流通科学大学論集―流通・経営編―第 26 巻第 2 号，19-34（2014）

Comparison of Different Prioritization Methods in the Combination Methods of the Structural Equation Model (SEM) and Analytical Hierarchy Process (AHP) on the Performance Measurement of a Thai Frozen Shrimp Supply Chain

Sirirat Pungchompoo*, Takayuki Mori†, Apichat Sopadang‡

This paper proposes a combination method between SEM and AHP by applying the eigenvector method, the geometric mean method, and the new least squares method to calculate weights and rank elements in the comparison process for balance score card alternatives. The results show no difference in the ranking scores of the three ranking methods and show the financial perspective was prioritized first, followed by the customer perspective. However, the eigenvector is easier to calculate and is a valid method for deriving the priority vector from a pairwise comparison matrix than other methods.

Keywords: Performance measurement; structural equation model; analytical hierarchy process; least squares method.

I. Introduction

Thailand is the world's leading producer and exporter of the globalized shrimp market, with approximately 33% of the world's market share. More than 300,000 tons of Thailand's shrimp products were exported to the global market, and 81,000 tons of the total shrimp products were exported to Japan in 2012. Thailand's shrimp cultivation is highest in SuratThani province, Chachoengsao province, Chanthaburi province, and Songkla province, respectively. The area of the shrimp cultures comprises approximately 23,333 farms, embracing an area of 509 square kilometer. Production of white shrimp is the best representation of the shrimp industry chain in Thailand, because it represents 553,899 tons of Thailand's total shrimp production of 559,644 tons, which represents 98.97%of all shrimp production in 2012 (Office of Agricultural Economics, 2012).

The shrimp supply chain is divided into three main sections: first, upstream hatcheries, nurseries, farms, and shrimp farms cultivate shrimp over a period of 90–120 days. Next, the midstream section consists of an intermediary business. There are shrimp brokers, markets, and a central shrimp market, which buy shrimp and distribute it downstream. Finally, the downstream section is composed of frozen industrial companies and seafood processing centers. All raw shrimp material is processed to frozen food or others seafood companies. This is the value addition to the shrimp product and forms product characteristics,

* University of Marketing and Distribution Sciences, Visiting Researcher, 651-2188 3-1, Gakuen-nishimachi, Nishi-ku, Kobe
† University of Marketing and Distribution Sciences, Faculty of Commerce, 651-2188 3-1, Gakuen-nishimachi, Nishi-ku, Kobe
‡ Chiang Mai University, Faculty of Engineering, Chiang Mai, Thailand 50202

（2013 年 8 月 30 日受理）

which results in offering more choice to the market than other competitors. The Department of Fisheries is responsible for the regulation of fishery products; it ensures that shrimp farming is done to relevant standards (Good Agriculture Practice: GAP), in order to produce quality, trustworthy shrimp for consumers. The next standard includes guidelines and procedures in manufacturing (General Manufacturing Practice: GMP), in order to enforce the law. Food is provided in sealed containers to meet the GMP and the laws surrounding food production. The Hazard Analysis and Critical Control Point (HACCP) can be seen as the shrimp industry's standards. All standards are enforced to meet the requirements of government agencies and international partners.

Thailand's main foreign competitors are China and Vietnam. Both countries export 290,000 tons and 240,000 tons, respectively, of shrimp products to the global market (Office of Agricultural Economics, 2012).In addition, there are many problems in the Thai shrimp chain, including the high cultivation cost of shrimp, disease, not enough cold storage for frozen shrimp, and child labor and forced labor. Therefore, efficient performance is necessary for benchmarking and to compete effectively. The shrimp organization and shrimp supply chain should improve their performance, in terms of marketing, quality, distribution, and environmental issues. However, the overall performance of the Thai shrimp supply chain only focuses on a financial dimension. For example, the upstream is focused on improving performance in production costs and the quality of shrimp. The midstream focuses on the costs of transportation, and downstream enterprises focus on labor costs and the quality of shrimp products.

This paper proposes combination methods between SEM and AHP by applying the eigenvector method, (EM) the geometric mean method (GM), and the new least squares method (NLSM) to calculate weights and rank the elements of Balance Score Card (BSC) perspectives for comparison. By synthesizing a new performance measurement model, the researcher will integrate the conceptual ideas using the Confirmatory Factor Analysis (CFA) technique, which is a component of structural equation modeling (SEM) based on multiple decisions being made. The Confirmatory Factor Analysis (CFA) method is used to analyze the model. The reliability and validity of the research instrument will be tested to ensure the adequacy and feasibility of the model. The confirming structure of the model and the explicit correlation among KPIs will be presented, in terms of a causal relationship. SEM suggests the importance and significance of the relationship between the indicators. Then, the research will apply the analytical hierarchy process (AHP) to synthesize and prioritize the important BSC perspectives and criteria.

First, we developed concept ideas for a new performance measurement model based on the 4 selection aspects of the BSC from the literature review. The model will be formulated using five criteria: finance efficiency, flexibility, responsibility, quality, and innovativeness. This will be done as a theory hypothesis using the CFA method. Second, we find weight scores from the second-order factor loading of CFA and

AHP and also estimate weights and prioritize all criteria from the pairwise comparisons matrix by using the EM method, the CM method, and The NLSM method.

II. Literature review

Performance measurement is widely used to evaluate supply chains (e.g. Olugu et al., 2010; Setthasakko, 2009; Theeranuphattana and Tang, 2007; Chan and Qi, 2003; Bhagwatand Sharma, 2010; Wong and Wong, 2007; Xu et al., 2009; Tseng and Lee, 2009). It is a necessary component of business planning and decision making, and it can also contribute to the development and improvement of supply chain management (SCM) (Chan and Qi, 2003). Performance measurement can be defined as a process to measure the efficiency and effectiveness of past actions (Neely et al., 1995). Moreover, performance measurement can also be defined as a process of assessing and evaluating the effective and efficient utilization of the people, resources, and technology that make up an organization. The number of studies on performance measurement has been increasing and covers not only financial dimensions, but also non-financial measurements (Sen and Yeng, 1998; Beamon, 1998). Many researchers have applied systematic thinking, such as multiple criteria decision making (MCDM), the analytical hierarchy process (AHP) (Bhagwat and Shama, 2007), and the fuzzy-AHP to develop performance measurement models and/or to evaluate an organization's efficiency and effectiveness (Chan and Qi, 2003). The measurement of supply chain performance is essential, since it can affect decision making through the evaluation of past behavior; it is also an opportunity for benchmarking (Van der Vorst, 2006). In order to improve the efficiency and effectiveness of a supply chain, the BSC concept has been widely used to evaluate specific business processes and SCMs (Kaplan and Norton, 1992; Bhawat and Shama, 2007). However, the methods described above have two weaknesses (Zhu et al., 2008; Kim, 2009). First, the performance model used to test are search instrument must have good reliability and validity, in case the data are collected with a questionnaire. Second, the completed performance model, which came from the decision making method, did not show a correlation among factors, in terms of a causal relationship.

A performance model can be improved by model testing. In this case, Tippayawong et al. (2010) applied factor analysis (FA) to determine a performance structure for high-tech and low-tech industry groups and to evaluate operational performance in both industries by using the SCM Logistics Scorecard model. The results clearly showed that the high-tech industry group was significantly better at determining performance structures than the low-tech industry group; it also exposed the factors that were different, in terms of IT utilization.

Furthermore, many researchers have suggested using structure equation modeling (SEM), which is widely used in sociology, psychology, management, and economics (Li et al., 2009; Zhu et al., 2008; Kim, 2009;

Punniyamoothy et al., 2011; Chinho et al.,2005). Puuniyamoorthy et al. (2011) used SEM combined with fuzzy logic to select suppliers, while Tseng and Lee (2009) used SEM to explain how human resource practices have affected organizational performance. Li et al. (2005) developed and validated six indicators of supply chain management practices using SEM: strategic supplier partnerships, customer relationships, information sharing, information quality, internal lean practices, and postponement.

To achieve an explanation in terms of a causal model, many researchers applied LISREL software to calculate statistical values (Li et al., 2005; Tseng and Lee, 2009; Puuniyamoorthy et al., 2011). Moreover, the application of SEM usually includes complicated models, such as confirmatory factor analysis (CFA), full models, simplexes, multi-models, t-tests, variance analyses, and path analyses of SEM (Mueller, 1996). To increase the efficiency of the synthesis model, a researcher must integrate the SEM into AHP, using experts or specialists to determine the weight of each indicator. This process can decrease subjective error in performance evaluation.

III. A framework of Thailand's frozen shrimp supply chain

This section proposes a framework of criteria and sub-criteria designed to improve Thailand's frozen shrimp industry. The proposed conceptual framework is composed of the efficiency of environmental KPIs, flexibility, and quality (product and process quality), which include environmental aspects, responsiveness, and innovativeness (Pungchompoo and Sopadang, 2010). A description of the key components of the performance measurement framework is given in a table (see Appendix A for the table).

IV. Model proposed using the SEM method

In this research, we applied first-order and second-order factor models. The first-order factor models are the main criteria that correlate among sub-criteria (the observed variables) in the performance measurement model. Second-order factor models are those that correlate among the-first order factors. In other words, each perspective of BSC relates to each criterion. It explains that each perspective is linked indirectly to those measuring the first order factor and hypothesized second-order CFA model. Therefore, the notation of their sub-criteria and measurement errors variables is explained by the measure equation Y-model. The measure equation can be summarized as:

$$Y=\Lambda_y\eta+\varepsilon \qquad (1)$$

Where;

Λ_y is the first order factor loading

η is criteria (the latent endogenous variables)

ε is the measurement error term

And the higher order structure can be summarized as:

$$\eta = \Gamma\xi + \varsigma \tag{2}$$

Where;

Γ is the second order factor loading.

ξ is the BSC perspectives.

ς is the residual error term.

The factor loading from SEM can be linked into weight method for AHP and also this combined weight method has strong support in the literature (Zhu et al., 2009; and Puuniyamoorthy et al. 2012). Therefore, this research applied the relative weightage (RW) for each criterion (η) to evaluate performance measurement model by AHP.

$$RWj = r_j/\Sigma r_j \tag{3}$$

Where;

Γ_j is the second order factor loading.

$\Sigma\Gamma_j$ is the sum of all the second order factor loadings.

j is 1,2…,5

The preference BSC perspectives (BSC) for i=1 to 4:

$$BSC_i = \Sigma^m{}_{j=1} RW_j b_{ij} \tag{4}$$

Where;

b_{ij} is relative weightage for BSC_i with respect *to* j^{th} criterion.

RW_j is relative weightage for criterion.

BSC_i is BSC perspectives i for performance evaluation.

So the weight can be expressed in the form of

$$W_i = (\Pi^n{}_{j=1}\, a_{ij})^{1/n} \tag{5}$$

Where;

a_{ij} is a pair-wise comparison score in each criterion with respect to BSC perspectives.

W_i is the relative weights of criteria.

V. Pairwise estimation Method to calculate weight and rank elements.

V-1. Eigenvalue Method (EM)

The eigenvalue method can be used to determine the required prioritization, both for consistent and inconsistent points of judgment. The quintessence of the most common form of this AHP is Saaty's eigenvalue technique. Let A be the desired priority vector w; then, the linear system is as follows:

$$\mathrm{Aw} = \boldsymbol{\lambda}_{max} w \qquad (6)$$

Where$\boldsymbol{\lambda}_{max}$ is the largest eigenvalue of A. It has to be noted that the eigenvector solution is normalized additively, i.e. $\sum_{i=1}^{n} w_i = 1$.

V-2. Geometric Mean Method (GMM)

According to Gao et al., (2009), the geometric mean method derives from the Logarithmic Least-Squares method (LLS), which defines the objective function of the optimization problem as follows:

$$min \sum_{i=1}^{n} \sum_{j>1}^{n} \left[ln a_{ij} - \left(ln w_i - ln w_j\right)\right]^2,$$

subject to

$$\prod_{j=1}^{n} w_i = 1$$

$$w_i > 0, i = 1, 2, \ldots, n. \qquad (7)$$

Therefore, the geometric mean method is defined as

$$w_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \Big/ \sum_{k=1}^{n} \left(\prod_{j=1}^{n} a_{kj}\right)^{1/n} \qquad (8)$$

V-3. New Least Squares Method (NLSM)

Usually, the general form of LSM is a minimization problem, and the objective function is nonlinear and ordinarily non convex (equation 9). Thus, the LSM is difficult to solve, difficult to compute, and has no unique solution:

$$min\sum_{i=1}^{n}\sum_{j=1}^{n}\left(a_{ij}-w_i/w_j\right)^2 \quad (9)$$

$$\sum_{i=1}^{n}w_i=1, w_i>0\ for\ i=1,\ldots.,n.$$

To solve the LSM problem, Gao et al., (2009) suggested a new method. They defined the error term, a nonlinear expression, as $a_{ij}-w_i/w_j$. If this error term changes to $a_{ij}w_j-w_i$, the expression is linear. The new LSM uses the sum of square error as an objective function, and the new LSM model is:

$$min\sum_{i=1}^{n}\sum_{j=1}^{n}\left(a_{ij}w_j-w_i\right)^2 \quad (10)$$

$$\text{subject to}\sum_{i=1}^{n}w_i=1, w_i>0\ for\ i=1,\ldots.,n.$$

Thus, the Lagrange function's construction is

$$L=\sum_{i=1}^{n}\sum_{j=1}^{n}\left(a_{ij}-w_i/w_j\right)^2+\boldsymbol{\lambda}\sum_{i=1}^{n}w_i-1.$$

We need to know the w_i value, and then set the first partial derivatives $\partial L/\partial w_i=0$ (i=1,2,..,n).The results are:

$$-2(a_{i1}+a_{1i})w_1-2(a_{i2}+a_{2i})w_2-\cdots+\left[2(n-1)+2\sum_{\substack{1\le j\le n\\ j\ne i}}a_{ij}{}^2\right]w_i-\cdots-$$

$$2(a_{in}+a_{ni})w_n+\boldsymbol{\lambda}w_i=0. \quad (11)$$

By adding $\sum_{i=1}^{n}w_i=1$, this is a linear system that has n +1 equation. We can solve this problem and obtain $w_1, w_{2,\ldots,}w_n$ and λ.

VI. Proposed methodology

First, the CFA model is used to confirm our performance measurement model consistent and acceptable. Moreover, the factor loading from CFA mode can be linked into weight method for AHP, this combined weight method has strong support in the literature (Zhu et al., 2009; and Puuniyamoorthy et al. 2012). Therefore, this research applied the relative weightage (*RW*) for each criterion (η) to rank the alternatives by AHP. Second, when factor load as relative weights in the AHP process.,There are four steps to the AHP process, which can be summarized as follows.

Step 1: Break the problem down into a hierarchy of significant levels. There are three significant main levels: the goal, objective, and alternatives. This paper measures the performance of the Thai frozen shrimp chain base using BSC, which is expressed in Figure 1 in the first level.

Step 2: Formulate a pairwise comparison matrix for the elements at a single level of the hierarchy, with respect to each of the elements at a level immediately above.

Step 3: Pairwise matrix estimation is a way to calculate weight and rank elements. There are several methods to extract priority weights using the AHP. Practically, the quintessence of the most common form of this AHP is EM, GMM, and NLSM.

Step 4: The final step is to calculate a Consistency Ratio (CR) for measuring how consistent the judgments have been, relative to large samples of random judgments. Usually, the CR should not exceed 0.1; if CR is much greater than 0.1, the judgments will not be trustworthy because they are too close for comfort to randomness, and the research will need to be repeated.

We can determine the consistency ratio by using the equation CR=CI/ mean random CI. The consistency index (CI) is the difference ratio between λ_{max}- n and n-1.Because $\lambda_{max}$is closely related to n, it implies more consistent judgments. Thus, the difference λ_{max} –n can be used as a measure of inconsistency (if the difference is zero, it is a perfect judgment).We can discover the mean random CI for differently sized matrices by using a random consistency index (RI) table.

VII. Numerical Example

Suppose that judgment matrix A is as follows:

$$A = \begin{bmatrix} 1 & 3 & 2 & 2 \\ 1/3 & 1 & 1/2 & 2 \\ 1/2 & 2 & 1 & 2 \\ 1/2 & 1/2 & 1/2 & 1 \end{bmatrix}$$

VII-1. Using Eigenvalue Method (EM)

Our first example in Table 1 is a simple AHP model. It is the *4x4* judgment matrix A.

Table 1: Judgment matrix A

i/j	*j=1*	*j=2*	*j=3*	*j=4*
i=1	1	3	5	5
i=2	0.33	1	1	4
i=3	0.2	1	1	2
i=4	0.2	0.25	0.5	1
Sum in column	1.733	5.25	7.5	12

The priority vector derived by using EM from equation (5) is listed in Table 2 below. We can normalize the weights for all value *I, j* and estimate priority vectors.

Table 2: Judgment matrix A by EM

i/j	*j=1*	*j=2*	*j=3*	*j=4*	Sum in row	Priority vectors
i=1	0.577	0.571	0.667	0.417	2.232	0.558
i=2	0.192	0.190	0.133	0.333	0.849	0.212
i=3	0.115	0.190	0.133	0.167	0.606	0.151
i=4	0.115	0.048	0.067	0.083	0.313	0.078
λ_{max}= 4.063, CI =0.042, CR = 0.047						

Using the GM method, we can compute the priority vectors in each *i, j*, which are shown in Table 3below:

Table 3: Judgment matrix A by GM

i/j	*j=1*	*j=2*	*j=3*	*j=4*	Sum (GM)	weights	Priority vectors
i=1	1	3	5	5	2.943		0.565
i=2	0.33	1	1	4	1.075		0.206
i=3	0.2	1	1	2	0.795		0.153
i=4	0.2	0.25	0.5	1	0.398		0.076
λ_{max}= 4.126, CI =0.042, CR = 0.047							

By using the new form of NLSM, the resulting equation is as follows

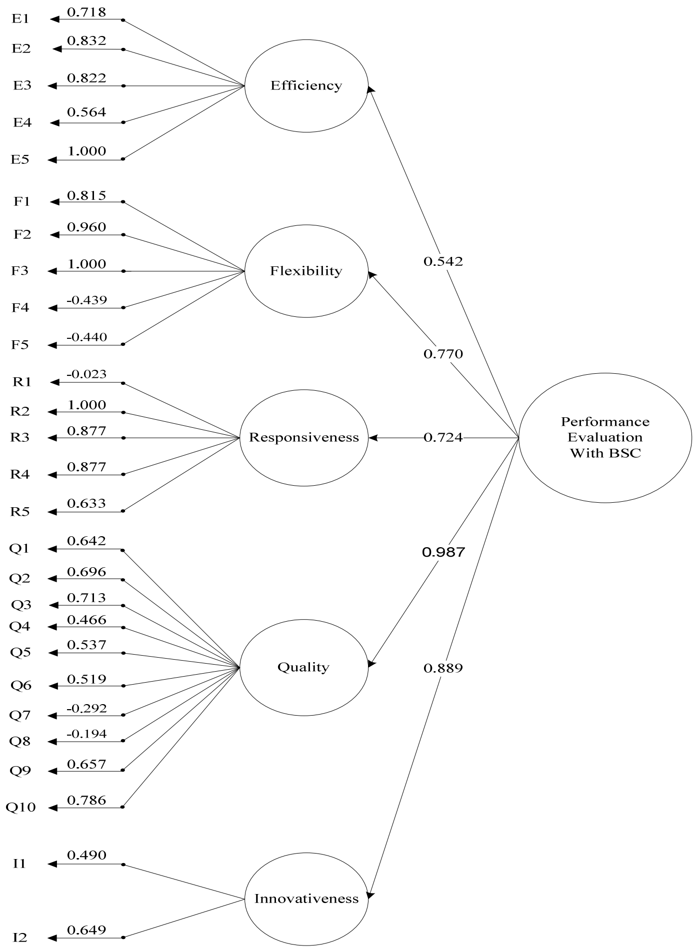
$$\begin{bmatrix} 2.382 & -6.666 & -10.40 & -20.40 & 1 \\ -6.666 & 22.125 & -4.00 & -17.00 & 1 \\ -10.40 & -4.00 & 54.50 & -10.40 & 1 \\ -10.40 & -18.50 & -5.00 & 88.00 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

To solve this linear programming, a software optimization of Lingo was utilized to find the priority vector of $[w_1,\ w_2, w_3, w_4]$as[0.642, 0.177, 0.108, 0.073].

VII. Results

VII-1. Model Fitting Degree Analysis

The completed CFA performance model is shown in Figure 1. It represents a path between sub-criteria and first order main criteria. Parameter estimation used maximum likelihood estimation, and used model fitting to evaluate the degree. As the results of CFA analysis, chi-square value (χ^2) is 93.36 with *df* = 48, normed χ^2 = 1.945.The root mean square error of approximation (RMSEA) was 0.031 at 90% CI, less than 0.080. It indicates a good fit and reaches an acceptable level. With comparative fit index (CFI) of 0.999 and goodness of fit index (GFI) of 0.993, it represents the overall goodness of fit of the model GFI, which is higher than 0.90. Therefore, the performance model can be acceptably conceptualized as a 2nd multidimensional construct consisting of Efficiency, Flexibility, Responsiveness, Quality and Innovation. Moreover, the higher order factor given by the second order CFA of the performance model in Figure 1as follow was considered for the relative weightage of the criteria that we can conclude in Table 4. The weightings show the importance of the criteria for the Thai shrimp chain. Herein, it is common in the Thai shrimp chain for the potential participants to concentrate more on shrimp products and process quality criteria than for other criteria required by the market. We tested this model using SEM, which was performed in LISREL 8.57 v.



Chi Square (48) = 93.36(P-*value*<0.001), RMSEA = 0.031

Figure 1: The first-order factors and hypothesized second-order CFA

VII-2. Relative weight calculation of BSC alternatives, with respect to each attributes (b_{ij})

From the consensus of its manager, the largest integrated company in the Thai shrimp chain was considered in the pairwise matrices analysis. Through four different aspects of BSC using Satty's scale and three different pairwise methods—EM, GM, and NLSM—the relative weight of the performance BSC, with respect to each attribute, was calculated in Table 5.The results in Table 5 show that there is no difference in the ranks given by EM, GM, and NLSM. The pairwise comparison for the second level of the hierarchy was performed by comparing the different BSC perspectives, with respect to the criteria.

For the first viewpoint of efficiency, the financial perspective (0.558, 0.565, and 0.642) was the most important in the EM method, GM method, and NLSM method, respectively, followed by the customer perspective (0.212, 0.206, and 0.177). Secondly, we addressed flexibility, which is the first concentration from a financial perspective (0.554, 0.558, and 0.670) in the EM method, GM method, and LSM method, respectively, and the customer perspective (0.271, 0.259, and 0.167). Thirdly, on responsiveness, the potential participants prioritized the customer perspective (0.444, 0.449, and 0.523) using the EM method, GM method, and NLSM method, respectively, and secondly, an internal process perspective (0.298, 0.300, and 0.257). Fourthly, the customer perspective (0.531, 0.535, and 0.610) using the EM method, GM method, and NLSM method, respectively, was found to be the most important for the quality criteria, in terms of the product and process aspects of the Thai shrimp chain. Finally, the participants indicated that a financial perspective (0.566, 0.581, and, 0.672) is the most preferred perspective.

After that, we applied equation 4 before obtaining the overall ranking because we found that the five criteria influence the BSC performance measurement. The final BSC performance measurement scores were calculated, and rankings of each BSC aspect are shown in Table 6. From the ranking of BSC perspectives in Table 6, using the EM, GM, and NLSM pairwise methods, the financial perspective was prioritized first at0.363,0.356, and 0.402 using the EM method, GM method, and NLSM method, respectively, followed by the customer perspective (0.342, 0.349, and 0.343). These data show the criteria that can influence the financial and customer perspectives. To summarize, the above results show that both perspectives should be emphasized in the performance measurement of the Thai shrimp chain.

Table 4: Relative weighting of criteria from Y model

Criteria	Efficiency	Flexibility	Responsive	Quality	Innovativen
Relative weightage	0.542	0.770	0.724	0.987	0.889

Table 5: Relative weight calculation of BSC alternatives, with respect to each attributes (b_{ij})

Criteria	EM$(b_{i1},b_{i2},b_{i3},b_{i4})$	GM$(b_{i1},b_{i2},b_{i3},b_{i4})$	NLSM$(b_{i1},b_{i2},b_{i3},b_{i4})$
Efficiency	(0.558,0.212,0.151,0.078)	(0.565,0.206,0.153,0.076)	(0.642,0.177,0.108,0.073)
Flexibility	(0.554,0.271,0.092,0.094)	(0.558,0.259,0.095,0.088)	(0.670,0.167,0.092,0.070)
Responsiveness	(0.104,0.444,0.298,0.155)	(0.100,0.449,0.300,0.150)	(0.079,0.523,0.257,0.141)
Quality	(0.072,0.531,0.153,0.244)	(0.069,0.535,0.150,0.246)	(0.072,0.610,0.156,0.162)
Innovativeness	(0.566,0.225,0.134,0.075)	(0.581,0.225,0.123,0.071)	(0.672,0.152,0.098,0.078)

Table 6: Final priority vectors for BSC alternatives for three prioritization methods using integrated methods between SEM and AHP

BSC perspectives	EM	GM	NLSM	Rank
Financial	0.363	0.356	0.402	1
Customer	0.342	0.349	0.343	2
Internal process	0.163	0.161	0.142	3
Learning & Growth	0.132	0.134	0.109	4

VIII. Discussion and conclusion

The suggested performance measurement model is a multidimensional construct. It is necessary to prove that it has a strong theoretical foundation; therefore, the construct of the performance was proved using a CFA model. Our performance construct model groups all 27 measurement factors into five criteria. The model proposes that efficiency, flexibility, responsiveness, quality (of the product, as well as process quality, which includes environmental aspects), and innovation have influenced the supply chain performance evaluation. The two benefits of this paper include the application of combinations between the SEM and AHP method; we show how to combine the high factor loading from SEM, which is a relative weighting for AHP prioritization, with the ranking process of AHP. The second benefit of this research is that it applies how to extract the priority vector using three methods—the eigenvector, geometric mean, and the new least square method. The results show that there is no difference in the ranking results. Although eigenvectors are easier to calculate and are a valid method for deriving the priority vector from a pairwise comparison matrix, the NLSM is oblivious, converges quickly, and has lower computational complexity.

Acknowledgments

The authors thank their office of the Higher Education Commission, Supply Chain and Engineering Research Unit at Department of Industrial Engineering, Chiang Mai University, University of Marketing and Distribution Sciences and Rajamangala University of Technology Srivijaya, for supporting this research.

REFERNCES

A. Neely, M. Gregory, and K. Platts, "Performance measurement system design: A literature review and research agenda", *International Journal of Operations and Production Management*, 15(4), (1995) 80-16.

A.Theeranuphattana and J. C. S. Tang, "A conceptual model of performance measurement for supply chains: Alternative considerations" *Journal of Manufacturing Technology Management*, 19(1), (2007) 125 – 148.

B. Bigliaridi and E. Bottani, "Performance measurement in food supply chain: a balanced scored approach." *Facilities* , 28(5/6), (2010) 249-260.

B.M. Beamon, "Supply Chain Design and Analysis: Model and Methods", *International Journal of Production Economics*, 55(3), (1998) 281-294.

E. U. Olugu, K.Y. Wong, and A. M. Shaharoun,"Development of key performance measures for the automobile green supply chain, Resources", *Conservation and Recycling*, 55(6), (2010)567-579.

F.T.S Chan and H.J. Qi, "An innovative performance measurement method for supply chain management", *Supply Chain Management: An International Journal*, 2003, 8(3), 209-223.

F.T.S Chan, "Performance measurement in supply chain", *International Journal of Advanced Manufacturing Technology*, 21, (2003) 534-548.

G. Li, H. Yang, L. Sun and A.S. Sohal, "The impact of IT implementation on supply chain integration and performance", *International Journal of Production Economics*, 120(1), (2009) 125–138.

J. G. A. J. Van der Vorst, "Performance measurement in agri-food supply –chain networks", Quantifying The Agri-Food Supply Chain, Netherlands, Springer, Ch. 2, (2006) pp.13-24.

J. Xu, L. Bin and D. Wu, "Rough data envelopment analysis and its application to supply chain performance evaluation" *International Journal production Economics,*122(2), (2009) 628-638.

K.Y. Tippayawong, P. Patitad, A. Sopadang and T. Enkawa , "Factors affecting efficient supply chain operational performance of high and low technology companies in Thailand" *Management science and Engineering*, 4(3), (2010) 24-33.

M. Punniyamoorthy, P. Mathiyalagan and G. Lakshmi, 2011, "A multi system for management of supplier selection process in Fuzzy supply chain", *Expert System with Applications*, 38, (2011) 458-474.

M. Punniyamoorthy, P. Mathiyalagan and G. Lakshmi, "A combined application of structural equation modeling (SEM) and analytical hierarchy process (AHP) in supplier selection", *Benchmarking: An International Journal*, 19(1), (2012) 70-92.

Office of Agriculture Economic, "Agricultural Statistics", Ministry of Agriculture and Cooperatives, 2009.

P. Sen and J. B. Yang, "Multi criteria decision support in engineering design", Springer, 1998.

Q. Zhu, J. Sarkis and K. H. Lai, "Confirmation of a measurement model for green supply chain management practices implementation" *International Journal Production Economics,* 111, (2008) 261-273.

R. Bhagwat and M.K. Shama, "Performance measurement of supply chain management: A balanced scorecard approach", *Computer & Industrial Engineering*, 53, (2007) 43-62.

R. Bhagwat and M.K. Shama, " Performance measurement of supply chain management using the analytical hierarchy process" *Production Planning & control*,18(8), (2007) 666-680.

R. Bhagwat and M.K. Shama, " An application of the integrated AHP-PGP model for performance measurement of supply chain management", *Production Planning & control*, 20(8), (2010) 678-690.

R. O. Mueller, “ Basic principles of structural equation modeling; An introduction to LISREL and EQS”, New York, Sprinkler, 1996.

R.S. Kaplan and D.P. Norton, “The balance scorecard-measures that drive performance”, *Harvard Business Review*, 70(1), (1992) 71-90.

S. Gao, Z. Zhang and C. Cao, “New Methods of Estimating Weights in AHP”,Proceedings of the 2009 International Symposium on Information Processing (ISIP’09), 2009, Huangshan, P. R. China, pp. 201-204.

S. W. Kim, “An investigation on the direct and indirect effect on supply chain integration on firm performance” *International Journal of Production economics*, 119, (2009) 328-346.

S. Pungchompoo and A. Sopadang, “A supply chain performance measurement improving with integrated methods FDSM, MOO and DEA Part I: A Conceptual of Performance Measurement Framework in Thailand frozen shrimp chains”, paper presented at 2010 IEEE International Engineering management Conference.

V.P. Wong and K. Y.Wong, 2007. “Supply chain performance measurement system using DEA modeling”, *Industrial Management & Data Systems*, 107(3), (2007) 361-381.

W. Setthasakko, “Barriers to implementing cororperate environmental responsibility in hailand:Aqualitative approach” *International Journal of Organizational Analysis* , 17(3), (2009) 169-183.

Y. F. Tseng and T. Z. Lee, “ Comparing appropriate decision support of human resource practices on organizational performance with DEA/AHP model”, Expert Systems with Applications, 36, (2009) 6548-6558.

Appendix A. Table 1 of the observed variables and the latent variables in the performance measurement model

Latent variable	Observed variables	Definitions
Financial Efficiency	1. Manufacturing costs (E1)	Combined costs of raw materials and labor used to produce goods
	2. Distribution costs (E2)	Transportation and handing costs, safety stock costs, and duties
	3. Inventory costs (E3)	Work in process and inventories of finished goods
	4. Profit (E4)	The positive gain from investment, after subtracting all expenses
	5. Return on investments (E5)	A measure of a firm's profitability and how effectively the firm uses its capital to generate profit
Flexibility	6. Volume flexibility (F1)	The ability to change the output levels of the products produced
	7. Delivery flexibility (F2)	The ability to change the planned delivery dates
	8. Customer satisfaction (F3)	The degree to which the customers are satisfied with the products or services
	9. Back orders (F4)	An order that is currently not in stock, but is being re-ordered and will be available at a later time
	10. Lost sale (F5)	An order that was lost due to a lack of stock and because the customer was not willing to wait or permit a backorder.
Responsiveness	11. Full rate (R1)	Percentage of units ordered that are shipped on a given order
	12. Product lateness (R2)	The amount of time between the promised product delivery date and the actual product delivery date
	13. Customer response time (R3)	The amount of time between completing an order and its corresponding delivery
	14. Lead time (R4)	Total amount of time required to produce a particular product or service
	15. Customer complaints (R50)	The registered complaints from customers about a product or service
Qualities	16. Appearance (Q1)	All attributes of the products
	17. Product safety (Q2)	Whether the product exceeds an acceptable level of risk associated with pathogenic organisms or chemical and physical hazards, such as microbiological or chemical contaminants in products, or micro-organisms
	18. Product reliability (Q3)	Refers to compliance of the actual product composition with the product description
	19. Traceability (Q4)	The ability to trace the history, application, or location of an product using recorded identifications
	20. Storage and transport Conditions (Q5)	Standard conditions required for transportation and storage of products that ensures good quality
	21. Working condition (Q6)	Standards that ensure a hygienic, safe working environment, with correct handling and good conditions
	22. Energy use (Q7)	The content of energy used in all productions
	23. Carbon credit (Q8)	Greenhouse gases that each plant can reduce to be sold as credits to developed countries
	24. Water use (Q9)	The water content used in all productions
	25. Chemical use (Q10)	The chemical contents used in all productions
Innovativeness	26. Launch of a new product (I1)	The number of products launched by a particular company within a given period
	27. New technology use (I2)	The percentage decrease in time necessary for producing the same product