Fuzzy Evaluation on Supply Chains' Overall Performance Based on AHM and M(1,2,3)

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***Abstract*—To effectively measure supply chain performance is one of the most important aspects for supply chain management, which can help decision makers analyze the historical performance and current status, and can help them set future performance targets. We firstly base on the Supply Chain Operations Reference-model (SCOR-model) to construct an index system for evaluating the supply chains' overall performance, and then use Analytic Hierarchical Model (AHM) to determine the weight of every index in the system. In order to effectively evaluate the supply chains' overall performance, we define the distinguishable weight to eliminate the redundant index data and extract valid values to compute object membership. Lastly, we use an example to illustrate the effectiveness of the proposed approach, whose results show that the combined model could effectively evaluate supply chains' overall performance and identify improvement aspects.**

***Index Terms*—supply chains, overall performance, fuzzy evaluation, analytic hierarchical model, M(1,2,3) model**

I. Introduction

Today's fierce market conditions drive the enterprise to effectively assess the overall performance of the supply chain, and to determine the aspects that need improvement in order to gain a competitive advantage. In recent decades, enterprises have been improving their internal performances by using practices such as JIT, Kanban, Kaizen, and TQM. Meanwhile new methods in Supply Chain Management have forced enterprises to enhance not only their internal performances but also their supply chain performance. Many companies have not been successful to maximize the potential of their supply chain, because they often fail to develop the performance metrics needed to fully integrate their supply chain [1]. Lee and Billington [2] observed that the discrete sites in a supply chain do not maximize efficiency if each pursues goals independently. In recent years, more and more researchers and practitioners pay much attention to supply chain performance measurement.

In order to assess the supply chain performance, many scholars have, from different perspectives, proposed corresponding evaluation index systems which can be generally classified into three kinds: the evaluation index system based on Supply Chain Operations Reference model (SCOR-model), the evaluation system based on Supply Chain Balanced Scorecard and ROF (Resources, Output, Flexibility) system proposed by Beamon [3]. Of the three evaluation systems, SCOR-model is the most influential and most widespread applied which can measure and improve enterprises' internal and external business processes, making the implementation of Strategic Enterprise Management (SEM) possible [4].

Bullinger et al [5], according to the SCOR framework, carried out a "bottom-up" performance evaluation of supply chains. Kee-hung Lai et al [6], based on the SCOR-model and various established measures, proposed a measurement model and a measurement instrument for supply chain performance in transporttion logistics. Robert S. Kaplan et al [7] proposed the Balanced Scorecard (BSC) evaluation system. BSC is not only an evaluation system but also a manifestation of management thinking. Since the BSC was proposed, with its simplicity and easy-to-operate advantage, it has been recognized in a wide range. Kleijnen J.P.C et al [8] and Ma Shi-hua [9] applied the basic principles of BSC in supply chain performance evaluation, and established a supply chain balanced scorecard evaluation system according to the characteristics of supply chains. Beamon [3], starting with the strategic objectives of supply chains, determined a few key factors influencing strategic objectives to establish an index system framework of supply chain performance evaluation.

In addition to the above mentioned supply chain performance evaluation index systems, more scholars from other perspectives put forward corresponding evaluation index systems, but these systems are not from the perspective of the overall supply chain, and proposed indexes are numerous and complex, even containing redundant data. Although many scholars have pointed out the evaluation indexes in theoretical level, few are in operational level.

As the process of supply chain operations contains a lot of vague information which is difficult to use conventional methods to measure and quantify; In addition, the characteristics of the supply chain itself require its decision-making issues seeking an integrated,

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coordinated balance and overall optimization, which makes supply chain performance evaluation with a number of qualitative indicators. These bring a certain degree of difficulty to performance evaluation of supply chains. Currently main methods in the supply chain performance evaluation include Analytic Hierarchy Process (AHP), fuzzy decision-making evaluation method, Data Envelopment Analysis and so on.

AHP, proposed by T. L. Saaty in the early 70s last century, is a flexible and practical method of multi-criteria decision-making. As supply chain performance evaluation is a typical multi-objective decision making issue, AHP has been widely used in the area. F.T.S. Chan [10] took the electronic industry as an example to demonstrate the priority of AHP technique in performance measurement in a supply Chain. R. BHAGWAT [11] used AHP methodology as aid in making SCM evaluation decisions. The application of AHP in supply chain performance evaluation brings a set of systematic analysis for the problem, providing a more convincing basis of scientific management and decision-making. However, AHP also has its limitations, so many scholars had tried a variety of improved and perfected ways to overcome the shortcomings of AHP. F.T.S. Chan and Qi H.J. [12] proposed a novel channel-spanning performance measurement method from a system perspective and introduced fuzzy set theory to address the real situation in the judgement and evaluation processes of supply chains. Rajat Bhagwat [13] proposed a new mathematical model to optimize the overall performance measurement of SCM for Small- and Medium-sized Enterprises (SMEs). Besides above evaluation methods, there are also many other attempts. Qinghua Zhu et al [14], taking 341 Chinese manufacturers as samples, applied confirmatory factor analysis to test and compare two measurement models of green supply chain management (GSCM) practices implementation.

Although there have been many researches on the performance measurement of supply chains, few are on the overall performance evaluation of supply chains. So, it is of important practical and theoretical significance to evaluate the overall performance of supply chains. The objective of this paper is to apply Analytic Hierarchical Model (AHM) and a new membership transformation method M(1,2,3) to evaluate the supply chains' overall performance. The contributions of this study include: i) constructing an index system for assessing the overall performance of supply chain; ii) using AHM to determine the index weights in the system; iii) building an evaluation model by M(1,2,3) for evaluating the supply chains' overall performance.

The rest of the paper is organized as follows. Section 2 introduces the models of AHM and M(1,2,3) and establishes the framework of applying the models to evaluate the performance measurement of supply chains. Section 3, according to the SCOR-model proposed by Supply Chain Council (SCC), constructs an evaluation index system of the overall performance of supply chains. Section 4 determines the weight of every index by applying Analytic Hierarchical Model. Section 5 applies the M(1,2,3) model in the fuzzy evaluation on supply chains' overall performance. The last section concludes our discussion by summarizing our findings and implications for future research.

II. The Models

This section introduces the AHM and M(1,2,3) model. AHM is a multi-criteria decision-making tool which can be used to evaluate alternative programs or to determine the weights of evaluation indexes. M(1,2,3) model is a more accurate evaluation model. We also construct the framework of applying AHM and M(1,2,3) to evaluate the overall performance of supply chains which is the guideline of next sections.

A. Analytic Hierarchical Model

AHM is different from AHP [15]. There is no eigenvalues calculation or consistency test in AHM, often called Ball Game model. The concrete contents are as follows [16]:

Assume that there are *N* elements, $u_1, u_2, \cdots, u_n$, which respectively represent *n* ball teams. There are two teams in one game, so there will be $\frac{1}{2}n(n-1)$ games totally. Every game gains one score, μ_{ij} and μ_{ji} representing the corresponding scores of u_i and $u_j (i \neq j)$ in the same game. The score denotes the criterion, short for *C*. Under *C* criterion, we can sort $u_1, u_2, \cdots, u_n$ according to their gained scores.

μ_{ij} and μ_{ji} should satisfy the following conditions:

$$\begin{cases} \mu_{ij} \geq 0\,, \mu_{ji} \geq 0 \\ \mu_{ij} + \mu_{ji} = 1 \quad i \neq j \\ \mu_{ii} = 0 \ \text{(A team can't match with itself)} \end{cases} \tag{1}$$

In the practical problems, μ_{ij} can take all real values from 0 to 1. We call μ_{ij} as Relative Measurement of u_i and $u_j (i \neq j)$ and call $\mu = (\mu_{ij})_{n \times n}$ as pair-wise comparison matrix.

If $\mu_{ij} > \mu_{ji}$, it means u_i is stronger than u_j, denoted by $u_i > u_j$. So, after the game, if the score of u_i is larger than that of u_j, u_i is the winner. If $(\mu_{ij})_{n \times n}$ satisfies: If $u_i > u_j$, $u_j > u_k$, then $u_i > u_k$, meaning that comparison matrix satisfies the consistency.

The final score of u_i is : $f_i = \sum_{j=1}^{n} \mu_{ij}$, obviously, $\sum_{i=1}^{n} f_i = \frac{1}{2} n(n-1)$. There are $\frac{1}{2} n(n-1)$ games totally, so the total score should be $\frac{1}{2} n(n-1)$. Supposing:

$$\begin{cases} \omega_C = \left(\omega_{u_1}^C, \omega_{u_2}^C, \cdots, \omega_{u_n}^C \right)^T \\ \omega_{u_i}^C = \dfrac{2}{n(n-1)} \sum_{j=1}^{n} \mu_{ij} \end{cases} \quad (2)$$

where ω_C is called the Relative Weight Vector.

Usually, it is not easy to directly get the comparison matrix $(\mu_{ij})_{n\times n}$ in AHM, but we can deduce it from the comparison Matrix $(a_{ij})_{n\times n}$ in AHP. When $(a_{ij})_{n\times n}$ satisfies the consistency, we can sort $u_1, u_2, \cdots, u_n$ according to the relative components of ω_C.

B. M(1,2,3) Model

Assume that there are m indexes which affect the evaluation object Q, where the importance weights $\lambda_j(Q)$ of j ($j = 1 \sim m$) index about object Q is given and satisfies:

$$0 \le \lambda_j(Q) \le 1, \ \sum_{j=1}^{m} \lambda_j(Q) = 1 \quad (3)$$

Every index is classified into p classes. C_K represents the K th class and C_K is prior to C_{K+1}. If the membership $\mu_{jK}(Q)$ of j th index belonging to C_K is given, where $K = 1 \sim P$ and $j = 1 \sim m$, and $\mu_{jK}(Q)$ satisfies:

$$0 \le \mu_{jK}(Q) \le 1, \ \sum_{K=1}^{P} \mu_{jK}(Q) = 1 \quad (4)$$

1) The distinguishable weight

Let $\alpha_j(Q)$ represent the normalized and quantized value describing j th index contributes to classification. And it can be described quantitatively by the entropy $H_j(Q)$. Therefore, $\alpha_j(Q)$ is a function of $H_j(Q)$:

$$H_j(Q) = -\sum_{k=1}^{p} \mu_{jk}(Q) \cdot \log \mu_{jk}(Q) \quad (5)$$

$$v_j(Q) = 1 - \frac{1}{\log p} H_j(Q) \quad (6)$$

$$\alpha_j(Q) = v_j(Q) \Big/ \sum_{t=1}^{m} v_t(Q) \quad (j = 1 \sim m) \quad (7)$$

Definition 1: If $\mu_{jk}(Q)$ $(k = 1 \sim p, j = 1 \sim m)$ is the membership of j th index belonging to C_k and satisfies Eq. (4); by (5) (6) (7), $\alpha_j(Q)$ is called distinguishable weight of j th index corresponding to Q. Obviously, $\alpha_j(Q)$ satisfies

$$0 \le \alpha_j(Q) \le 1, \quad \sum_{j=1}^{m} \alpha_j(Q) = 1 \quad (8)$$

2) The effective value

Definition 2: If $\mu_{jk}(Q)$ $(k = 1 \sim p, j = 1 \sim m)$ is the membership of j th index belonging to C_k and satisfies Eq. (8), and $\alpha_j(Q)$ is the distinguishable weight of j th index corresponding to Q, then

$$\alpha_j(Q) \cdot \mu_{jk}(Q) \quad (k = 1 \sim p) \quad (9)$$

is called effective distinguishable value of K th class membership of j th index, or K th class effective value for short.

3) The comparable value

Definition 3: If $\alpha_j(Q) \cdot \mu_{jk}(Q)$ is K th class effective value of j th index, and $\beta_j(Q)$ is importance weight of j th index related to object Q, then

$$\beta_j(Q) \cdot \alpha_j(Q) \cdot \mu_{jk}(Q) \quad (k = 1 \sim p) \quad (10)$$

is called comparable effective value of K th class membership of j th index, or K th class comparable value for short.

Definition 4: If $\beta_j(Q) \cdot \alpha_j(Q) \cdot \mu_{jk}(Q)$ is K th class comparable value of j th index of Q, where $(j = 1 \sim m)$, then

$$M_k(Q) = \sum_{j=1}^{m} \beta_j(Q) \cdot \alpha_j(Q) \cdot \mu_{jk}(Q) \quad (k = 1 \sim p) \quad (11)$$

is named K th class comparable sum of object Q.

Definition 5: If $M_k(Q)$ is K th class comparable sum of object Q, and $\mu_k(Q)$ is the membership of object Q belonging to C_K, then

$$\mu_k(Q) \stackrel{\Delta}{=} M_k(Q) \Big/ \sum_{t=1}^{p} M_t(Q) \quad (k = 1 \sim p) \quad (12)$$

Obviously, given by Eq. (13), membership degree $\mu_k(Q)$ satisfies:

$$0 \le \mu_k(Q) \le 1, \quad \sum_{k=1}^{p} \mu_k(Q) = 1 \quad (13)$$

The above membership transformation method can be summarized as “effective, comparison and composition”, which is denoted as $M(1,2,3)$ model [17].

C. The Framework of Applying AHM and M(1,2,3) to Evaluate Supply Chains' Overall Performance

According to the calculation processes of the AHM and M(1,2,3), we can construct the framework of applying the two models to evaluate the overall performance of supply chains, as Fig.1 shows. The first step is to construct an evaluation index system of supply chains' overall performance; the second step is to apply AHM to determine the weight of every index; the third step is to establish the fuzzy evaluation matrix of supply chains' overall; the fourth step is to calculate the evaluation results by M(1,2,3) model; the fifth step is to analyze the results and propose improvement measurements in the last step.

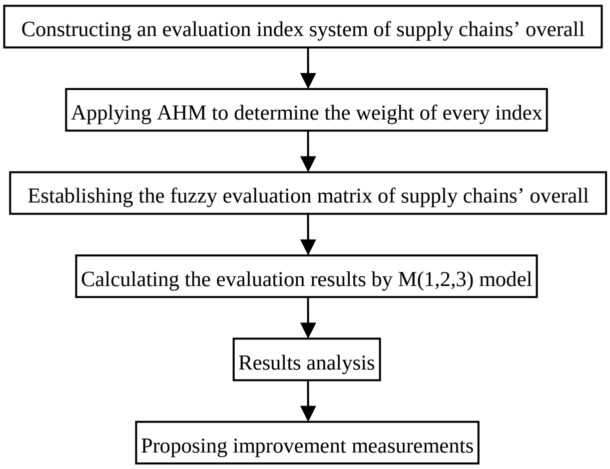

Figure 1. The framework of applying AHM and M(1,2,3) to evaluate supply chains' overall performance.

III. THE EVALUATION INDEX SYSTEM OF SUPPLY CHAINS' OVERALL PERFORMANCE

We, according to the SCOR-model, establish an evaluation index system of supply chains' total performance, as Table I shows [18].

IV. APPLYING AHM TO DETERMINE THE WEIGHT OF EVERY INDEX IN THE EVALUATION INDEX SYSTEM OF SUPPLY CHAINS' OVERALL PERFORMANCE

This section applies AHM to determine the weight of every index in the evaluation index system of supply chains' total performance.

A. 1-9 Proportional Scaling Method

N elements, $u_1, u_2, \cdots, u_n$, compare importance

TABLE I.
THE EVALUATION INDEX SYSTEM OF SUPPLY CHAINS' OVERALL PERFORMANCE

The goal	**Criteria layer**	**Index layer**
Evaluation on supply chains' total performance G	C_1: Reliability	F_{11}: Delivery performance
		F_{12}: Order fill rate
		F_{13}: On time delivery
	C_2: Responsiveness	F_{21}: Order lead-time
		F_{22}: Planning cycle time
		F_{23}: Information transmission rate
	C_3: Flexibility	F_{31}: Supply chain responsiveness time
		F_{32}: Production flexibility
		F_{33}: Delivery flexibility
	C_4: Cost	F_{41}: Supply chain total costs
		F_{42}: Value-added employee productivity
		F_{43}: Quality warranty costs
	C_5: Assets	F_{51}: Cash turn age
		F_{52}: Inventory days
		F_{53}: Asset turns

pairwise, so there will be $\frac{n(n-1)}{2}$ times. The importance ratio of u_i and u_j is a_{ij}. The problem is how to get a_{ij}. AHP uses 1-9 proportional scaling method to determine a_{ij}.

B. Constructing Pairwise Comparison Judgment Matrix in AHP

In this paper, we compare the criterions layer based on the goal: improving the overall performance of supply chains and will get a 5 x 5 comparison matrix; we compare the factors layer based on corresponding criterion and will get five 3 x 3 comparison matrices. The comparison matrices are as follows:

G	Reliability C_1	Responsiveness C_2	Flexibility C_3	Cost C_4	Assets C_5
Reliability C_1	1	2	2	3	5
Responsiveness C_2	1/2	1	1	2	3
Flexibility C_3	1/2	1	1	2	3
Cost C_4	1/3	1/2	1/2	1	2
Assets C_5	1/5	1/3	1/3	1/2	1

Reliability C_1	F_{11}	F_{12}	F_{13}
Delivery performance F_{11}	1	2	2
Order fill rate F_{12}	1/2	1	1
On time delivery F_{13}	1/2	1	1

Responsiveness C_2	F_{21}	F_{22}	F_{23}
Order lead-time F_{21}	1	2	3
Planning cycle time F_{22}	1/2	1	2
Information transmission rate F_{23}	1/3	1/2	1

Flexibility C_3	F_{31}	F_{32}	F_{33}
Supply chain responsiveness time F_{31}	1	2	4
Production flexibility F_{32}	1/2	1	2
Delivery flexibility F_{33}	1/4	1/2	1

Costs C_4	F_{41}	F_{42}	F_{43}
Supply chain total costs F_{41}	1	2	2
Value-added employee productivity F_{42}	1/2	1	1
Quality warranty costs F_{43}	1/2	1	1

Assets C_5	F_{51}	F_{52}	F_{53}
Cash turn age F_{51}	1	3	5
Inventory days F_{52}	1/3	1	2
Asset turns F_{53}	1/5	1/2	1

C. The Pairwise Comparison Judgment Matrix in AHM after Converting from AHP

Using the models mentioned in Section II, we can convert the comparison judgment matrix $(a_{ij})_{n\times n}$ in AHP into the comparison judgment matrix $(\mu_{ij})_{n\times n}$ in AHM, as follows:

G	Reliability C_1	Responsiveness C_2	Flexibility C_3	Cost C_4	Assets C_5
Reliability C_1	0	0.8	0.8	0.857	0.909
Responsiveness C_2	0.2	0	0.5	0.8	0.857
Flexibility C_3	0.2	0.5	0	0.8	0.857
Cost C_4	0.143	0.2	0.2	0	0.8
Assets C_5	0.091	0.143	0.143	0.2	0

Reliability C_1	F_{11}	F_{12}	F_{13}
Delivery performance F_{11}	0	0.8	0.8
Order fill rate F_{12}	0.2	0	0.5
On time delivery F_{13}	0.2	0.5	0

Responsiveness C_2	F_{21}	F_{22}	F_{23}
Order lead-time F_{21}	0	0.8	0.857
Planning cycle time F_{22}	0.2	0	0.8
Information transmission rate F_{23}	0.143	0.2	0

Flexibility C_3	F_{31}	F_{32}	F_{33}
Supply chain responsiveness time F_{31}	0	0.8	0.889
Production flexibility F_{32}	0.2	0	0.8
Delivery flexibility F_{33}	0.111	0.2	0

Costs C_4	F_{41}	F_{42}	F_{43}
Supply chain total costs F_{41}	0	0.8	0.8
Value-added employee productivity F_{42}	0.2	0	0.5
Quality warranty costs F_{43}	0.2	0.5	0

Assets C_5	F_{51}	F_{52}	F_{53}
Cash turn age F_{51}	0	0.857	0.909
Inventory days F_{52}	0.143	0	0.8
Asset turns F_{53}	0.091	0.2	0

From the above conversion results, we can see that all the conversed comparison judgment matrices in AHM satisfy the consistency.

D. Calculating the Relative Weights in AHM under the Single Criterion

Using the single criterion C, we can calculate the relative weight by the formula of each factor which is as follows:

$$\omega_C = \left(\omega_{u_1}^C, \omega_{u_2}^C, \cdots, \omega_{u_n}^C\right)^T, \quad \omega_{u_i}^C = \frac{2}{n(n-1)}\sum_{j=1}^{n}\mu_{ij}$$

The detailed values of the factor relative weight are as follows:

$$\omega_{\mathrm{G}} = \left(\omega_{\mathrm{C}_1}, \omega_{\mathrm{C}_2}, \omega_{\mathrm{C}_3}, \omega_{\mathrm{C}_4}, \omega_{\mathrm{C}_5}\right)^T = (0.337, 0.236, 0.236, 0.133, 0.058)^T$$

$$\omega_{\mathrm{C}_1} = \left(\omega_{\mathrm{C}_1}^{\mathrm{F}_{11}}, \omega_{\mathrm{C}_1}^{\mathrm{F}_{12}}, \omega_{\mathrm{C}_1}^{\mathrm{F}_{13}}\right)^T = (0.534, 0.233, 0.233)^T$$

$$\omega_{\mathrm{C}_2} = \left(\omega_{\mathrm{C}_2}^{\mathrm{F}_{21}}, \omega_{\mathrm{C}_2}^{\mathrm{F}_{22}}, \omega_{\mathrm{C}_2}^{\mathrm{F}_{23}}\right)^T = (0.552, 0.334, 0.114)^T$$

$$\omega_{\mathrm{C}_3} = \left(\omega_{\mathrm{C}_3}^{\mathrm{F}_{31}}, \omega_{\mathrm{C}_3}^{\mathrm{F}_{32}}, \omega_{\mathrm{C}_3}^{\mathrm{F}_{33}}\right)^T = (0.562, 0.334, 0.104)^T$$

$$\omega_{\mathrm{C}_4} = \left(\omega_{\mathrm{C}_4}^{\mathrm{F}_{41}}, \omega_{\mathrm{C}_4}^{\mathrm{F}_{42}}, \omega_{\mathrm{C}_4}^{\mathrm{F}_{43}}\right)^T = (0.534, 0.233, 0.233)^T$$

$$\omega_{\mathrm{C}_5} = \left(\omega_{\mathrm{C}_5}^{\mathrm{F}_{51}}, \omega_{\mathrm{C}_5}^{\mathrm{F}_{52}}, \omega_{\mathrm{C}_5}^{\mathrm{F}_{53}}\right)^T = (0.588, 0.314, 0.098)^T$$

E. Calculating the Synthetic Weight of Each Factor to the Goal

According to the relative weights under the single criterion in every layer gained in the above subsection, we can calculate the synthetic weights of factors in the bottom layer to the goal which are as follows:

$$\omega_{\mathrm{G}}^{\mathrm{F}_{ij}} = (\omega_{\mathrm{G}}^{\mathrm{F}_{11}}, \omega_{\mathrm{G}}^{\mathrm{F}_{12}}, \omega_{\mathrm{G}}^{\mathrm{F}_{13}}, \omega_{\mathrm{G}}^{\mathrm{F}_{21}}, \omega_{\mathrm{G}}^{\mathrm{F}_{22}}, \omega_{\mathrm{G}}^{\mathrm{F}_{23}}, \omega_{\mathrm{G}}^{\mathrm{F}_{31}}, \omega_{\mathrm{G}}^{\mathrm{F}_{32}}, \omega_{\mathrm{G}}^{\mathrm{F}_{33}}, \omega_{\mathrm{G}}^{\mathrm{F}_{41}}, \omega_{\mathrm{G}}^{\mathrm{F}_{42}}, \omega_{\mathrm{G}}^{\mathrm{F}_{43}}, \omega_{\mathrm{G}}^{\mathrm{F}_{51}}, \omega_{\mathrm{G}}^{\mathrm{F}_{52}}, \omega_{\mathrm{G}}^{\mathrm{F}_{53}})^{\mathrm{T}}$$
$$= (0.180, 0.079, 0.079, 0.130, 0.079, 0.027, 0.133, 0.079, 0.025, 0.071, 0.031, 0.031, 0.034, 0.018, 0.006)^T$$

V. Fuzzy Evaluation on Supply Chains' Total Performance Based on M(1,2,3)

A. The Fuzzy Evaluation Matrix of Supply Chains' Total Performance

According to the evaluation index system of the total performance of supply chains we have constructed in Section III, we invited fifty domain experts including the top leaders of the supply chain to evaluate the total performance of some supply chain. The evaluation results on the each base index are as Table II shows. In Table II, the values in the corresponding brackets of each index represent the corresponding importance weights; the vectors behind the base indexes represent the corresponding membership vectors which are classified into five levels: G_1: Very satisfied, G_2: Satisfied, G_3: General, G_4: Dissatisfied, G_5: Very dissatisfied.

B. Fuzzy Evaluation Based on M(1,2,3) Model

(1) We take the criterion C_1 (Reliability) as the example. The calculation processes of its membership vector are:

1) From Table II, on the index of "Delivery performance", 24% of experts regarded it as very satisfied, 22% regarded it as satisfied, 22% regarded it as general, 20% regarded it as dissatisfied and 12% regarded it as very dissatisfied, so its evaluation membership vector is $[0.24\ 0.22\ 0.22\ 0.20\ 0.12]$.

TABLE II.
THE INDEX DATA OF SUPPLY CHAINS' TOTAL PERFORMANCE

The Goal	Criteria	Indexes	Very satisfied	Satisfied	General	Dissatisfied	Very dissatisfied
Fuzzy evaluation on supply chains' total performance *S*	C_1: Reliability (0.337)	F_{11}: Delivery performance (0.534)	12	11	11	10	6
		F_{12}: Order fill rate (0.233)	15	14	10	7	4
		F_{13}: On time delivery (0.233)	14	14	10	6	6
	C_2: Responsiveness (0.236)	F_{21}: Order lead-time (0.552)	6	7	14	13	10
		F_{22}: Planning cycle time (0.334)	5	4	14	14	13
		F_{23}: Information transmission rate (0.114)	10	11	14	10	5
	C_3: Flexibility (0.236)	F_{31}: Supply chain responsiveness time (0.562)	11	16	14	6	3
		F_{32}: Production flexibility (0.334)	16	14	12	6	2
		F_{33}: Delivery flexibility (0.104)	18	12	11	6	3
	C_4: Costs (0.133)	F_{41}: Supply chain total costs (0.534)	11	12	13	10	4
		F_{42}: Value-added employee productivity (0.233)	10	13	13	10	4
		F_{43}: Quality warranty costs (0.233)	14	14	10	8	4
	C_5: Assets (0.058)	F_{51}: Cash turn age (0.588)	13	14	10	10	3
		F_{52}: Inventory days (0.314)	12	11	12	10	5
		F_{53}: Asset turns (0.098)	14	12	12	10	2

According to the fuzzy theory, we can draw the evaluation matrix of the criterion " Reliability" as follows:

$$U(C_1)=\begin{pmatrix} 0.24 & 0.22 & 0.22 & 0.20 & 0.12 \\ 0.30 & 0.28 & 0.20 & 0.14 & 0.08 \\ 0.28 & 0.28 & 0.20 & 0.12 & 0.12 \end{pmatrix}$$

According to the j th row $F_{11} \sim F_{13}$ of $U(C_1)$, the distinguishable weights of F_{1j} are obtained and the distinguishable weight vector is:

$$\alpha(C_1)=(\ 0.1334 \quad 0.5065 \quad 0.3600)$$

2) In Table II, the importance weight vector of $F_{11} \sim F_{13}$ on C_1 is given:

$$\beta(C_1)=(0.534 \quad 0.233 \quad 0.233)$$

3) Calculate the K th comparable value of F_{1j} and obtain the comparable value matrix $N(C_1)$ of C_1:

$$N(C_1)=\begin{pmatrix} 0.0171 & 0.0157 & 0.0157 & 0.0142 & 0.0085 \\ 0.0354 & 0.0330 & 0.0236 & 0.0165 & 0.0094 \\ 0.0235 & 0.0235 & 0.0168 & 0.0101 & 0.0101 \end{pmatrix}$$

4) According to $N(C_1)$, calculate the K th comparable sum of C_1 and obtain the comparable sum vector:

$$M(C_1)=(\ 0.0760 \quad 0.0722 \quad 0.0561 \quad 0.0408 \quad 0.0281)$$

5) According to $M(C_1)$, calculate the membership vector $\mu(C_1)$ of C_1:

$$\mu(C_1)=(0.2782 \quad 0.2644 \quad 0.2052 \quad 0.1495 \quad 0.1027)$$

In the same steps, we can calculate $\mu(C_2)$, $\mu(C_3)$, $\mu(C_4)$ and $\mu(C_5)$, which, with $\mu(C_1)$, form the evaluation matrix $U(S)$ of supply chains' total performance:

$$U(S)=\begin{pmatrix} \mu(C_1) \\ \mu(C_2) \\ \mu(C_3) \\ \mu(C_4) \\ \mu(C_5) \end{pmatrix}=\begin{pmatrix} 0.2782 & 0.2644 & 0.2052 & 0.1495 & 0.1027 \\ 0.1152 & 0.1139 & 0.2800 & 0.2663 & 0.2246 \\ 0.2724 & 0.2966 & 0.2586 & 0.1200 & 0.0524 \\ 0.2325 & 0.2559 & 0.2429 & 0.1886 & 0.0800 \\ 0.2598 & 0.2644 & 0.2124 & 0.2000 & 0.0634 \end{pmatrix}$$

(2) According to $U(S)$ and the weights of each criteria in the criterion level, we can calculate the final membership vector $\mu(S)$ of the goal S:

$$\mu(S)=(\mu_1(S),\cdots,\mu_5(S)) \\ =(\ 0.2366 \quad 0.2437 \quad 0.2481 \quad 0.1634 \quad 0.1081)$$

C. Recognition

Because the evaluation grades of the overall performance of supply chains are orderly, that is, G_k is superior to G_{k+1}, so we apply confidence recognition rule to determine the grade of the overall performance of the supply chain.

Let $\lambda(\lambda > 0.7)$ represent the confidence degree, then we can calculate

$$K_0 = \min\left\{k \left| \sum_{t=1}^{k} \mu_t(S) \geq \lambda, 1 \leq k \leq 5 \right.\right\}.$$

and judge that S belongs the kth grade, of which the confidence degree is no lower than $\sum_{t=1}^{k} \mu_t(S)$.

In the example, according to the final membership vector $\mu(S)$ gained in the above subsection, we can judge that the overall performance of the supply chain S belongs the G_3 (General) level, with the confidence degree 72.84% (0.2366+0.2437+0.2481= 0.7284).

D. Results Analysis

We have judged the total performance of the supply chain as the “General” level with the confidence level 72.84%. By the evaluation matrix $U(S)$, we judge it as "Very satisfied" with the confidence level only being 23.66%, indicating that the supply chain should improve its total performance from every aspect greatly, especially from the “Responsiveness” aspect, which is with the lowest confidence level 50.91% if we judge it as the “General” level.

VI. Conclusions

In this paper, we integrated Analytic Hierarchical Model (AHM) and a new membership transformation method M(1,2,3) to evaluate the overall performance of supply chains. The contributions of this study include: i) constructing an index system for assessing the overall performance of supply chain; ii) using AHM to determine the index weights in the system; iii) building an evaluation model by M(1,2,3) for evaluating the supply chains' overall performance. From the proposed approach, we can not only judge the overall levels of supply chains but also find out which aspects the decision makers should enhance to increase the overall performance of supply chains.

However this study has several limitations. First, we just used the the first layer indicators in the SCOR-model proposed in the last 90s and didn't consider modern factors such as Green and Ecological aspect [14]. Second, in Part IV, the pairwise comparison matrices are determined only according to author' own consideration, which is too subjective. The focus of this research was to propose a new evaluation method for evaluating supply chains' total performance. Whether the method achieves effective and scientific results also depends on the index and the data used in the method. So, Future research can focus on improving the evaluation index system of supply chains’ total performance and developing accurate way to attain index data.

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