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Research Article

A Novel Evaluation Indicator System and Evaluation Method for Supply Chain Performance of Food Production

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Abstract: Supply chain performance evaluation is a research hotspot and lies in the core status in supply chain management. The study presents a new evaluation indicator system and evaluation algorithm for supply chain performance. First, the balanced score card is used to construct an evaluation indicator system for supply chain performance evaluation through analyzing the basic principle and connotation characteristics of supply chain management; Second analytic hierarchy process and fuzzy comprehensive evaluation algorithms are combined to satisfy the dynamic, subjective and transitional characteristics of evaluation indicators and improve evaluation accuracy. Thirdly the evaluation indicator system and evaluation algorithm are used in supply chain performance evaluation of fresh food products and the experimental results shows that the presented evaluation indicator system and evaluation algorithm has satisfied validity and feasibility.

Keywords: Analytic hierarchy process, balanced score card, multistage comprehensive fuzzy evaluation, supply chain performance evaluation

INTRODUCTION

In the 1990's, traditional purchase and logistics had already developed into a broadly-defined supply chain management system with strategic significance. Even to this day, the idea of supply chain management has been rooted in the hearts of the corporations already and paid attention by more and more corporations and researcher and used in a lot of industries, In the system of supply chain management, it is an urgent problem to be solved to construct a new scientific, overall, accurate performance evaluation indicator system and method in order to evaluate supply chain management efficiency. Any kind of performance evaluation indictor system and method should reflect the desire and target of organization, management mode, the way of communication and relation, the way of feedback and learning, the way of business programming, etc. Because modern supply chain management is different from traditional business administration and has unique personality and characteristics, designing and constructing new performance evaluation indicator systems and evaluation methods has become one of the key techniques and a research hotspot in supply chain management and in the fields related (Feng and Ma, 2013).

There are many methods used for the overall evaluation of the performance of supply chain, but all of them has their own disadvantages and advantages (Xi and Shi, 2013). In light of subjectivity, fuzziness, dynamics and intermediate transitivity of evaluation indicator of supply chain performance, it cannot be described and verified accurately and rigidly (Luong and Phien, 2007; Disney *et al*., 2006); this study, through study on fuzzy membership functions of evaluation indicators, combines analytic hierarchy process with fuzzy hierarchy evaluation method to carry out comprehensive evaluation, so as to overcome the problems analytical hierarchy process and fuzzy evaluation method, respectively. The former method has low evaluation accuracy when evaluating multi-indicator system (Duc *et al*., 2008) and fuzzy evaluation method should determine membership function rigidly which destroys the fuzzy subjective indicator characteristics (Chen *et al*., 2000a).

MATERIALS AND METHODS

Analysis and establishment of evaluation indicator system: Supply chain performance evaluation is a complicated comprehensive operation system constituted by multiple elements, the numerous elements and subsystems of which exist in different forms, jointly assembly and forming competitiveness. This study uses Balanced Score Card (BSC) to analyzes the basic principle and connotation characteristics of

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Table 1: Evaluation indicator system of supply chain performance

Target hierarchy	First-class indicator	Second-class indicator	Third-class indicator
Performance of supply chain	External factors	Logistics level	Product adaptability
			Time adaptability
			Quantity adaptability
			Lead time
		CRM level	Delivery accuracy
			Product security
			Customer satisfaction rate
			Customer complaints rate
			Customer loyalty
		Service integration level	Integration service level
			Logistics cohesion
	Internal factors	Corporation input	Management input
			Hardware input
			Logistics input
		Internal operation	Informatization level
			Resource utilization
			Logistics operation
		Corporation benefit	Cost/benefit rate
			Business growth rate
			Profit growth rate
			Cost decrease rate

supply chain management, combines with literatures and experts consultations and establishes a wide and scientific evaluation indicator system of online education performance evaluation (Lee *et al*., 2000; Cai and Yang, 2009; Shifei *et al*., 2010; Li and Ning, 2012), which includes four hierarchies, 2 categories, 6 second-grade indicator, 21 third-grade indicator; Table 1 for details.

Membership function determination of new model: The basic thought of fuzzy theory is the thought of the membership degree attribute towards subject; as previously mentioned, the key to apply fuzzy evaluation model lies in establishing reasonable fuzzy evaluation model, while the key to build fuzzy comprehensive evaluation model is to reasonably build membership function conforming to the facts. The method of determining the membership function of certain fuzzy set remains a difficulty needing to be solved up till now. According to the specific features of comprehensive evaluation of PE course teaching effect, this thesis adopts fuzzy statistical method to determine the membership function of fuzzy evaluation model (Yuan, 2012).

Determining membership function of attribute towards object with fuzzy statistical method is a relatively objective method, which is also widely used. This method, in the specific operation, through fuzzy statistical test, according to the actual existence of membership of attribute, determines specific membership. Fuzzy statistical test generally includes four factors which are domain of discourse U, fixed element x_0 in U, a common set A^* formed by random variables in U, a fuzzy set A in U (taking A^* as elastic boundary and restricting the change of A^*). Among the above four elements, $x_0 \in A^*$, thus, the membership function of x_0 towards A is unable to be fixed and determined.

Now suppose that experimenter does n times of fuzzy statistical test, he/she can carry out calculation according to Formula 1 as follows. Membership frequency of x_0 towards:

$$A = \frac{Times of x_0 \in A}{n} \tag{1}$$

In specific calculation, with the increase of test times n, membership frequency is gradually stable; the stable frequency value is called membership of x_0 towards A in fuzzy mathematics, i.e., Formula (2):

$$\mu_A(x_0) = \lim_{n \to \infty} \frac{Times of x_0 \in A}{n} \tag{2}$$

Fuzzy comprehensive evaluation matrix establishment: The second key to successfully use fuzzy comprehensive evaluation model is to reasonably build fuzzy comprehensive evaluation matrix. Now use $U = \{u_1, u_2, u_3 \ldots u_n\}$ to express n kinds of indicators (or influencing factors) of study object, which can be called indicator set (or factor set). Use $V = \{v_1, v_2, v_3 \ldots v_m\}$ to express evaluation set (also called evaluation set, decision set, etc.), formed by m kinds of evaluation indicators of all the indicators (i.e., factors). Indicators (number and name of indicators) can be generally determined according to decider's specific demand in specific evaluation. As previous said, in the practical practice of evaluation, the evaluation set of indicators (factors) of many problems is not that clear, instead, it is relatively fuzzy. So comprehensive evaluation result is a fuzzy subset on V, as shown in Formula (3):

$$B = (b_1, b_2, b_3 \ldots b_k) \in F(V) \tag{3}$$

In Formula (3), membership of evaluation b_k towards fuzzy subset B is obtained through the calculation of $\mu_B(v_k) = b_k(k = 1, 2, 3,\dots m)$, which can reflect the role of the kth evaluation v_k played in comprehensive evaluation. Comprehensive evaluation set B relies on the weight values of each indicator, i.e., B shall be the fuzzy subset on indicator set U, $A = (a_1, a_2, a_3, \dots, a_n) \in F(U)$ and meeting that the sum of indicator weight is 1; in which a_i indicates the weight of the ith indicator. Hence, while the weight set A is set, a corresponding comprehensive evaluation set B can be determined. General steps to determine fuzzy comprehensive evaluation mainly include the following ones:

- Determine indicator set $U = \{u_1, u_2, u_3\dots u_n\}$
- Calculate determination evaluation set $V = \{v_1, v_2, v_3\dots v_m\}$
- Calculate determination fuzzy evaluation matrix $R = (r_{ij})_{n\times m}$

While determining fuzzy evaluation matrix $R = (r_{ij})_{n\times m}$, first, carry out evaluation of $f(u_i) = (i = 1, 2, 3, \dots n)$on each indicator u_i, a fuzzy mapping f from indicator set U to evaluation set V can be obtained; the mapping is as shown in Formula (4):

$$\begin{aligned} &f: U \to F(U) \\ &\quad u_i \mapsto f(u_i) = (r_{i1}, r_{r2}, r_{i3} \dots r_{im}) \in F(V) \end{aligned} \tag{4}$$

Then, deduce fuzzy relation $R_f \in F(U\times V)$ according fuzzy mapping f, as shown in Formula 5:

$$\begin{aligned} &R_f(u_i, v_j) \in f(u_i)(v_j) = r_{ij} = \\ &\quad (i = 1,2,3\dots n;\ j = 1,2,3\dots m) \end{aligned} \tag{5}$$

As a result, fuzzy evaluation matrix $R = (r_{ij})n\times m$ can be calculated, (U, V, R) is the model of fuzzy comprehensive evaluation; U, V, R are generally called the necessary elements of the model.

- **Comprehensive evaluation:** As to a set in which weight $A = (a_1, a_2, a_3,\dots a_n) \in F(U)$, through model $M(\vee,\wedge)$, take compositional operation of maximum-minimum, then obtain final comprehensive evaluation matrix, as shown in Formula 6:

$$B = A \circ R(\Leftrightarrow b_j = \bigvee_{i=1}^{n}(a_i \wedge r_{ij}), j = 1,2,3,\dots m) \tag{6}$$

According to the above, we can know that the correct determination of weight $A = (a_1, a_2, a_3,\dots a_n)$ in evaluation set V plays a critical role in final comprehensive evaluation. $A = (a_1, a_2, a_3, \dots a_n)$ is generally determined by model designer by virtue of self relevant experience, but this is often subjective. If the weight set is to reflect actual situation, to objectively and faithfully reflect actual situation, weighting statistics, experts evaluation or fuzzy relation can be adopted to determine $A = (a_1, a_2, a_3,\dots a_n)$; for practical application, different determination methods can be chosen according to different situations (Yuan, 2012).

Overall evaluation step design of the model: Fuzzy overall evaluation in this study is conducted according to the following five steps:

- **Establish evaluation element set:** Evaluation element set is an ordinary set constituted by all the elements influencing evaluation object; suppose there are n evaluation indicator elements expressed by $u_1, u_2, u_3, \dots, u_n$, respectively, then the set constituted by these n evaluation elements is called evaluation element set, i.e., $U = \{u_1, u_2, u_3\dots u_n\}$.
- **Confirm evaluation set:** Evaluation set is also called judgment set, which is comprised of all the evaluation results of evaluator on evaluation object, is an ordinary set formed by all the possible evaluation results of evaluators on evaluation object. Evaluation results can be divided into m hierarchies according to actual demand of specific cases, which can be expressed by $v_1, v_2, v_3\dots v_m$, respectively, then evaluation set can be constituted as $V = \{v_1, v_2, v_3\dots v_m\}$.
- **Confirm the weight of evaluation indicator:** The reasonable confirmation of indicator weight embodies the different weight relations among all the evaluation indicators in the system, increases the comparability among all the evaluation indicators and the effectiveness of evaluation result. AHP is objective with such merits as practicability, conciseness and systematicness. Thus, this study adopts AHP to confirm the weights of all the evaluation indicators, obtaining the weight wi of each evaluation indicator ui. The set constituted by each weight called weight set W.
- **Single-factor fuzzy evaluation:** Suppose that evaluation object carries out evaluation according to the ith factor in factor set $U = \{u_1, u_2, u_3, \dots, u_n\}$, the subordination of which as to the jth factor in evaluation set $V = \{v_1, v_2, v_3, \dots, v_m\}$is expressed as $r_{i,j}$, formula 7 can be used to show the evaluation result of the ith factor u_i:

$$R = \{r_{i1}, r_{i2}, r_{i3}, \dots r_{im}\} \tag{7}$$

- **Build evaluation model to carry out fuzzy overall evaluation:** In consideration of difference importance of each factor, i.e., different indicator weights, it is necessary to combine the weight set *W* and *R* of all the evaluation indicators, to carry out overall evaluation, building overall evaluation model.

The model first multiplies W_i by R_{ij}, then do the sum operation. The model, according to the weight of indicator factor, evenly gives consideration to all the indicator factors, especially applicable to the situation when multiple factors jointly work. Therefore, the competitiveness evaluation of commercial banks in this study adopts that model for calculation.

Multi-hierarchy fuzzy overall evaluation design: In actual cases, if the evaluation object is multiple factors and the weight distribution among all the factors is relatively balanced, we can adopt multi-hierarchy model for evaluation. Following is the introduction to build third-grade model.

- **Divide factor set:** Divide factor U into several hierarchies $U = \{u_1, u_2, u_3, \ldots, u_n\}$, conditions satisfied formula 8:

$$u_i \cap u_j \neq \varphi, \quad when \quad i \neq j \qquad u = \bigcup_{i=1}^{n} u_i \tag{8}$$

  $U = \{u_1, u_2, u_3, \ldots, u_n\}$ is called the first factor set. Suppose $u_i = \{u_{i1}, u_{i2}, u_{i3}, \ldots, u_{in}\}$, $i = 1, 2, 3, \ldots n$, is called the second factor set; $u_{ij} = \{u_{ij1}, u_{ij2}, u_{ij3}, \ldots, u_{ijn}\}$, $i = 1, 2, 3, \ldots n$, $j = 1, 2, 3, \ldots k$ is called the third factor set.
- Carry out first-hierarchy fuzzy overall evaluation on u_{ij}. Suppose that the weight set of $u_{ij} = \{u_{ij1}, u_{ij2}, u_{ij3}, \ldots, u_{ijn}\}$ is $W_{ij} = \{w_{ij1}, w_{ij2}, w_{ij3}, \ldots, w_{ijn}\}$.
- Carry out second-hierarchy fuzzy overall evaluation on u_i. Suppose that the weight set of $u_i = \{u_{i1}, u_{i2}, u_{i3}, \ldots, u_{in}\}$ is $W_{ij} = \{w_{ij1}, w_{ij2}, w_{ij3}, \ldots, w_{ijk}\}$, according to formula 11, overall evaluation is $W_i \circ R_i = B_i$, $i = 1,2,3\ldots n$.
- Carry out third-hierarchy fuzzy overall evaluation on u. Suppose that the weight set of $U = \{u_1, u_2, u_3, \ldots, u_n\}$ is $W_i = \{w_{i1}, w_{i2}, w_{i3}, \ldots, w_{in}\}$, so overall evaluation is $W_i \circ R_i = B_i$, at last, adopt weighted average method to get evaluation result.

RESULTS AND DISCUSSION

Data acquisition and pre-processing: The paper chooses 3 typical supply chains of fresh food products, makes use of statistical data to compute the values of *n* indicators of each supply chain and compute corresponding overall evaluation score of each supply chain with *n* indicator weights through determination and normalization processing of experts, so as to obtain *m* training mode pairs, training the model of this study with such *m* training mode pairs. Subsequently, model in this study can be applied to the performance evaluation of supply chain of fresh food products. Every time when inputting 18 third-class evaluation indicators of supply chain to be evaluated, we can obtain the performance of supply chain of the fresh food products.

The questionnaires of all the evaluation indicators were made and surveyed to the corporations and consumers related to get the score of each indicator for different supply chains of fresh food products. The original data acquired by the survey are pre-processed to the scope of the fuzzy matrix and the final scope of the score is [0, 5].

Experimental results and analysis: Limited to paper space, here only provides parts of (secondary) evaluation results and final comprehensive evaluation results (Table 2) and in which the average evaluation results of the teachers of each university.

As for the performance of the presented algorithm, this study also realizes the application of the ordinary BP neural network (Yanjie *et al*., 2010) and ordinary Fuzzy algorithm (Yuan, 2012), evaluation performance of different algorithms is shown in Table 3. In Table 3 evaluation results of training effects of different students are selected and compared with artificial evaluation to calculate the evaluation accuracy. And the calculation platform as follows: hardware is Dell Poweredge R710, in which processor is E5506, memory 2G, hard disk 160G; software platform is Windows XP operating system, C programming language environment.

Table 2: Secondary results of supply chain

	Logistics level	CRM level	Service integration level	Corporation input	Internal operation	Corporation benefit	Final results
1	3.689	3.461	3.607	3.599	3.422	3.677	3.583
2	4.102	4.381	4.142	4.288	4.107	4.361	4.2008
3	4.429	4.630	4.167	4.380	4.619	4.531	4.449

Table 3: The application performance of different algorithms

Algorithm	Algorithm in this study	Ordinary BP algorithm	Ordinary fuzzy algorithm
Accuracy rate	92.83 %	82.67%	68.82%
Time consuming (S)	12	584	11

CONCLUSION

Comprehensive evaluation of supply chain performance lies in the core status in supply chain management. This study uses BSC to analyze and build comprehensive evaluation system of supply chain performance, makes use of multi-hierarchy fuzzy evaluation method to establish comprehensive evaluation model for supply chain performance and the experimental results illustrates the practicability of the model presented in the study when taking supply chain of food products for example.

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