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Supply Chain Logistics Information Quality Evaluation From Just-In-Time Perspective

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ABSTRACT In this paper, we seek to evaluate supply chain logistics information quality (SCLIQ) from the Just-In-Time (JIT) perspective. First, based on the analysis of SCLIQ, it is proposed that the SCLIQ evaluation should be combined with JIT philosophy. Second, based on SPC and information entropy method, an evaluation method of SCLIQ is presented. The statistical process control method (SPC) is adopted to evaluate the information quality of quantity and time respectively, the information entropy method is employed to determine their weight and the comprehensive evaluation results, and these results are analyzed according to SPC. Finally, a numerical example is used to demonstrate the feasibility of the proposed method. The major contribution of this paper is the combination of SQLIQ and JIT philosophy, while an objective and comprehensive evaluation method of SCLIQ from the JIT perspective is developed. The results are useful for evaluating SCLIQ and determining the best direction of improvement activities.

INDEX TERMS Supply chain, logistics, information quality, just-in-time, statistical process control method (SPC), information entropy method.

I. INTRODUCTION

In the context of globalization, the increasingly fierce and dynamic competition has forced many manufacturing enterprises to select the most appropriate improvement initiatives for improving customer satisfaction [1]. However, it is very difficult to achieve these goals because different value chain activities, such as the design, manufacturing of the components or parts, and the assembly, are often in different countries or regions. Users of the final product are still in another place. To overcome these difficulties, the manufacturing enterprises are adopting several new techniques, methods, and strategies among which lean production (LP) has shown salient presence [2]. The concept of LP became popular through the book The Machine That Changed the World by Womack and Jones in the 1990s [3]. The wide adoption of LP practices and principles has consistently occurred throughout different industries and contexts during the last few decades [4], [5]. LP targets at removing any kind of waste and inconsistency in the production system. The two pillars of LP are Just-In-Time (JIT) and Jidoka. As one of the most widely used production strategies [6], JIT is a manufacturing philosophy developed in Japan, which emphasizes excellence in all phases of the production cycle [7]. Reference [2] has reported 31 benefits after a successful JIT implementation had been obtained by a manufacturing enterprise. The best characteristic of JIT is that it aims at producing the requisite product, at the right time, in the right quantity, and should take away the unnecessary stocks [3], [8], [9]. Moreover, JIT production practices improve the responsiveness and efficiency of supply chains [10], while the prompt response to customer demand has always been the focus of the supply chain [11].

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In general, an assembly line is commonly coupled with upstream production systems through a JIT-supply of required materials [12]. JIT system involves frequent shipments of smaller batch sizes from the supplier to the manufacturing enterprise [13], [14]. To achieve the objectives of JIT, the manufacturing enterprise must select the most appropriate supply chain network (an effective supply chain logistics system is necessary to support production processes [15]) for the reduction of total costs and waste of time [16].

Supply chain logistics activities will produce logistics information from beginning to end. In the supply chain logistics system, information is closely related to transportation, storage, distribution, and so on. Logistics informatization is regarded as the soul of modern logistics [17]. Supply chain logistics information collaboration is the basis and premise of supply chain logistics collaboration [18]. Effective management of supply chain logistics information is an important basis for improving logistics efficiency, reducing logistics cost, improving service level, and realizing logistics resource allocation. Information quality is an essential attribute of information [19]. Many studies suggest that making correct decisions depends on high-quality information [20]. When information quality is maintained, then better supply chain performance is attained [21]. Therefore, a high level of supply chain logistics information quality (SCLIQ) is the basis of an effective supply chain logistics system.

In recent years, a large amount of data on logistics information can be collected from the wide application of automatic identification technologies such as barcode technology, radio frequency identification (RFID), and all kinds of sensors. Although these data can provide more information to enable the supply chain to make correct decisions, this information is disorganized and complicated [22], [23]. Therefore, how to evaluate SCLIQ has become a complicated problem. Moreover, in the context of JIT being adopted by more and more enterprises, it is very necessary to evaluate information quality from the JIT perspective.

To date, many researchers have discussed information quality evaluation. However, to our best of our knowledge, this paper is the first to evaluate SCLIQ from the JIT perspective. The main contributions of this paper are as follows: 1) We propose to combine SCLIQ with JIT philosophy in SCLIQ evaluation. 2) We present a novel evaluation method of SCLIQ based on the SPC and information entropy method. Compared with prior relevant literature on information quality evaluation, the proposed evaluation is based on the combination of SCLIQ and JIT philosophy. Moreover, the final evaluation result depends on ''right time'' and ''right amounts'' derived from the JIT philosophy. The proposed method can not only evaluate the two parameters respectively but also provide a comprehensive evaluation.

The remainder of this paper is structured as follows. In Section 2, the literature on information quality is briefly reviewed. In Section 3, we explain why SCLIQ and JIT philosophy should be combined in the SCLIQ evaluation. The research question is described too. Based on SPC and information entropy method, the details of the proposed method are presented in Section 4. In Section 5, a numerical example is provided to verify the feasibility of the proposed method. Finally, Section 6 presents the conclusion, the research limitations, and directions for further research.

II. LITERATURE REVIEW

Information quality has received considerable attention due to its critical impact on the accuracy of the decision-making process [24]. Most research mainly focuses on accounting information quality and statistical information quality [25]. Information quality begins with the data quality so that some research uses information quality and data quality interchangeably [24], which is also the case in this paper.

Information quality is defined, described, and interpreted from different perspectives [26]. Information quality measures the degree to which the information exchanged between organizations meets the needs of the organizations [27]. It refers to information richness, rather than the amount, and thus it emphasizes the quality and nature of information shared between buyers and suppliers [28]. Besides, information quality can be regarded as the ability to satisfy both stated and implied needs of an information consumer [29]. Although there is no consensus on the definition of information quality up to now, information quality can be often defined briefly as the 'fitness for use' of information [30], [31]. More completely as 'people's subjective judgment of goodness and usefulness of the information in certain information use settings concerning their expectations of information or regarding other information available' [32]. It lies in how the information is perceived and used by its customer [33]. Information quality is proposed as a mechanism that can largely determine the success of the supply chain integration effort [34].

These definitions mainly focus on the quality of the information itself and the subjective feeling of information users (customer or organization). However, these definitions only represent the quality of information at a certain point so that the results are only useful for information quality improvement of the node [35]. When it comes to the global context, in which the information quality of all nodes should be investigated, these definitions become improper. For example, in the supply chain logistics whose targets are to meet the customers' requirements, the information quality of all nodes is important and should be investigated. Therefore, the definition of information quality should be further explored.

Information quality is inherently a hierarchical multi-dimensional concept [21], [31], [36]–[38] with inherent limitations when applied to a specific application domain [31]. Though the dimensions of information quality changes dynamically [33], several typical dimension classifications of information quality in the literature are shown in Table 1. Practically, the different dimensions are always grouped into different categories according to the research objectives so that the different hierarchical structure models of information quality are constructed. In sum, different research uses different dimensions of information quality that could achieve

TABLE 1. Several typical dimension classifications.

Dimensions	
Accuracy, objectivity, believability, reputation, relevancy, value-added, timeliness, completeness, amount of information, interpretability, ease of understanding, concise representation, consistent representation, access, convenience, and security	[19]
Free-of-error, appropriate amount, concise representation relevancy, completeness understandability, consistent representation, interpretability, objectivity, timeliness, believability, security accessibility, ease of operation, and reputation	[24], [39]
Correlation, truth, understanding, maintainability, timeliness, portability, expansibility, security, amount of information, and information cost.	[25]
Relevance, accuracy, completeness, coherence, format, accessibility, compatibility, security, and validity	[33]
Accessibility, accuracy, appropriate amount, believability, completeness, complexity, consistency, ease of operation, objectiveness, relevancy, reputation, security, timeliness, and understandability	[40]
Accuracy, completeness, objectivity, and representation	[41]

research goals. However, some dimensions of information quality can only be qualitatively measured so that the final evaluation results are significantly affected by subjective factors. To evaluate information quality objectively, the dimensions of information quality should be further discussed in the supply chain logistics.

Researchers have proposed many methods to evaluate information quality. Due to the hierarchical structures models of information quality, the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation are often applied to evaluate the information quality [19], [24], [25]. Meanwhile, statistical analysis is also used. For example, reference [39] and [40] use the standard Cronbach alpha to assess the information quality based on data from the questionnaire. Information entropy is an important concept of information theory, reference [42] takes information entropy as a tool to evaluate the information quality. Besides, the mean designates method and grey incidence clustering model are employed to evaluate the marketing information quality based on the questionnaire [43]. Based on in-depth semi-structured interviews, reference [44] applies the cross-case analysis method to explore the determinants of information quality in dyadic supply chain relationships. Based on the content and organizational structure of the data item, reference [45] combines the rough set theory and the objective information six-tuple model to define the data quality evaluation model. In sum, the existing methods can evaluate the specific information quality of research. The results can also apply to improve specific information quality. However, many current methods contain some qualitative evaluation indicators. Moreover, most of the data sources are questionnaires or interviews. Therefore, the final evaluation results are easy to be affected by subjective factors. To evaluate the information quality more objectively and accurately, objective methods should be developed. We can also develop these methods based on the existing approaches.

In addition, some scholars and practitioners have also studied the information quality of the supply chain. However, most researches mainly focus on the relationship between supply chain and information quality. The researches indicate: Information quality is a key point in the quality management of the supply chain and can affect the decision of the supply chain [20], [46]. Moreover, although the supply chain performance and forecast information quality are not necessarily positively correlated [47], and the association of information quality with supply chain performance is fully mediated by information sharing [21], to achieve good performance, supply chain practice should be aligned with their information quality [27]. Furthermore, information quality is influenced negatively by supplier uncertainty, but positively by trust and shared vision in supply chain partners [48]. In sum, information quality plays an important role in supply chain management. Therefore, it is very necessary to study the information quality of the supply chain deeply.

In summary, the current relevant researches yield some useful research results, which play a very positive role in improving information quality. However, some important problems should be further discussed. First, most definitions of information quality are from the 'fitness for use'. They represent the local quality of information and have some limitations on the global quality of information. Therefore, some global definitions should be proposed. Second, some dimensions of the information quality are qualitative. These dimensions are the subjective feeling of the information user. It is very difficult to evaluate the information quality objectively based on these dimensions. Therefore, based on the dynamic changing characteristics of dimensions, to realize the objective evaluation of information quality, the reasonable dimensions of the information quality should be further studied. Third, the current evaluation methods realize the evaluation of the local information quality. However, these methods may not be appropriate for global information quality assessment. Therefore, the evaluation method of global information quality should be developed. Finally, nowadays, competition venues are transforming from enterprises to supply chains. However, the research on the information quality of the supply chain is insufficient. Therefore, more research should be done on the information quality of the supply chain. In this paper, based on the context of JIT being adopted by more and more enterprises, SCLIQ evaluation is studied from the JIT perspective. We propose that the SCLIQ should be combined with JIT philosophy in SCLIQ evaluation. Meanwhile, based on SPC and information entropy method, an objective and comprehensive evaluation method of SCLIQ is presented.

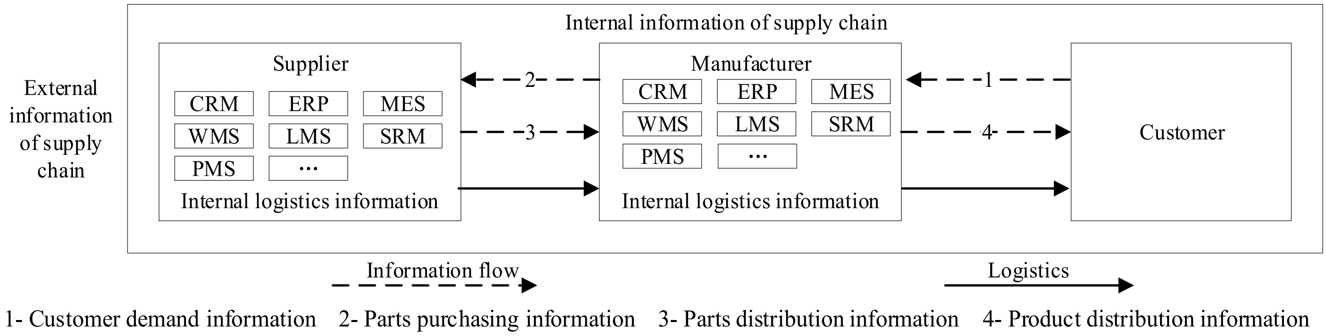

FIGURE 1. Supply chain logistics information process.

The method includes the evaluation of time, quantity, and comprehensive evaluation. The research results will provide a new perspective and an objective and comprehensive method of SCLIQ evaluation.

III. PROBLEM STATEMENT

In this section, the connotation of SCLIQ is analyzed, it is proposed that the SCLIQ evaluation should be combined with the JIT philosophy in the context of JIT being adopted by more and more enterprises, and the problem statement, assumptions, and conditions are presented.

A. CONNOTATION OF SCLIQ

Supply chain logistics may be considered to be an extension of traditional logistics. Logistics activities are the core of the supply chain. Supply chain logistics coordinates production and purchase plans in the supply field, customer service and order processing in the sales field, and inventory control in the financial field. The primary goal of supply chain logistics is to provide satisfactory service to customers, that is, to deliver the right products to the designated place by customers at the right time in the right way. Supply chain logistics activities will produce logistics information from beginning to end. A large amount of accurate, immediate, and comprehensive information is the basis of effective logistics management. Moreover, supply chain logistics management is mainly to strengthen the information exchange and coordination among the entities in the supply chain, to keep the logistics smooth and efficient.

Take a supply chain composed of suppliers, manufacturers, and customers as an example. The logistics information flow of the supply chain is shown in Figure 1. In this process, the relevant information systems include customer relationship management (CRM), enterprise resource planning (ERP), manufacturing execution system (MES), purchasing management system (PMS), warehouse management system (WMS), logistics management system (LMS), supplier relationship management system (SRM), and so on. The information system covers the organizational processes, procedures, and roles employed in collecting, processing, distributing, and using data [19]. Information quality results from the information system are essential attributes of information. and serve for all steps in the process [19]. Therefore, any information quality problem will directly affect the efficiency and effect of supply chain logistics system operation. As a kind of domain information, supply chain logistics information is limited in the content range of information expression, and there is no essential difference between the requirements of information quality and content structure.

According to the traditional definition of information quality, SCLIQ can be defined as the satisfaction of supply chain logistics information users with logistics information received. If the information can meet the user's requirements, the information quality is high, and vice versa. According to this view, SCLIQ should be evaluated from the perspective of a supply chain logistics information node. The results are the local quality of information. However, from the perspective of the whole supply chain, the ultimate goal of the logistics is to deliver the products (or parts) to the customers (or the final consumers) on time. Although SCLIQ plays an important role in the realization of the ultimate goal of supply chain logistics, the high quality of a supply chain logistics information node (the local quality of information) does not guarantee that supply chain logistics can achieve its ultimate goal. The root cause of this phenomenon is that supply chain logistics information contains many elements (or systems) and involves many departments (and enterprises). Just as a part cannot replace the whole, the information quality of a department cannot replace the information quality of the whole supply chain. On the other hand, certainly, SCLIQ can also be defined as the quality of logistic information itself. However, based on the definition, the evaluation results only are the information quality itself, unrelated to the ultimate goal of supply chain logistics. Therefore, it is not scientific to evaluate the quality of logistics information from the perspective of information itself or a single node of the supply chain.

Since the purpose of studying SCLIQ is to ensure the realization of the ultimate goal of supply chain logistics, it is necessary to link information quality with the ultimate goal of supply chain logistics. Therefore, in this paper, we define the SCLIQ as follows. Definition: SCLIQ refers to the degree of the realization of supply chain logistics objectives.

This definition is results-oriented, and it is proposed from the perspective of the whole supply chain logistics. Instead of focusing on local information quality as the traditional definition of the information quality, it focuses on the ultimate objectives and the results of global information quality of the supply chain logistics. If the ultimate objectives are achieved, then the information quality is high.

In a two-echelon supply chain composed of multiple suppliers and a manufacturer, the primary goal of supply chain logistics is to provide satisfactory logistics service for the manufacturer. Therefore, SCLIQ is the satisfaction degree of the manufacturer's logistics demand. In the JIT system, the requisite product (the components or parts) should be distributed from the supplier to the manufacturer at the right time, in the right quantity. So, the SCLIQ should be evaluated from the requisite product, the right time, and the right quantity (JIT perspective).

JIT is a set of principles, tools, and techniques that allows a company to produce and deliver products in small quantities, with short lead times, to meet specific customer needs. In brief, JIT delivers the right items at the right time in the right amounts [49]. On the other hand, suppliers in the supply chain cooperate with manufacturers for a long time, and each supplier supplies fixed materials (or parts) to manufacturers. That is to say, "the right items" can be considered as known elements. Therefore, from the JIT perspective, the evaluation of SCLIQ is transformed into the evaluation of "at the right time in the right amounts" under given conditions.

B. PROBLEM STATEMENT

In this paper, we study a two-echelon supply chain composed of a manufacturer and multiple suppliers. The supply chain is the manufacturer-centered supply chain. Each supplier supplies a certain type of part for a long time. Many manufacturers implement JIT in recent years. Therefore, the suppliers are required to deliver the right items (components or parts) at the right time in the right amounts. In this supply chain, the primary goal of logistics is to provide satisfactory logistics services for the manufacturer. Therefore, the SCLIQ should be evaluated from the JIT perspective. Next, we will mainly study how to evaluate SCLIQ from the JIT perspective objectively and comprehensively.

In this paper, the proposed method of SCLIQ evaluation is based on the following assumptions and conditions:

(1) The manufacturer determines the quantity and time of the materials (components or parts) according to the required quantity and time of the final product.

(2) There is only one supplier for each material.

(3) The suppliers should supply the materials (components or parts) at the right time in the right amounts.

(4) For standard parts (such as bolts and nuts, etc.), batch distribution is often adopted. For non-standard parts with large volume and weight, the small-batch and multi-frequency distribution are often adopted. Due to the different volume, weight, and distribution tools of each material, the delivery times of different materials are different. There is no limit on the delivery quantity and times of the supplier.

(5) The price, delivery method, and transportation distance of the materials are not considered.

(6) The manufacturer can obtain accurate information about the quantity and time of the materials received.

TABLE 2. Notations.

Notation	Meaning
A	Material demand relation matrix of Y
a_{ij}	Material demand relation coefficient, $a_{ij} \in A$
B	Given output B of Y
b_i	Output of product y_i, $b_i \geq 0$ and $b_i \in B$
e_j	Entropy of the jth index
F_i	Required material (part) quantity for y_i
g_j	Different coefficient g_j of x_j
K_j	The required quantity of the jth material for given Y
LIQ_j	The comprehensive evaluation result of the jth index
$N_{T_i^j}$	Binary expression (a process parameter) of T_i^j
P_{ij}	The characteristic proportion of the i th coefficient of the jth index
q_j	The actual amount of the jth material received
rt_i^j	Actual arrival time of the j th delivery of material x_i
st_i^j	Standard arrival time of the jth delivery of material x_i
T_i^j	Material delivery time difference of the jth delivery of material x_i
X	Material set of product Y
x_i	The ith material, $x_i \in X$
Y	Product set
y_i	The ith product, $y_i \in Y$
θ_j	The delivery rate of jth material
ρ_i	The on-time delivery rate of x_i
ω_j	Weight coefficient the jth index

C. NOTATIONS

The main notations and their meaning in this paper are shown in Table 2.

IV. SCLIQ EVALUATION FROM JIT PERSPECTIVE

In this section, the basic methods of the proposed method are briefly described. Then, based on SPC and the information entropy method, the SCLIQ evaluation method from the JIT perspective is presented in detail.

A. BASIC METHODS

1) SPC

In the 1920s, a statistician at the AT&T Bell Laboratories in the USA, Walter Shewhart develops SPC to improve industrial manufacturing [50]. Dr. W Edwards Deming, an engineer from Bell Laboratories popularizes it worldwide after World War II [51]. Since then, SPC plays an important role in product quality improvement and quality supervision [52]. Now, SPC is not only a key tool of quality improvement but also a philosophy, a strategy, and a set of methods for ongoing improvement of systems, processes, and outcomes [50].

The key tool of SPC is the control chart. The chart usually includes a series of measurement plots and three horizontal lines (the center line (typically, the mean), the upper control limit (UCL), and the lower control limit (LCL)) [51], [53]. Reference [52] presents nine typical control charts patterns of the production process. In the traditional application of SPC, the UCL and LCL are usually calculated from the inherent in the data, and most SPC experts recommend control limits set at $\pm 3\sigma$, where σ is the standard deviation of uncorrelated noise in the process [51], [53]. For the normal distribution, whatever the mean and σ are, the probability of the data fall within $\pm 3\sigma$ of the mean is 97.3% if the process is stable and does change [51], [54].

For researchers and practitioners of quality, SPC can help them to distinguish the abnormal fluctuations and the random fluctuation in the process. Then, the quality manager can take specific measures to eliminate abnormalities and maintain the stability of the process. SPC can be utilized to improve the quality of manufacturing processes and service processes [54].

2) INFORMATION ENTROPY

Entropy is originally a thermodynamic concept [55]. In 1948, Shannon, the father of information theory, first proposes the concept of information entropy. In information theory, information quantity measures the information brought about by a specific event, and information entropy is the expectation of the information quantity [56]. Entropy is often used to measure the out-of-order degree of a system [57]. The higher the degree of order of a system, the lower the entropy value is, the larger the information contained; on the contrary, the higher the degree of disorder, the higher the entropy, the smaller the information contained [58]. Information entropy is a useful mechanism and has been used in a variety of applications [57] including the quality evaluation [59], [60].

In the supply chain, logistics information is a generalized system. Information entropy can quantitatively describe its static and dynamic characteristics, reflect the degree of disorder, complexity, or dispersion from a certain index of the information process. Moreover, by analyzing the degree of uncertainty of information, it can measure the information quality problem caused by various factors to the information process.

The supply chain logistics information process is a service process while all the logistics information of the supply chain can be regarded as a generalized system. Therefore, we employ SPC and information entropy method to distinguish the abnormalities and evaluate SCLIQ in this paper.

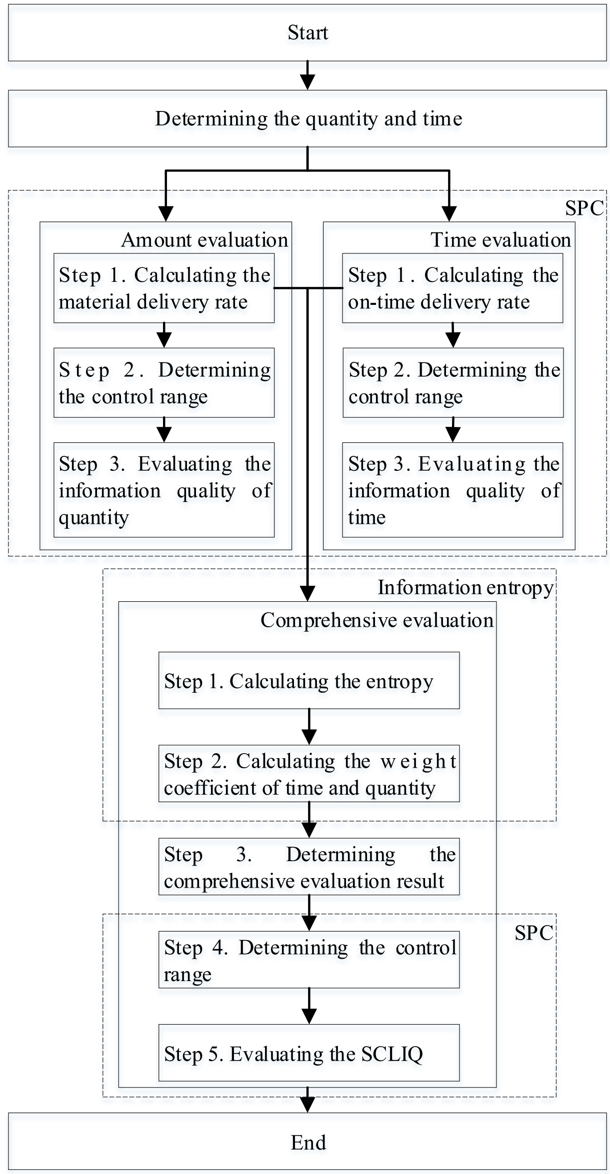

FIGURE 2. Flow chart of the proposed method.

B. PROPOSED METHOD

As mentioned above, from the JIT perspective, SCLIQ can be evaluated from "at the right time in the right amounts" when "the right items" are determined. In this paper, based on SPC and the information entropy method, we propose a novel method to evaluate SCLIQ from the JIT perspective. The flow chart of the proposed method is shown in Figure 2.

C. DETERMINING THE QUANTITY AND TIME

1) QUANTITY OF MATERIAL REQUIRED

The manufacturer's product is Y, and the material of the product Y is X. According to the bill of materials (BOM) of

Y, the relationship between Y and X is:

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = AX \quad (1)$$

where A is the material demand matrix of Y, which is different for the various enterprise. $a_{ij} \in A$ and $a_{ij} \geq 0$. When $a_{ij} = 0$, the product y_i does not need to use material x_j. When $a_{ij} > 0$, the product y_i contains a_{ij} material x_j.

Therefore, corresponding to each product y_i, the required material (part) quantity F_i is:

$$F_i = (y_i,\ a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n) \quad (2)$$

For a given output B of Y ($b_i \geq 0$ and $b_i \in B$), the required quantity of material K_j is:

$$K_j = \left(a_{1j}b_1 + a_{2j}b_2 + \ldots + a_{nj}b_n\right) \quad (3)$$

The material requirement matrix of product Y can be expressed as:

$$F = [F_1 F_2 \ldots F_{\mathrm{m}}]^{\mathrm{T}} = [Y\ AX] \quad (4)$$

2) TIME OF MATERIAL REQUIRED

According to the production sequence plan and the manufacturing process of products, the manufacturer can determine the time required for each material (theoretical arrival time, also known as standard arrival time). Then, the supplier is required to deliver each material to the designated place on time in a JIT system.

3) OBTAINING THE ACTUAL QUANTITY AND TIME

The logistics information includes the actual quantity of each material received and the actual arrival time of each batch material. In modern logistics systems, data can be obtained from the information system related to logistics (such as WMS).

D. AMOUNT EVALUATION

Step 1. Calculating the material delivery rate

Based on (3), if the output of Y is known, the theoretical requirement amount of each material can be determined. Let $[K_1 K_2 \cdots K_m]$ ($K_j \geq 0$) be the theoretical requirement amount of each material, and $[q_1 q_2 \cdots q_m]$ ($q_j \geq 0$) be the actual amount of each material received. Then, the ratio between the theoretical requirement amount and the actual amount of each material received is $\theta_j = K_j / q_j$. Therefore, the ratio matrix θ can be obtained:

$$\theta = [\theta_1\ \theta_2\ \cdots\ \theta_m] \quad (5)$$

Ideally, $\theta_j \equiv 1$, therefore, θ is a row vector and each vector value is 1. However, in the actual manufacturing process, various random factors (such as waste products, losses, etc.) may lead to the quantity deviation of received materials. To ensure normal production, the demand relationship matrix A will be appropriately modified to eliminate the impact of waste products and losses. Besides, the quantity of materials delivered each time cannot always be equal to the quantity required. That is to say, in a certain period, the quantity of materials delivered fluctuates randomly. Therefore, the distribution of value θ_j will be randomly distributed within a certain control range.

Step 2. Determining the control range

According to SPC, when the process is under control, the product quality characteristic value will follow a certain normal distribution $N(\mu\sigma^2)$. At this point, the probability of the quality eigenvalue within $\mu\pm3\sigma$ range is 99.73%, while the probability of falling outside the range is 0.27%, almost negligible. In this paper, there is only one supplier for each material, so the supply of each material is independent. Therefore, the distribution of θ should follow a definite normal distribution $N(\mu\sigma^2)$. Moreover, in manufacturing enterprises, the supply of materials should be controlled. So, $\mu\pm3\sigma$ can be used as the control interval for θ, namely:

$$\begin{cases} Center\ line: CL = \mu \\ Upper\ control\ line: UCL = \mu + 3\sigma \\ Low\ control\ line: LCL = \mu - 3\sigma \end{cases} \quad (6)$$

Meanwhile, in the evaluation of SCLIQ, the mean $\bar{\theta}$ and standard variance σ_θ of θ can be obtained:

$$\begin{cases} \bar{\theta} = \dfrac{\sum_{j=0}^{m} \theta_j}{m} \\ \sigma_\theta = \sqrt{\dfrac{\sum_{j=0}^{m} \left(\theta_j - \theta\right)^2}{m}} \end{cases} \quad (7)$$

According to (6) and (7), the UCL, CL, and LCL of θ can be calculated. Then, the control chart of θ can be got.

Step 3. Evaluating the information quality of quantity

According to SPC, for a specific θ_j, if θ_j is within this control range, it means that the actual quantity of material received is the same as the theoretical requirement quantity of material. The supply chain logistics information is true, accurate, and complete. Therefore, the amount aspect of SCLIQ is good. On the contrary, if θ_j exceeds this control range, it indicates that there are information quality problems (such as false, inaccurate, and incomplete information) in the process of supply chain logistics information. Therefore, the amount aspect of SCLIQ is poor. The confidence probability of θ_j in $\mu\pm3\sigma$ for dynamic information quality evaluation is 99%. Therefore, the accuracy and authenticity of supply chain logistics information can be objectively evaluated.

E. TIME EVALUATION

Step 1. Calculating the on-time delivery rate

The delivery time difference of the jth delivery of material x_i is:

$$T_i^j = rt_i^j - st_i^j \quad (8)$$

where rt_i^j represents the actual arrival time of the jth delivery of material x_i, and st_i^j represents the standard arrival time of the jth delivery of material x_i. $T_i^j > 0$ means that the actual arrival time is later than the standard arrival time. Let:

$$N_{T_i^j} = \begin{cases} 1, & T_i^j \leq 0 \\ 0, & T_i^j > 0 \end{cases} \tag{9}$$

where $N_{T_i^j}$ is the binary expression (a process parameter) of T_i^j. Then, the on-time delivery rate of certain material x_i in a certain period is:

$$\rho_i = \frac{\sum_{j=1}^{n} N_{T_i^j}}{n} \tag{10}$$

The on-time delivery rate matrix ρ can be obtained:

$$\rho = \left[\rho_1, \rho_2, \cdots, \rho_n \right] \tag{11}$$

From the JIT perspective, either early or late delivery would have a negative impact on the supply chain. Therefore, ideally, $\rho_i \equiv 1$. At this point, ρ is a row vector and each vector value is 1. However, in the actual manufacturing process, various random factors (such as information input lag, transmission delay, information processing untimely, etc.) may lead to the delay of delivery. Therefore, the distribution of value ρ_j will be randomly distributed within a certain control range.

Step 2. Determining the control range

As mentioned above, according to SPC, the control range of ρ_i can be obtained according to (6). Similar to $\bar{\theta}$ and σ_θ, in the evaluation of SCLIQ, the mean $\bar{\rho}$ and standard deviation σ_ρ of ρ can be calculated:

$$\begin{cases} \bar{\rho} = \dfrac{\sum_{i=1}^{n} \rho_i}{n} \\ \sigma_\rho = \sqrt{\dfrac{\sum_{i=1}^{n} (\rho_i - \bar{\rho})^2}{n}} \end{cases} \tag{12}$$

According to (6) and (12), the UCL, CL, and LCL of ρ can be calculated. Then, the control chart of ρ can be got.

Step 3. Determining the information quality of time

According to SPC, similar to the amount evaluation, for a specific ρ_i, if ρ_i is within this control range, the supply chain logistics information is on time. Therefore, the time aspect of SCLIQ is good. On the contrary, if ρ_i exceeds this control range, it indicates that there are abnormalities (such as decision delay, delivery delay, etc.) in the process of supply chain logistics information. The time aspect of SCLIQ is poor. Therefore, the timeliness of logistics information transmission in the supply chain can be objectively evaluated.

F. COMPREHENSIVE EVALUATION

Step 1. Calculating the entropy

The idea of entropy, of which Shannon entropy is accepted by most people, is an important concept to the probability distribution on the space $X = \left[x_1, x_2, \cdots, x_i \right]$. Then, the Shannon entropy is [23], [59]:

$$H(P) = -\sum_{i=1}^{n} P_i ln P_i \tag{13}$$

where P_i represents the probability of ith element in the vector.

According to (13), the characteristic proportion P_{ij} of the ith coefficient of the jth index is calculated:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{14}$$

where x_{ij} represents the measured value of the ith information expression form on the jth index. Then, the entropy e_j of the jth index:

$$e_j = -k \sum_{i=1}^{n} P_{ij} ln P_{ij} \tag{15}$$

To $0 \leq e_j \leq 1$, in (15), the coefficient k should be calculated according to (16). When x_{ij} is all equal, $P_{ij} = 1/n$, and at this time, $e_j = e_{max} = 1$.

$$k = \frac{1}{lnn} \tag{16}$$

Step 2. Calculating the weight coefficient of time and quantity

When the difference of x_{ij} is smaller, e_j is larger. When e_j is equal to e_{max}, x_j is meaningless for the comparison between systems. Meanwhile, when the difference of x_{ij} is larger, e_j is smaller, and the index will play a more important role. Therefore, the different coefficient g_j of x_j can be calculated according to (17), and when g_i is larger, the more attention should be paid to the index.

$$g_i = 1 - e_j \tag{17}$$

The weight coefficient ω_j of the jth index is:

$$\omega_j = \frac{g_j}{\sum_{i=1}^{m} g_i} \tag{18}$$

where $j = 1, 2, \ldots, m$.

Step 3. Determining the comprehensive evaluation result

The comprehensive evaluation result LIQ_j of the jth index is:

$$LIQ_j = \omega_j \theta_j + \left(1 - \omega_j\right) \rho_j \tag{19}$$

Step 4. Determining the control range

Similar to $\bar{\theta}$ and σ_θ, in the evaluation of SCLIQ, the mean $\overline{LIQ}$ and standard deviation σ_{LIQ} of LIQ can be obtained:

$$\begin{cases} \overline{LIQ} = \dfrac{\sum_{i=1}^{n} LIQ_i}{n} \\ \sigma_{LIQ} = \sqrt{\dfrac{\sum_{i=1}^{n} \left(LIQ_i - \overline{LIQ}\right)^2}{n}} \end{cases} \tag{20}$$

As mentioned above, the UCL, CL, and LCL of LIQ can be obtained according to (6) and (20). Then, the control chart of LIQ can be drawn.

Step 5. Evaluating the SCLIQ

According to SPC, similar to the amount and time evaluation, for a specific LIQ_j, if it is within this control range, it means that the SCLIQ meets the JIT requirement of the manufacturer. Therefore, SCLIQ is good. On the contrary, if LIQ_j exceeds this control range, it indicates that there

TABLE 3. Products and materials relationship.

Product	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
y_1	1	0	0	4	1	1	0	0	10	6	0	2	2	13
y_2	1	0	0	4	1	1	0	0	10	6	0	2	2	17
y_3	1	0	0	4	1	1	0	0	10	10	0	4	2	17
y_4	1	0	0	4	1	0	0	0	10	10	0	4	2	17
y_5	1	0	0	4	1	0	0	0	10	10	0	4	8	17
y_6	1	0	0	6	2	1	1	4	22	4	8	8	8	28
y_7	1	0	0	6	2	1	0	4	20	4	8	0	8	28
y_8	1	1	0	4	1	1	0	0	10	6	0	2	2	17
y_9	1	1	0	4	1	0	0	0	10	6	0	2	2	17
y_{10}	1	1	0	4	1	1	0	0	10	6	0	4	2	17
y_{11}	1	1	0	4	1	1	0	0	10	6	0	4	2	17
y_{12}	1	1	0	4	1	1	1	0	10	6	0	8	2	17
y_{13}	1	1	0	6	2	0	0	4	20	4	8	0	8	28
y_{14}	1	1	0	6	2	1	0	4	20	4	8	0	8	28
y_{15}	1	1	1	8	2	0	0	4	20	4	8	6	8	28
y_{16}	1	1	1	8	2	1	1	4	24	4	8	8	8	28
y_{17}	1	1	0	4	1	0	0	4	10	10	0	2	2	17

are abnormalities in the process of supply chain logistics information. Therefore, SCLIQ is poor. The SCLIQ can be objectively evaluated from the JIT perspective.

V. NUMERICAL EXAMPLES

In this section, we take a manufacturing supply chain as a numerical example. The proposed method is applied to evaluate the logistics information quality of the manufacturing supply chain. The results show that the proposed method can evaluate the SCLIQ from the JIT perspective.

The manufacturing supply chain includes a core manufacturer and multiple suppliers. The supply chain is a manufacturer-centered two-echelon supply chain. The core manufacturer is a mechanical assembly manufacturing company. All products of the manufacturer are assembled on the assembly line. The manufacturer cooperates with all suppliers for a long time. The logistics informatization foundation of the supply chain is better. In recent years, the manufacturer implements JIT. As the core of the supply chain, the manufacturer requires all suppliers to deliver various materials based on JIT supply. To monitor and improve the supply chain logistics information according to JIT requirements, it is necessary to evaluate SCLIQ from the JIT perspective. The information systems of the manufacturer include CRM, ERP, MES, PMS, WMS, LMS, SRM, etc. The data of quantity and time can be got from the information systems. In this paper, we collect the relevant data through the investigation of the manufacturers.

A. DETERMINING QUANTITY AND TIME

Because the calculation process of time data is relatively simple, only the calculation process of material quantity related data is given here.

1) QUANTITY OF MATERIAL REQUIRED

The relationship between some products and materials is shown in Table 3.

Then the corresponding material demand transformation matrix A is:

$$A = \begin{bmatrix}
1 & 0 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 6 & 0 & 2 & 2 & 13 \\
1 & 0 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 6 & 0 & 2 & 2 & 17 \\
1 & 0 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 10 & 0 & 4 & 2 & 17 \\
1 & 0 & 0 & 4 & 1 & 0 & 0 & 0 & 10 & 10 & 0 & 4 & 2 & 17 \\
1 & 0 & 0 & 4 & 1 & 0 & 0 & 0 & 10 & 10 & 0 & 4 & 8 & 17 \\
1 & 0 & 0 & 6 & 2 & 1 & 1 & 4 & 22 & 4 & 8 & 8 & 8 & 28 \\
1 & 0 & 0 & 6 & 2 & 1 & 0 & 4 & 20 & 4 & 8 & 0 & 8 & 28 \\
1 & 1 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 6 & 0 & 2 & 2 & 17 \\
1 & 1 & 0 & 4 & 1 & 0 & 0 & 0 & 10 & 6 & 0 & 2 & 2 & 17 \\
1 & 1 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 6 & 0 & 4 & 2 & 17 \\
1 & 1 & 0 & 4 & 1 & 1 & 0 & 0 & 10 & 6 & 0 & 4 & 2 & 17 \\
1 & 1 & 0 & 4 & 1 & 1 & 1 & 0 & 10 & 6 & 0 & 8 & 2 & 17 \\
1 & 1 & 0 & 6 & 2 & 0 & 0 & 4 & 20 & 4 & 8 & 0 & 8 & 28 \\
1 & 1 & 0 & 6 & 2 & 0 & 0 & 4 & 20 & 4 & 8 & 0 & 8 & 28 \\
1 & 1 & 1 & 8 & 2 & 0 & 0 & 4 & 20 & 4 & 8 & 6 & 8 & 28 \\
1 & 1 & 1 & 8 & 2 & 1 & 1 & 4 & 24 & 4 & 8 & 8 & 8 & 28 \\
1 & 1 & 0 & 4 & 1 & 0 & 0 & 4 & 10 & 10 & 0 & 2 & 2 & 17
\end{bmatrix}$$

The actual product output of the manufacturer from October to December is shown in Table 4.

The theoretical requirement quantity of materials can be obtained through calculation, as shown in Table 5.

2) TIME OF MATERIAL REQUIRED

According to the orders (or product plan) of the manufacturer, the time of the material required can be calculated by ERP. Then, the suppliers are required to deliver each material to the designated place on time.

TABLE 4. Actual product output.

Product	October	November	December
y_1	0	5	0
y_2	10	3	16
y_3	12	14	0
y_4	17	0	24
y_5	6	9	17
y_6	19	6	107
y_7	31	18	45
y_8	9	9	10
y_9	43	46	148
y_{10}	380	0	0
y_{11}	78	0	0
y_{12}	17	53	131
y_{13}	11	64	71
y_{14}	0	0	202
y_{15}	9	19	0
y_{16}	45	117	23
y_{17}	90	82	76
Total	777	445	870

TABLE 5. Theoretical requirement quantity.

Material	October	November	December
x_1	777	445	870
x_2	682	390	661
x_3	54	136	23
x_4	3650	2603	4628
x_5	1000	735	1831
x_6	690	264	618
x_7	85	215	270
x_8	900	2251	2245
x_9	9600	7200	14300
x_{10}	5100	2860	5200
x_{11}	1200	1850	3850
x_{12}	3018	2106	2900
x_{13}	2600	2400	4650
x_{14}	18000	11800	21200

3) OBTAINING THE ACTUAL QUANTITY AND TIME

In the manufacturer, all the materials will be delivered to the assembly line after the warehousing procedure. Therefore, the data of the actual quantity and time can be obtained from the WMS of the manufacturer.

The actual quantity of material received by the manufacturer is shown in Table 6.

TABLE 6. The actual quantity of material received.

Material	October	November	December
x_1	777	445	870
x_2	682	390	661
x_3	54	136	23
x_4	3600	2603	4628
x_5	1000	735	1831
x_6	660	264	618
x_7	85	215	270
x_8	900	2251	2245
x_9	9300	7200	14300
x_{10}	5000	2860	5200
x_{11}	1000	1850	3750
x_{12}	3018	2106	2900
x_{13}	2600	2400	4650
x_{14}	18000	11800	21200

B. AMOUNT EVALUATION

Step 1. Calculating the ratio of material quantity

According to $\theta_j = K_j / q_j$, the matrix θ is obtained as shown in Table 7.

Step 2. Determining the control range

According to (6), the control range of θ from October to December should be: (0.82, 1.36), (0.5, 1.76), (0.78, 1.38). Taking into account the company's implementation of JIT, to ensure output, the quantity of actual arrival material must be equal to the theoretical demand, namely, $\theta = 1$. However, in the actual production process, to guarantee the supply, the supplier often provides materials more than the theoretical demand quantity. Therefore, $\theta \geq 1$. The revised control range of θ from October to December should be changed as shown in Table 8.

Take the quantity of materials in November as an example, the logistics information quality control chart is shown in Figure 3.

Step 3. Evaluating the information quality of quantity

According to SPC, θ should be near the center limit and randomly distributed on both sides of the center line. However, in Figure 3, most of them are located between the center line and the lowest line, or even close to (or equal to) the lowest line. The reason is that enterprises implement JIT, the actual amount of material received should be equal to the theoretical demand. Nevertheless, due to the delivery batch, cost, and other reasons, suppliers may still distribute more materials (within a certain range). Therefore, the supply of material x_1, x_2, x_3, and x_9 meet the requirements of JIT. And the supply of other materials (except x_8) is normal. However, for material x_8, the ratio between the actual material quantity received and the theoretical demand material quantity is 1.84, and 0.08 more than the upper control limit of 1.76. If the information problem of the material conversion relationship between the material and corresponding products (i.e. y_6, y_7, y_{13}, y_{14}, y_{15}, y_{16} and y_{17}) is excluded, then the supply chain logistics information of material x_8 has an information quality problem of quantity aspect.

In summary, in terms of quantity, the supply of material x_1, x_2, x_3, and x_9 completely meet the requirements, and their SCLIQ is high. Meanwhile, if the influence of distribution volume, cost, and other factors is considered, the supply of other materials (except x_8) can also be accepted, and their SCLIQ is acceptable. However, the supply of material x_8 cannot be accepted if the material conversion relationship between the material and corresponding product is excluded, and its SCLIQ is unacceptable. Therefore, the supply chain

TABLE 7. θ of October to December.

Month	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	μ	σ
10	1.00	1.00	1.00	1.06	1.12	1.15	1.05	1.10	1.05	1.03	1.30	1.01	1.14	1.24	1.09	0.09
11	1.00	1.00	1.00	1.04	1.10	1.17	1.22	1.84	1.00	1.08	1.03	1.11	1.05	1.18	1.13	0.21
12	1.00	1.00	1.00	1.05	1.39	1.16	1.03	1.07	1.06	1.09	1.07	1.05	1.03	1.08	1.08	0.10

TABLE 8. Control range of the quantity of materials.

Month	μ	σ	3σ	$CL=\mu$	$UCL=\mu+3\sigma$	$LCL=\mu-3\sigma$
10	1.09	0.09	0.27	1.09	1.36	1.00
11	1.13	0.21	0.63	1.13	1.76	1.00
12	1.08	0.10	0.30	1.08	1.38	1.00

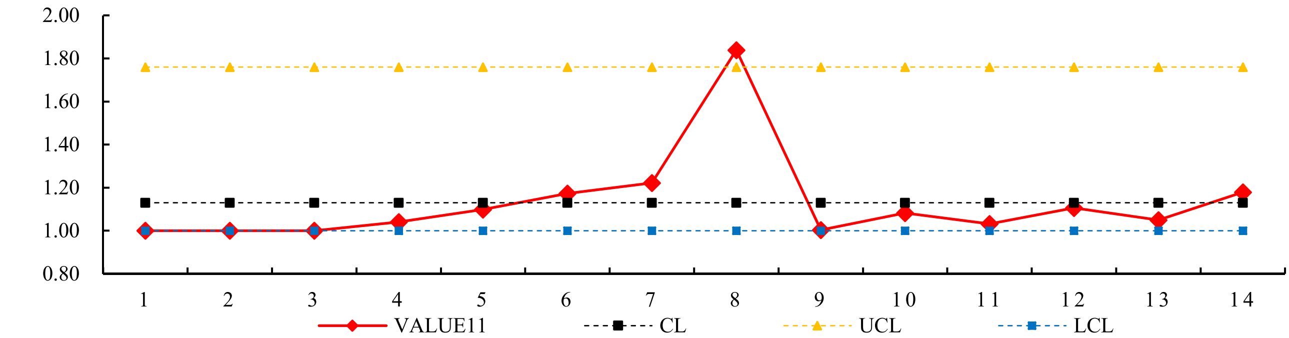

FIGURE 3. Logistics information quality control (Quantity).

TABLE 9. The on-time delivery rate of materials.

Month	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	μ	σ
10	0.974	0.979	0.963	0.973	0.950	0.870	0.894	0.833	0.875	0.569	1.000	0.968	0.923	0.906	0.905	0.109
11	0.955	0.944	0.956	0.889	0.946	0.815	0.944	0.826	0.903	0.759	0.789	0.864	0.833	0.907	0.881	0.067
12	0.968	0.977	1.000	0.936	0.789	0.903	0.870	0.870	0.916	0.923	0.769	0.724	0.851	0.934	0.888	0.081

TABLE 10. Control range of the on-time delivery rate of materials.

Month	μ	σ	3σ	CL	UCL	LCL
10	0.905	0.109	0.327	0.905	1.00	0.578
11	0.881	0.067	0.201	0.881	1.00	0.680
12	0.888	0.081	0.243	0.888	1.00	0.645

of material x_8 should pay more attention to the quality of logistics information. The results are helpful to determine the direction of the problem and take corresponding measures for meeting the requirements of JIT supply.

C. TIME EVALUATION

Step 1. Calculating the on-time delivery rate

According to the production sequence plan of a company from October to December, the standard time and the distribution times of 14 kinds of materials can be obtained, and the actual time of delivery can be measured. According to (8) - (10), the on-time delivery rate of materials is shown in Table 9.

Step 2. Determining the control range

According to (12), the mean and standard variance of ρ can be calculated. Due to JIT implementation, all suppliers are required to distribute materials on time (namely, $\rho_j \equiv 1$), therefore, $UCL = 1$. This is a maximum and an ideal value. Therefore, the revised control range can be obtained according to (6) and shown in Table 10. According to Table 10, the control chart of ρ can be drawn as shown in Figure 4.

Step 3. Determining the information quality of time

In Figure 4, $\bar{\rho} = 0.905$. According to SPC, ρ_j should be near 0.905 and randomly distributed on both sides of the center line. Meanwhile, according to JIT, $\rho_j \equiv 1$. Therefore, for material x_{11}, the on-time delivery rate is 1.000, which is equal to the upper control limit of 1.00 and meets the requirements of JIT. The supply of other materials (except x_{10}) is normal. However, for material x_{10}, the on-time delivery rate is 0.569, and 0.09 lower than the low control limit of 0.578. If the information problems of the production sequence plan and the manufacturing process of products are excluded, then the supply chain logistics information of material x_{10} have information quality problems of time aspect.

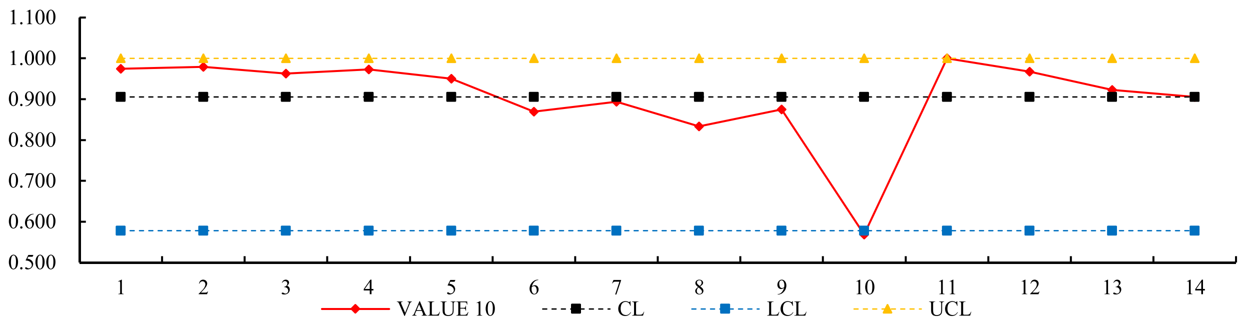

FIGURE 4. Logistics information quality control (Time).

TABLE 11. Comprehensive evaluation result.

Material	Quantity			Time			Comprehensive result
	θ	P_{ij}	$-P_{ij}lnP_{ij}$	ρ	P_{ij}	$-P_{ij}lnP_{ij}$	
x_1	1	0.0656	0.1787	0.974	0.0768	0.1971	0.9820
x_2	1	0.0656	0.1787	0.979	0.0772	0.1977	0.9855
x_3	1	0.0656	0.1787	0.963	0.076	0.1959	0.9745
x_4	1.06	0.0695	0.1853	0.973	0.0768	0.1971	0.9999
x_5	1.12	0.0734	0.1917	0.95	0.0749	0.1941	1.0026
x_6	1.15	0.0754	0.1949	0.87	0.0686	0.1838	0.9567
x_7	1.05	0.0689	0.1843	0.894	0.0705	0.187	0.9423
x_8	1.1	0.0721	0.1896	0.833	0.0657	0.1789	0.9156
x_9	1.05	0.0689	0.1843	0.875	0.069	0.1845	0.9292
x_{10}	1.03	0.0675	0.182	0.569	0.0449	0.1393	0.7117
x_{11}	1.3	0.0852	0.2098	1	0.0789	0.2004	1.0929
x_{12}	1.01	0.0662	0.1797	0.968	0.0764	0.1965	0.9810
x_{13}	1.14	0.0748	0.194	0.923	0.0728	0.1907	0.9902
x_{14}	1.24	0.0813	0.204	0.906	0.0715	0.1886	1.0094
Total	15.25	1	2.6357	12.677	1	2.6316	

In summary, in terms of time, the supply of material x_{11} completely meet the requirements, and its SCLIQ is high. Meanwhile, if the influence of various random factors is considered in the actual manufacturing process, the supply of other materials (except x_{10}) can also be accepted, and their SCLIQ is acceptable. However, the supply of material x_{10} cannot be accepted if the information problems of the production sequence plan and the manufacturing process of products are excluded, and its SCLIQ is unacceptable. Therefore, the supply chain of material x_{10} should pay more attention to the quality of logistics information, especially in terms of time.

D. COMPREHENSIVE EVALUATION

Step 1. Calculating the entropy

Take the data of materials in October as an example. According to (14), the calculation results of amount and time are shown in Table 11. According to (16), when $n = 14$, $k = 0.3789$. Therefore, according to (15), the entropy of time and quantity can be obtained as follows:

$$\begin{cases} e_Q = -0.3789 \times 2.6357 = 0.9987 \\ e_T = -0.3789 \times 2.6316 = 0.9972 \end{cases} \tag{21}$$

According to (17), the different coefficient of time and quantity can be calculated as follows:

$$\begin{cases} g_Q = 1 - e_Q = 1 - 0.9987 = 0.0013 \\ g_T = 1 - e_T = 1 - 0.9972 = 0.0028 \end{cases} \tag{22}$$

Step 2. Calculating the weight coefficient of time and quantity

According to (18), the weights of time and quantity can be calculated as follows:

$$\begin{cases} w_Q = \dfrac{0.0013}{0.0013 + 0.0028} = 0.3095 \\ w_T = \dfrac{0.0028}{0.0013 + 0.0028} = 0.6905 \end{cases} \tag{23}$$

From the result of weights, the weight of time is greater than the weight of quantity. Therefore, when controlling information quality, we should pay attention to the quality of time information.

Step 3. Determining the comprehensive evaluation result

According to (19), the comprehensive evaluation result is shown in Table 11.

Step 4. Determining the control range

According to (20), the mean and standard variance of *LIQ* can be calculated as follows:

$$\begin{cases} \overline{LIQ} = 0.9624 \\ \sigma_{LIQ} = 0.0806 \end{cases} \tag{24}$$

TABLE 12. Control range of *LIQ*.

Month	μ	σ	3σ	CL	UCL	LCL
10	0.9624	0.0806	0.2418	0.9624	1.2042	0.7206

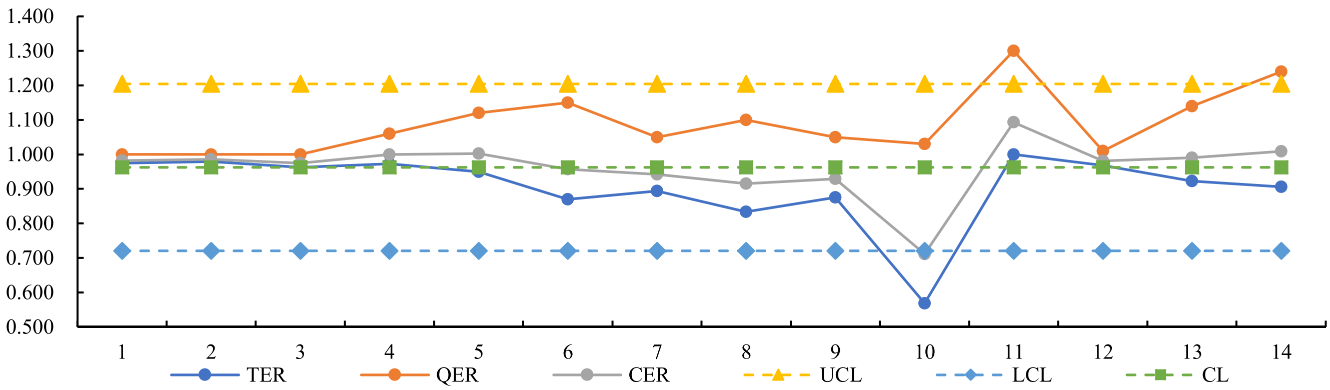

FIGURE 5. Comparison figure.

According to (6), the control range of LIQ can be obtained in October and shown in Table 12. The comparison of comprehensive evaluation results (CER), UCL and LCL of CER, time evaluation results (TER), and quantity evaluation results (QER) in October are shown in Figure 5. Similar to the comprehensive evaluation process of October, the comprehensive evaluation results for November and December are also available.

Step 5. Evaluating the SCLIQ

In Figure 5. $\overline{LIQ}$= 0.9624. From the comprehensive evaluation results, the distribution of most materials can meet their corresponding requirements, so SCLIQ of most materials is in a normal state. However, for material x_{10}, the comprehensive evaluation result is 0.7117, which is close to the low control line and just 0.0009 more than the low control limit of 0.7206. At the same time, for material x_{11}, the comprehensive evaluation result is 1.0929, which is just 0.0113 below the upper control limit of 1.2042. Therefore, the supply chain logistics information of material x_{10} and x_{11} have a quality problem. Meanwhile, SCLIQ of x_{10} has relatively serious problems. Therefore, in future supply chain logistics cooperation, more attention should be paid to the quality of information related to x_{10} and x_{11}, especially x_{10}.

By comparing the data of October, it is not difficult to find that although the supply of most materials meets the requirements, the information quality of material quantity and time still exists. Especially when the quantity and time information quality change in the opposite direction, even if the change is large, the comprehensive evaluation results may still be within the control range, such as x_{13} and x_{14}. Meanwhile, the influence of time information quality on the comprehensive results is greater than that of quantity information quality. That is to say, the information quality problem in the time aspect tends to cause more serious problems. For example, the major reason that the low comprehensive evaluation of material x_{10} is that the supply of material x_{10} is not on time. The second reason is the quantity of material x_{10} is not accurate enough. Furthermore, When the quantity and time information quality change in the same direction, the change of them will be superimposed and the change of the comprehensive evaluation result will be intensified, such as x_{11}. Therefore, the enterprises of the supply chain should regularly evaluate the quality of logistics information in the supply chain and take targeted measures to solve the problems found, to ensure the JIT supply of materials.

The results of the numerical example verify the feasibility of the proposed method. Compared with current approaches, the proposed method is based on "the right time" and "the right amount" from the JIT perspective. Meanwhile, in the process of evaluation, no subjective factors are involved, so the results are objective. Moreover, Not only the time and quantity evaluation results are given, but also the comprehensive evaluation results are given. This is useful for the manufacturer to make the right conclusion and determining the best direction of improvement activities. It helps improve SCLIQ. However, the proposed method is result-oriented and does not pay enough attention to the information quality of each node in the process. It is not conducive to discovering the specific causes of quality problems. Besides, although the proposed method can be applied to evaluate the SCLIQ, we also need to explore whether this method is suitable for the assessment of information quality in other fields.

VI. CONCLUSION

SCLIQ plays an important role in improving logistics efficiency, reducing logistics costs, and improving logistics service level. In the context of JIT being adopted by more and more enterprises, we proposed that the SCLIQ evaluation should be combined with JIT philosophy. Based on "right items" known elements, the evaluation of SCLIQ was transformed into the evaluation of "at the right time in the right amounts". Then, based on the SPC and information entropy method, a novel evaluation method of SCLIQ was presented. SPC was applied to evaluate the information quality of the time and quantity aspects. The information entropy method was employed to determine the weight of time and quantity, respectively. The comprehensive evaluation results of the time and quantity were determined. According to SPC, the comprehensive evaluation results of SCLIQ could be determined. Finally, we presented a numerical example to demonstrate the feasibility of the proposed method. The combination of SQLIQ and JIT philosophy was the main contribution of this paper including, while we proposed a novel evaluation method of SCLIQ based on SPC and information entropy method. The results not only provided a new perspective for SCLIQ evaluation but also presented a feasible novel method for the scientific and objective evaluation of SCLIQ.

Although some research results have been obtained in this paper, there are still some shortcomings: (1) The proposed method assumes that a supplier supplies only one material and does not consider the coordinated distribution of materials. (2) Time and quantity are considered as two important parameters without considering the influence of other factors. (3) It is a common thing for enterprises to stop work and wait for materials, but this paper does not consider the impact of material delivery time on the production system. (5) Although the objective evaluation results and the direction of improvement of SCLIQ are given, and the research objectives of this paper can be realized, no specific methods for improving SCLIQ are given. In addition, in the supplier-centered supply chain, the minimum delivery quantity of the supplier may often be more than the required quantity of manufacturers in practice. SCLIQ, in this case, isn't studied in the paper.

There are several directions for our future research. First, it may be an interesting direction to combine the information quality of a single node with the information quality of the supply chain logistics system to evaluate SCLIQ. Second, we can consider modifying and improving the method by adding more influencing factors (such as cost, logistics coordination, etc.). Third, how to combine the evaluation results with the specific indicators of information quality can determine the specific direction of information quality improvement according to the evaluation results. Finally, we can study SCLIQ from other perspectives.

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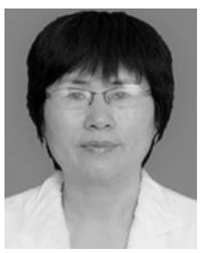

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