	0.74
	C_{321}	0.022	0.64
	C_{322}	16900	0.93
	C_{323}	0.823	0.98
	C_{324}	0.896	0.97

6.2.6. Step 6: Obtain the Final Score. Obtain the final score by the fixed data as shown in Table 8 and the index weights determined in Steps 1 and 4. The expressions are shown as in the following:

$$\begin{aligned}&(0.86 \times 0.25 + 0.61 \times 0.21 + 0.80 \times 0.24 + 0.85 \times 0.30) \times 0.34\\&+ (0.90 \times 0.22 + 0.72 \times 0.28 + 0.91 \times 0.22 + 0.77 \times 0.28)\\&\times 0.35 + (0.69 \times 0.135 + 0.93 \times 0.130 + 0.98 \times 0.109\\&+ 0.74 \times 0.141 + 0.64 \times 0.147 + 0.93 \times 0.119\\&+ 0.98 \times 0.106 + 0.97 \times 0.113) \times 0.31 = 0.815.\end{aligned} \tag{23}$$

Therefore, the final scheduling performance of the sixth month (June 2012) is 0.815. According to the performance ratings standardization of Baoyun Logistics Company, 0.815 reaches the good level, but it also has great potential to increase the scheduling performance in the future.

7. Conclusions

Evaluating the LSSC scheduling performance is beneficial to make better decision for LSI. In this paper, the scheduling performance evaluation of LSSC is explored in depth and the evaluation index system is established. Meanwhile, an evaluation method based on dynamic index weight is proposed. According to the study, the following conclusions are reached.

(1) The evaluation index system of LSSC scheduling performance should be designed from the perspective of strategic level, tactical level, and operational level. The system proposed in this context considers not only the different demands of different members in LSSC, but also the requirement of coordination and characteristics of service, which is scientific and can be used for reference to scheduling performance management.

(2) Considering the multiperiod feature of scheduling activities, the difficulty in measuring the qualitative indexes, and the needs of index weight adjustment, we propose a method based on dynamic index weight. In this method, firstly, for the difficulty in measuring the qualitative indexes, an improved method of multiphase dynamic interaction is adopted to improve the accuracy. Secondly, as for the need of index weight adjustment, an improved maximum deviation method based on deviation degree is utilized to determine the weight of second-level indexes, which can remove the uncertainty of human decision. Thirdly, an adjustment coefficient method based on set-valued statistics is developed to adjust the weight of first-level indexes reasonably. Thus, this method is more suitable than the traditional evaluation ones in LSSC scheduling performance evaluation.

(3) Actual data from Baoyun Logistics Company were collected to exemplify this new scheduling performance evaluation method. The application example illustrates that the method can evaluate the scheduling performance scientifically and provide good basis to LSI for improving the performance of LSSC scheduling.

In this paper, the problem of LSSC scheduling performance evaluation is investigated and a new evaluation method is proposed, but there are still some limitations. For instance, the evaluation index system reflects the factors of before, during, and after the schedule, while the more detailed factors, such as order allocation, process selection, and time flexibility scheduling, are not considered. As for the evaluation method proposed, the possible intervals of second-level indexes weights are obtained by experience, which contains some subjectivity. How to improve the objectivity of index weight intervals is one of future directions. Moreover, with the evaluation value obtained from the method proposed, how to use it to forecast the performance of next period and present improvement program is also the focus of future researches.

Conflict of Interests

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

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