An Empirical Study of Developing A Dynamic Performance Evaluation System of Green Supply Chain in The Distribution Service Industry from Perspective of International Logistics

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Abstract: - In studies on green supply chain, performance evaluation is an extremely important field. It aims to allow the nodes in supply chain to realize their positions and influence on benefit in overall supply chain in order enhance the supply chain. Thus, implementation of effective performance evaluation is the key to enhance green supply chain development. Distribution service industry is the important service pattern. Logistics of distribution service industry is also the rear service of transportation and storage among manufacturing industry, wholesale industry and retail industry and it is critical for customer satisfaction and reduction of distribution cost. Past researches on green supply chain mostly focus on manufacturing industry and there is no green supply chain study in distribution service industry. Therefore, this study will treat international logistics in distribution service industry as the theme to find how to develop dynamic performance evaluation system of green supply chain in distribution service industry. This study constructs dynamic performance evaluation system of green supply chain into dynamic green Balanced Scorecard, Fuzzy analytical hierarchy process, Fuzzy synthetic decision approach and Grey prediction. Performance evaluation system is constantly modified by PDSA cycle. This evaluation system of green supply chain is simple, cheap, precise, effective and dynamic; moreover, it also helps international logistics firms rapidly make decision regarding resource distribution of supply chain.
Key-Words: - International logistics, Green supply chain, Dynamic performance evaluation system, Dynamic green Balanced Scorecard.

1 Introduction

With the coming of economic globalization and knowledge economy era, industry significantly enhances the progress of society, economy and civilization. However, it leads to environmental problems. Environmental problems draw people's attention and there is the rise of global green movement to protect the environment, the Earth and enhance Sustainable development. Industry produces great amount of waste and considerably consume natural resources and it is overload for the Earth to be recovered. Thus, ecological system can not develop sustainably. In new circumstances, the firms will encounter new challenges and various environmental stresses [12].

Therefore, many countries adjust their development strategies. Global industrial structure reveals the trend of green strategy. Therefore, green strategy is related to various activities of all firms in the whole supply chain. Green supply chain management (GSCM) is thus constructed. Traditional supply chain management is the management of maximum business benefits in supply chain. Although it is associated with material and energy saving, it is simply the concern for business costs and improvement of internal business environment. It does not fully indicate the influences of plans of manufacturing and distribution on the surrounding and people. It also does not suggest the waste disposal, recycling and reuse after the use of products. Therefore, traditional supply chain management slightly functions for sustainable development of resources and environment. Including green idea in overall supply chain management, fulfilling GSCM and leading to the least resource consumption of the whole supply chain and environment influence are the essential measures for modern firms to fulfill sustainable development [1].

Currently, international researches on GSCM are dispersed and they only focus on one technique in supply chain, such as green design, green evaluation of supply chain, selection of green supply chain suppliers and supply chain environmental management. There is no systematic theoretical system and less quantitative analysis. Moreover, the pioneers of implementation only refer to international well-known companies such as HP, IBM and DELL. In studies on green supply chain, performance evaluation is an extremely important field. Corporate performance evaluation has been important in corporate management activity. As the authority of the field, Harrington (1991) has suggested that evaluation is the key. Without evaluation, we will not be able to control. Without control, we cannot manage. Without management, we will not be promoted [5]. In 1985, Kearney indicated that the companies with performance evaluation could increase total production rate by 14%-22%. Performance evaluation of supply chain management is a kind of managerial measure. It aims to allow the nodes in supply chain to realize their positions and influence on benefit in overall supply chain in order enhance the supply chain. By stimulation mechanism, performance evaluation can be valued by the nodes of supply chain. The stimulation mechanism breaks through internal business scope and turns into the mutual stimulation of nodes in supply chain. The stimulation depends on the outcomes of performance evaluation. Stimulation criterion can be established upon negotiation. Thus, implementation of effective performance evaluation is the key to enhance GSCM [2, 8].

According to review, past researches on green supply chain mostly focus on manufacturing industry and there is no green supply chain study in distribution service industry. Therefore, this study will treat international logistics in distribution service industry as the theme to find how to develop dynamic performance evaluation system of green supply chain in distribution service industry. This study aims to construct a green supply chain dynamic performance evaluation system in distribution service industry from perspective of international logistics. Based on the above, the purposes are as follows:

(1) construction of performance evaluation measure framework of green supply chain

(2) analysis of importance and ranking of dimensions of green supply chain and performance measures

(3) evaluation of degrees of dimensions of case study of green supply chain

(4) construction of dynamic performance evaluation system of green supply chain

2 Method

2.1 Research procedures

2.1.1 Establishing a performance evaluation indicator framework

This study designed two questionnaires to achieve questionnaire design suitability and reduce errors. The first questionnaire referenced Balanced Scorecard applications and relevant literature, and then categorized the performance evaluation indicator framework into a dynamic green Balanced Scorecard with five primary dimensions: green energy saving and carbon reduction, finance, customers, internal processes and learning, and growth.

2.1.2 Modifying the performance evaluation indicator framework

The first questionnaire designed adopts a seven point Likert scale. In the hopes of using the questionnaire results to evaluate these performance indicators, those operating in international logistics were selected as subjects. After eliminating unimportant performance indicators, the remaining indicators were used to design the second questionnaire.

2.1.3 The weighting and ranking of important performance evaluation indicators

The second questionnaire uses the hierarchical framework established for the fuzzy analytical hierarchy process. The primary purpose of this process is to understand the relative weighting of each dimension and criterion, and their importance.

2.1.4 Fuzzy analytical hierarchy process

The procedural explanation for using FAHP to perform decision-proposal selection is as follows:

(1) Establishing hierarchy

Assume that K number of experts perform decision analysis on the hierarchical structure of n number of proposals (criteria or alternatives) $(A_1, A_2, ..., A_n)$.

(2) Establishing a fuzzy positive reciprocal matrix

Each expert used linguistic variables to express his or her evaluation of the relative importance of two proposals. These linguistic variables can be expressed through triangular fuzzy numbers.

The fuzzy positive reciprocal matrix $\tilde{T}^k$ of k^{th} expert is constructed as follows:

$$\tilde{T}^k = [\tilde{T}^k_{ij}]$$

Where, $\tilde{T}^k{}_{ij}$, $i, j = 1,2,\cdots,n$, is the relative importance comparison value of i^th proposal relative versus the j^th proposal given by the *k*^th expert.

$$\tilde{T}^k{}_{ij} = 1 \text{，} \forall\ i = j$$

$$\tilde{T}^k{}_{ji} = 1/\ \tilde{T}^k{}_{ij} \text{，} \forall\ i, j = 1,2,\cdots,n$$

(3) Consistency test

When the comparison matrix is an inverted matrix, it is difficult to demand before and after consistency from decision makers. If the inconsistency of the situation is too severe, then the research results will show a significant deviation from actual conditions, thus producing incorrect decisions. Thus, consistency tests must be performed to obtain consistency indices to filter these messages and ensure the reflection of actual conditions. Slight changes in the element value of the positive reciprocal matrix will cause corresponding changes in maximum eigenvalue $\lambda\max$. Thus, the difference between $\lambda\max$ and *n* can be used as an evaluation standard for measuring consistency. The definitions of consistency index *C.I.* and consistency ratio *C.R.* are as follows:

$$C.I. = (\lambda_{\max} - n) / (n-1)$$

$$C.R. = C.I./R.I.$$

Where, n：Number of assessment elements,

R.I.: Random index.

When *C.I.* is 0, the judgment of the decision maker is completely consistent. The higher the *C.I.* value is, the higher the degree of inconsistency. Saaty (1988) recommends *C.R.* ≤ 0.1 as a level of acceptable consistency.

(4) Calculating fuzzy weighting

Buckley and Csutora's (2001) Lambda-Max method is used to calculate the fuzzy weighting values [6]. The calculation steps are as follows:

(a) Make α =1, the explicit positive reciprocal matrix $T_b^k = [T_{ijb}^k]_{n\times n}$ of the *k*^th expert can be obtained by using the *α* cut-set.

The analytic hierarchy process (AHP) is then used as the method for calculating weight to obtain the weighting matrix $W_b^k = [w_{ib}^k]$, $i = 1,2,\cdots,n$.

(b) Make α =0, using the *α*-cut series to obtain the lower-limit and upper-limit explicit positive matrices, which are $T_a^k = [T_{ija}^k]_{n\times n}$, and $T_c^k = [T_{ijc}^k]_{n\times n}$, respectively.

The AHP calculation method for weighting is used to obtain weighting matrices W_a^k , and W_c^k , respectively. Where, $W_a^k = [w_{ia}^k]$, $W_c^k = [w_{ic}^k]$, $i = 1,2,\cdots,n$.

(c) Ensure that the calculated weight value is a fuzzy number, using the following formulae to obtain the adjustment coefficient：

$$Q_a^k = \min \left\{ \frac{w_{ib}^k}{w_{ia}^k} \middle| 1 \le i \le n \right\}$$

$$Q_c^k = \max \left\{ \frac{w_{ib}^k}{w_{ic}^k} \middle| 1 \le i \le n \right\}$$

After using the adjustment coefficient, the lower-limit and upper-limit for the weighting of each proposal is:

$$w_{ia}^{k^*} = Q_a^k\ w_{ia}^k$$

$$w_{ic}^{k^*} = Q_c^k\ w_{ic}^k$$

Thus, the following upper-limit and lower-limit matrices of the weighting can be obtained:

$$W_a^{k^*} = [w_{ia}^{k^*}],\ i = 1,2,\cdots,n .$$

$$W_c^{k^*} = [w_{ic}^{k^*}],\ i = 1,2,\cdots,n .$$

(d) Combining $W_a^{k^*}$ **,** W_b^k and $W_c^{k^*}$ can obtain the PTFN weight matrix of the *k*^th expert $W^{k^*} = [w_i^{k^*}]$**,** $i = 1,2,\cdots\cdots,n$ ，Here, $\tilde{W}_i^k = \left(w_{ia}^{k^*}, w_{ib}^k, w_{ic}^{k^*}\right)$ is the fuzzy weighting value of the *k*^th expert on the *i*^th proposal

(5) Opinion integration

This study uses the following average method to integrate the fuzzy weighting values of multiple experts:

$$\tilde{\tilde{W}}_i = (1/K) \otimes \left(\tilde{W}_i^1 \oplus \tilde{W}_i^2 \oplus \cdots \oplus \tilde{W}_i^K\right)$$

Where, $\tilde{\tilde{W}}_i$ denotes the fuzzy integration weighting value of the all experts on the *i*^th proposal;

$\widetilde{W}_t^k$ denotes the fuzzy weighting of the k^{th} expert on the i^{th} proposal;

K denotes the number of experts.

(6) Fuzzy sequencing

This study uses Chen and Huang's (2002) defuzzification formula to obtain the defuzzification values of each proposal for sequencing [10]. The calculation formula is as follows:

$$r_{w_i} = \frac{d^-\left(\widetilde{\overline{W}}_i 0\right)}{d^-\left(\widetilde{\overline{W}}_i,0\right)+d^+\left(\widetilde{\overline{W}}_i,1\right)} \text{ , } i=1,2,\cdots,n \text{ ;}$$

$0 \leqq r_{w_i} \leqq 1$

Where, r_{w_i} represents the, sequence value of proposal A_i ,

and $\widetilde{\overline{W}}_i = (\overline{w}_{ia}, \overline{w}_{ib}, \overline{w}_{ic})$.

$$d^-\left(\widetilde{\overline{W}}_i,0\right) = \sqrt{\tfrac{1}{3}\left[\left(\overline{w}_{ia}-0\right)^2+\left(\overline{w}_{ib}-0\right)^2+\left(\overline{w}_{ic}-0\right)^2\right]}$$

$$d^+\left(\widetilde{\overline{W}}_i,1\right) = \sqrt{\tfrac{1}{3}\left[\left(\overline{w}_{ia}-1\right)^2+\left(\overline{w}_{ib}-1\right)^2+\left(\overline{w}_{ic}-1\right)^2\right]}$$

The greater r_{w_i} is, the higher the priority of proposal A_i.

2.1.5 Grey prediction

Among grey models, the first order grey model with one variable GM (1,1) has been applied widely. When the original data sequences imply exponential laws, it is very advisable to use GM (1,1) model for forecasting [7].

Suppose there is an original time sequence with n samples (time point) $x^{(0)}$ and $x^{(0)}$ can be expressed as,

$$x^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right)$$

where, $x^{(0)}(i)(i=1,2,3,\cdots)$ is the time series data at time i, n should be equal to or larger than 4.

In order to reveal the objective law of systems, the grey system theory adopts a unique data preprocessing method before model is to be established. It uses Accumulated generating operation (AGO) to accumulate the sequence $x^{(0)}$ and obtain $x^{(1)}$, that is,

$$\begin{aligned} x^{(1)} &= \left(x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\right) \\ &= \left(\sum_{k=1}^{1} x^{(0)}(k), \sum_{k=1}^{2} x^{(0)}(k), \cdots, \sum_{k=1}^{n} x^{(0)}(k)\right) \end{aligned}$$

The sequence $x^{(1)}(k)$ has exponential increasing rules, and the solution of one-order differential equation is just exponential increasing form. In fact, the sequence $x^{(1)}$ satisfies one-order linear differential equation:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = \text{u}. \tag{1}$$

Using discrete one-order linear difference Eq. (1), one can obtain a matrix as follows,

$$\begin{pmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{pmatrix} = \begin{bmatrix} -\frac{1}{2}\left[x^{(1)}(1)+x^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[x^{(1)}(2)+x^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\left[x^{(1)}(n-1)+x^{(1)}(n)\right] & 1 \end{bmatrix} \begin{pmatrix} a \\ u \end{pmatrix}$$

Let

$$Y_n = \begin{pmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{pmatrix} ,$$

$$\text{B} = \begin{bmatrix} -\frac{1}{2}\left[x^{(1)}(1)+x^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[x^{(1)}(2)+x^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\left[x^{(1)}(n-1)+x^{(1)}(n)\right] & 1 \end{bmatrix}, \quad \text{A} = \begin{pmatrix} a \\ u \end{pmatrix}$$

the matrix can be expressed as,

$$Y_n = B \times A. \tag{2}$$

In the Eq. (2), Y_n and B can be obtained directly by the original data, but A needs more calculation. One usually uses least square method to get the least-square approximation, and the Eq. (2) can be expressed as,

$$Y_n = B \times \hat{A} + e^*$$

where, e^* is an error term.

Using matrix derivation formula, one gets,

$$\hat{A} = (B^T B)^{-1} B^T Y_n = \begin{pmatrix} \hat{a} \\ \hat{u} \end{pmatrix}.$$

So, $\hat{u}$ and $\hat{a}$ are obtained, furthermore,

$$x^{(1)}(t+1) = \left[x^{(1)}(1) - \frac{\hat{u}}{\hat{a}} \right] e^{-\hat{a}t} + \frac{\hat{u}}{\hat{a}}.$$

Let $x^{(1)}(1) = x^{(0)}(1)$, the time response function of GM(1,1) model is also obtained,

$$\left[x^{(0)}(1) - \frac{\hat{u}}{\hat{a}} \right] \times e^{-\hat{a}k} + \frac{\hat{u}}{\hat{a}} \qquad (k = 1,2,3,\cdots)$$

(3)

Then, one does inverse accumulated revivification with the time response function (3), and gets Grey prediction model,

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) = \left[x^{(0)}(1) - \frac{\hat{u}}{\hat{a}} \right] (1 - e^{\hat{a}}) e^{-\hat{a}k}$$

$$(k = 1,2,3,\cdots)$$

(4)

After substituting the correlative data into expression (4), one can resolve the coefficients $\hat{u}$ and $\hat{a}$. Then, the concrete prediction formula can be confirmed [11].

2.1.6 Prediction errors

(1) Mean absolute percentage error

Mean absolute percentage error (MAPE) is measure of accuracy in a fitted time series value in statistics, specifically trending. It usually expresses accuracy as a percentage, and is defined by the formula:

$$\text{MAPE} = \frac{1}{n} \sum_{k=1}^{n} \frac{\left| \hat{x}^{(0)}(k) - x^{(0)}(k) \right|}{x^{(0)}(k)} \times 100\%$$

where $x^{(0)}(k)$ is the actual value and $\hat{x}^{(0)}(k)$ is the forecast value.

The difference between $x^{(0)}(k)$ and $\hat{x}^{(0)}(k)$ is divided by the actual value $x^{(0)}(k)$ again. The absolute value of this calculation is summed for every fitted or forecast point in time and divided again by the number of fitted point n. This makes it a percentage error so one can compare the error of fitted time series that differ in level.

(2)Mean squared error

In statistics, the Mean squared error (MSE) of an estimator is one of many ways to quantify the difference between values implied by an estimator and the actual value of the quantity being estimated. It usually expresses accuracy as a percentage, and is defined by the formula:

$$\text{MSE} = \frac{1}{n} \sum_{k=1}^{n} \left(\hat{x}^{(0)}(k) - x^{(0)}(k) \right)^2$$

where $x^{(0)}(k)$ is the actual value and $\hat{x}^{(0)}(k)$ is the forecast value.

MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss. MSE measures the average of the squares of the "errors". The error is the amount by which the value implied by the estimator differs from the quantity to be estimated.

2.1.7 PDSA cycle

In 1987 Moen and Nolan presented an overall strategy for process improvement with a modified version of Deming’s cycle of 1986 [3, 4]. The planning step of the improvement cycle required prediction and associated theory. The third step compared the observed data to the prediction as a basis for learning [9]. Langley, Nolan, and Nolan refined the improvement cycle and called it the PDSA cycle. The use of the word “study” in the third phase of the cycle emphasizes that the purpose of this phase is to build new knowledge.

2.2 Flowchart for developing dynamic performance evaluation system

This study will treat international logistics as the theme to find how to develop dynamic performance evaluation system of green supply chain. This study constructs dynamic performance evaluation system of green supply chain into dynamic green Balanced Scorecard, FAHP, Fuzzy synthetic decision approach and Grey prediction. Performance evaluation system is constantly modified by PDSA loop. The previous steps can be served as the baseline reference for the next step, and the flowchart are described as shown in Figure 1.

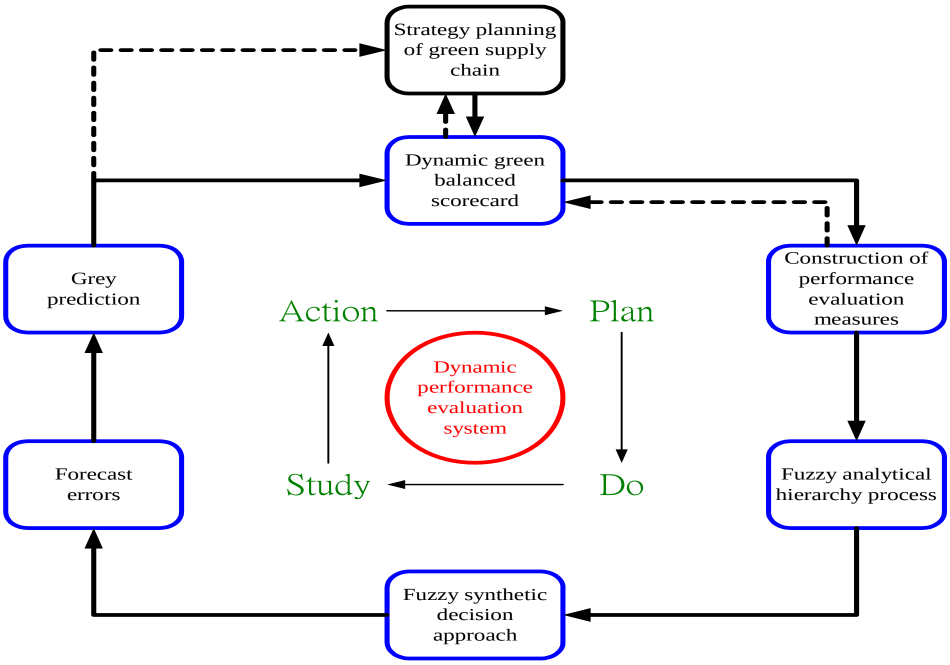

Figure 1. Flowchart for developing dynamic performance evaluation system.

4 An Empirical Example

This study constructs dynamic performance evaluation system of green supply chain into dynamic green Balanced Scorecard, FAHP, Fuzzy synthetic decision approach and Grey prediction. Performance evaluation system is constantly modified by PDSA loop. The previous steps can be served as the baseline reference for the next step, and the steps are described as follow.

4.1 Construction of performance evaluation measure framework

In the first questionnaire, upon Balanced Scorecard and related literatures, performance evaluation measure framework is generalized as dynamic green Balanced Scorecard with five dimensions. The previous measures found in literatures are reorganized into 53 performance evaluation measures which are included into five dimensions after proper explanation and definition. According to responses of international logistics industry, 53 measures are screened.

4.2 Modification of performance evaluation measure framework

In the first questionnaire designed, seven-point Likert scale is adopted. This study intends to screen 53 measures according to responses of international logistics industry. Regarding each dimension, this study only selects top seven measures with the highest means. Among 53 measures, this study eliminates 18 measures and keeps 35 of them to design the second questionnaire for FAHP of the next stage.

4.3 Questionnaire weight analysis of fuzzy analytical hierarchy process

There are three levels in hierarchical framework. The first level is study on development of distribution service industry of dynamic performance measure system of green supply chain. The second level refers to five dimensions of Balanced Scorecard. The third level is the performance evaluation measures in the dimensions. With the hierarchical framework, this paper can design the questionnaire of FAHP at the next stage.

4.3.1 Weight and ranking of dimensions at the second level

Performance evaluation of green supply chain at the second level includes five dimensions. After FAHP, green energy saving and carbon reduction reveals the highest weight. The following are finance and customers. Relative weight and ranking of dimensions are shown in Table 1.

Table 1. Weight and ranking of dimensions at the second level

Dimensions	Weight	Ranking
Green energy saving and carbon reduction	0.742609	1
Finance	0.202974	2
Customers	0.042206	3
Internal process	0.005209	5
Learning and growth	0.007002	4

4.3.2 Weight and ranking of dimensions at the third level

Taking customers as an example and third level is described as follow.

As to customers, there are seven performance evaluation measures. After FAHP, top three weights are on-time delivery rate, on-time delivery rate and customer retention rate. Weight and ranking of performance evaluation measures of customers are shown in Table 2.

Table 2. Weight and ranking of performance evaluation measures of customers

Performance evaluation measures	Weight	Ranking
3-1. Customer service satisfaction rate	0.231821	2
3-2. Customer retention rate	0.137925	3
3-3. Average response time for customers' needs	0.125488	4
3-4. On-time delivery rate	0.246511	1
3-5. Return rate	0.066847	7
3-6. Repair rate	0.075227	6
3-7. Perfect order percentage	0.116181	5

After pair comparison of performance evaluation measures at the second and third levels and acquisition of the relative weights, the researcher multiplies weight of performance evaluation measure by weight of dimensions to obtain total weight of performance evaluation measure.

As to overall weight, top ten measures are JIT distribution rate, on-time delivery rate, customer service satisfaction, receivables turnover ratio, material utilization ratio, operating profit ratio, operating profit ratio, profit of green new technique R&D, investment of green R&D expense and return on net assets.

4.4 Fuzzy synthetic decision approach of case supply chain

4.4.1 A case of supply chain

In order to validate the feasibility of research approach, this study conducts empirical analysis on one supply chain. The case supply chain is a member of FIATA, NOVCC and FMC was established in 1987, they have 60 staffs working for this group at the present time. They are responsible for the clearance of the cargoes through customs and delivery through air, sea, road, rail or combined mode of transport.

4.4.2 Fuzzy synthetic decision approach

In order to conduct fuzzy synthetic decision approach, the experts fill in the questionnaires regarding case supply chain as the evaluation outcomes. The examination is based on five dimensions and the levels include "excellent", "good", "general" and "poor". Weights of five dimensions are according to responses of ten industrial experts in questionnaires. Taking learning and growth as an example as follow.

(a) Learning and growth

According to industrial experts' evaluation on case supply chain by fuzzy synthetic decision approach, regarding learning and growth, overall supply chain is good, as shown in Table 3.

Table 3. Level of case supply chain regarding learning and growth

Excellent	Good	General	Poor
0.134234	0.483258	0.366151	0

(b) Overall dimension of supply chain

According to industrial experts' evaluation on case supply chain, regarding five dimensions, overall supply chain is good, as shown in Table 4.

Table 4. Level of case supply chain in overall dimension

Excellent	Good	General	Poor
0.194253	0.526966	0.257015	0.002351

According to fuzzy synthetic decision approach above, case supply chain is good regarding "green energy saving and carbon reduction", "finance", "internal process" and "learning and growth"; however, it is general in "customers". Case supply chain can make decisions of resource distribution according to the said experts' suggestions.

4.5 Evaluation outcome and analysis of dynamic performance measures of case supply chain

Operation of case supply chain in 2007-2010 is the subject of analysis. Historic figures of five dimensions and 35 performance evaluation measures are indicated for Grey prediction at the next stage. Using historic figures of green energy saving and carbon reduction as examples, performance of different years is shown in Table 5. This study will analyze performance measures of green energy saving and carbon reduction below.

Taking material utilization ratio as an example and evaluation outcome and analysis are described as follow.

Forecast error of material utilization ratio is shown in Table 6. This study tries to find if forecast errors are within upper and lower limits by mean-square error and MAPE and if prediction is precise.

(1) Mean-square error

$$\text{MSE} = \frac{1}{n}\sum_{k=1}^{n}\left(\hat{x}^{(0)}(k) - x^{(0)}(k)\right)^2 = 0.42/4 = 0.11$$

$$s = \sqrt{\text{MSE}} = 0.33$$

Decision of upper and lower limits 2s:

$$0 \pm 2s = 0 \pm 2 \times 0.33 = \pm 0.66$$

All errors are within upper and lower limits.

(2) Average absolute percentage error

$$\text{MAPE} = \frac{1}{n}\sum_{k=1}^{n}\frac{\left|\hat{x}^{(0)}(k) - x^{(0)}(k)\right|}{x^{(0)}(k)} \times 100\%$$

$$= (0/68.34 + 0.3/67.54 + 0.5/69.72 + 0.29/70.13)/4$$

$$= 0.39\%$$

The lower MAPE is, the stronger the correct prediction of the model will be. Model assessment outcome will be more likely to meet historic data. According to the finding, MAPE is below 10%. Thus, it means the prediction is highly precise.

By Grey prediction, prediction value of material utilization ratio in 2011 is 71.75, as shown in Table 7.

This study analyzes operation of case supply chain in 2007-2010 by Grey prediction. After assessing seven historic performance measures of green energy saving and carbon reduction, this study obtains prediction value in 2011, as shown in Table 8. Prediction values of performance measures of five dimensions are also calculated.

Table 5. Historic figures of performance measures of green energy saving and carbon reduction

Performance measures	2007	2008	2009	2010
Material utilization ratio%	68.34	67.54	69.72	70.13
Energy consumption rate%	19.86	20.02	19.88	19.81
Storage capacity utilization ratio %	67.21	70.63	69.42	76.78
Material re-utilization ratio%	45.24	47.75	51.21	48.17
Average fine to violate green regulations	7260	6530	4680	3250
Material recycling rate %	32.45	35.68	38.43	36.57
Percentage of green certification passing %	0.45	0.53	0.58	0.62

Table 6. Forecast error of material utilization ratio

Material utilization ratio %	2007	2008	2009	2010
Actual value	68.34	67.54	69.72	70.13
prediction value	68.34	67.84	69.12	70.42
Error＝actual value－prediction value	0	－0.3	0.5	－0.29
/Error/	0	0.3	0.5	0.29
Square of error	0	0.09	0.25	0.0841

Table 7. Prediction value of material utilization ratio in 2011 by grey prediction

Actual value	2007	2008	2009	2010	2011
prediction value	68.34	67.54	69.72	70.13	
Error＝actual value －prediction value	68.34	67.84	69.12	70.42	71.75
/Error/	0	－0.3	0.5	－0.29	
Square of error	0	0.3	0.5	0.29	
Actual value	0	0.09	0.25	0.0841	

Table 8. Prediction values of performance measures of dimensions of green energy saving and carbon reduction

Performance measures		2007	2008	2009	2010	2011
Material utilization ratio ％	Actual value	68.34	67.54	69.72	70.13	
	prediction value	68.34	67.84	69.12	70.42	71.75
Energy consumption rate ％	Actual value	19.86	20.02	19.88	19.81	
	prediction value	19.86	20.01	19.90	19.80	19.69
Storage capacity utilization ratio ％	Actual value	67.21	70.63	69.42	76.78	
	prediction value	67.21	69.15	72.22	75.42	78.76
Material re-utilization ratio ％	Actual value	45.24	47.75	51.21	48.17	
	prediction value	45.24	48.84	49.04	49.25	49.46
Average fine to violate green regulations	Actual value	7260	6530	4680	3250	
	prediction value	7260	6493	4613	3277	2328
Material recycling rate ％	Actual value	32.45	35.68	38.43	36.57	
	prediction value	32.45	36.46	36.89	37.33	37.77
Percentage of green certification passing	Actual value	0.45	0.53	0.58	0.62	
	prediction value	0.45	0.5322	0.5752	0.6217	0.672

5 Conclusions

Regarding this study, there are four conclusions:

(1) This study has constructed performance evaluation measure framework of green supply chain.

This study generalizes performance evaluation measure framework into Dynamic Green Balanced Scorecard with five dimensions. By 7-point Likert scale and according to responses of international logistics firms, this study eliminates 18 from 53 performance evaluation measures and finally keeps 35 measures for modified performance evaluation measure framework of green supply chain.

(2) This study has recognized importance and ranking of dimensions of green supply chain and performance measures by FAHP.

By FAHP, this study constructs performance evaluation measure framework in order to obtain relative weights of dimensions and performance measures to recognize the importance and ranking.

After FAHP, green energy saving and carbon reduction reveals the highest weight and the following are finance and customers.

As to green energy saving and carbon reduction, the top three weights refer to material utilization ratio, percentage of green certification passing and material re-utilization ratio. As to finance, top three weights are receivables turnover ratio, operating profit ratio and return on net assets. As to customers, top three weights refer to on-time delivery rate, on-time delivery rate and customer retention rate. Regarding internal process, top three weights are JIT distribution rate, unit transportation cost and production and sales rate of supply chain. Regarding learning and growth, top three weights are profit of green new technique R&D, investment of green R&D expense and employee satisfaction rate.

As to overall weight, top ten weight and ranking are JIT distribution rate, on-time delivery rate, customer service satisfaction, receivables turnover ratio, material utilization ratio, operating profit ratio, operating profit ratio, profit of green new technique R&D, investment of green R&D expense and return on net assets.

(3) This study has evaluated degrees of dimensions of case green supply chain by Fuzzy Synthetic Decision Approach

This study conducts empirical analysis according to fuzzy synthetic decision approach, case supply chain is good regarding “green energy saving and carbon reduction”, “finance”, “internal process” and “learning and growth”. However, it is general on “customers”. Industrial experts’ suggestions can serve as references for case supply chain to distribute the resources.

(4) This study has constructed a dynamic performance evaluation system of green supply chain

The most significant characteristic of dynamic performance evaluation system upon Grey prediction is that the model can be constructed by at least four pieces of data and the prediction is precise. International logistics firms can conduct prediction only by collecting at least four periods of data. These periods may be seasons, months, days and so on. They will thus obtain prediction value of the next period. It demonstrates the dynamic advantage and resources of supply chain can be distributed.

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