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Original Citation

Elgazzar, S., Tipi, Nicoleta S., Hubbard, Nick J. and Leach, David Z. (2010) An application of fuzzy AHP to SCOR performance measures: a case study of an Egyptian natural bottled water company. In: Proceedings of the 15th Annual Logistics Research Network Conference. The Chartered Institute of Logistics and Transport UK, Northamptonshire, UK, pp. 180-187. ISBN 9781904564348

INCORPORATING FUZZY AHP IN SCOR MODEL FOR MEASURING SUPPLY CHAIN OPERATIONS PERFORMANCE: A CASE STUDY OF AN EGYPTIAN NATURAL BOTTLED WATER COMPANY

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1. Introduction:

The real competition now is not company against company but supply chain against supply chain. Measuring the performance of supply chains can facilitate the integration between supply chain partners, and contribute to decision making in supply chain management (SCM), especially in redesigning business goals and strategies (Chan and Qi, 2003). Moreover, evaluating the performance of supply chain (SC) operations can help to assess the current operations to identify the core competence operations, identify operations which create value or create waste, and develop strategies to better manage the supply chain.

This paper proposes a method which incorporates the fuzzy analytic hierarchy process approach (Fuzzy AHP) and the supply chain operations reference-model (SCOR) to evaluate and improve the performance of SC operations.

The proposed method provides an objective tool to measure and analyze the performance of SC operations through quantifying: SC measurement criteria, environmental uncertainty, and subjective judgements of SC performance evaluators. Applying this method allows organizations to improve the effectiveness and efficiency of supply chain operations in meeting supply chain goals through identifying processes that are working well and areas where the supply chain might need improvement.

The proposed method was developed through: (i) describing the characteristics and the structure of the supply chain (ii) identifying the main processes and sub processes in the supply chain and mapping these processes to SCOR Model process IDs, (iii) identifying the corresponding performance measurement attributes for the previous mapped processes based on the SCOR Model standard performance metrics, (iv) determining the relative importance weight of each attribute using fuzzy pair-wise comparison, (v) assigning a performance rate for each attribute using performance rating scale. (vi) consequently, calculating the weighted rate for each attribute by multiplying the importance weight of each attribute by its performance rate. (vii) finally, aggregating the weighted rate for each attribute across all SC performance measurement attributes using the weighted averaging aggregation method to determine the performance index of the company's supply chain. To demonstrate the applicability of the proposed approach, a case study was conducted.

The remainder of this paper is organized as follows. In the next section the SCOR Model and Fuzzy AHP technique are reviewed. A framework for the proposed method is presented in section 3. In section 4, a case study is illustrated to demonstrate the applicability of the proposed method. Finally, conclusions are presented in section 5.

2. Literature review:

2.1 SCOR Model

The supply chain operation references (SCOR) model was introduced in 1996 by the Supply-Chain Council (SCC). It is a business process reference model integrating the concepts of business process reengineering, benchmarking, process measurement, and best practice analysis and applying them to SCs. This model is based on five core processes (plan, source, make, deliver, and return) and divided into three levels of process detail (top level, configuration level, and process element level). It provides standard descriptions of supply chain processes that make up the SC and a framework for defining relationships among these standard processes. (Lockamy and McCormack, 2004; and Huang et al., 2005).

The SCOR model focuses on identifying areas of improvement to provide cost reductions and improve efficiencies as it includes standard performance metrics for performance and process evaluation. The model includes 10 performance metrics (perfect order fulfillment, order fulfillment cycle time, upside supply chain flexibility, upside supply chain adaptability, downside supply chain adaptability, supply chain management cost, cost of good sold, cash to cash cycle time, return on supply chain fixed assets; and return on working capital) which fall into five performance categories: reliability, responsiveness, flexibility, cost, and asset metrics. Those 10 performance metrics are designed to provide a view of overall SC performance at the level 1 while the SCOR model levels 2 and 3 supporting metrics are keys to these 10 level 1 metrics (Huan et al., 2004, and Hwang et al, 2008).

Positioning the SCOR processes within operations strategy and prioritizing implementation initiatives that result from the framework will help maximize impact by aligning resources and goals (Ellram et al., 2004 cited by Johnson and Mena 2008).

2.2 Fuzzy AHP

The natural limitations of human capability to compare or to decide between more than two factors or alternatives makes the multi criteria decision-making process (MCDM) complex and challenging (Deng, 1999; and Abdul Moneim, 2008). To deal with decision or selection problems, numerous MCDM analysis methods have been developed (such as SAW analysis model, TOPSIS method, and VIKOR method) (Matsatsinis and Samaras, 2001, and Kuo et al., 2006). One of the most widely used approaches for MCDM is the analytic hierarchy process (AHP) method (Mikhailov, 2003). In the AHP, first, the decision problem is structured in a hierarchy of different levels of elements, and then a pair-wise comparison matrix is used to determine the relative priorities of the decision elements (weights of the criteria). The pair-wise comparisons are accepted as linguistic evaluations or assessments expressing relative importance of pairs. Finally, the weights of each element in each hierarchical level are aggregated to the next level applying the principle of hierarchic composition (Mikhailov, 2004).

In most cases in real life, the available data and information are incomplete and the decision environment is uncertain and complex. In these cases, the classical AHP technique is not valid and the decision makers could be uncertain about their level of preferences (Kahraman et al, 2003). In recent years, several studies have been developed to handle this kind of uncertainty in preferences using fuzzy set theory and the application of fuzzy set theory to multiple criteria evaluation methods (Kuo et al., 2006; and Leung and Cao, 2000). Fuzzy set theory is a tool which can deal with this type of inexact data by assigning to each object a grade of membership ranging between zero and one (Kahraman et al, 2003).

In the Fuzzy AHP procedure, the pair-wise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer’s emphasis. Preference weights among main-attributes, sub-attributes and indicators are obtained by using a questionnaire survey. The survey respondents are asked to rank the components of a given layer by giving interval judgments than fixed value judgments according to its comparative importance. Afterwards, the elements of a given pair-wise comparison matrix are generated to examine the relative significance of any two components in the proposed hierarchy layers. Correspondingly, the associated component utilizes Fuzzy AHP (Kunadhamraks and Hanaoka, 2008).

2.3 Combining the SCOR Model and Fuzzy AHP technique

As previously mentioned, SCOR provides standard performance metrics to measure the supply chain overall performance. However, this objective is not quantifiable which creates a debate about how these metrics can be used to derive a quantifiable supply chain performance measure.

Although Fuzzy AHP is a flexible and unbiased tool for analyzing complex multi-criteria decision-making problems, it involves too many performance measures and too much data. The inability to reach relevant performance measures and to define SC metrics can represent a barrier for successful implementation of the technique.

To overcome the above obstacle, according to the proposed methodology, supply chain performance metrics will be based on a new approach combining the SCOR Model and Fuzzy AHP technique.

Theeranuphattana and Tang (2008) proposed a model combining the SCOR model and Chan and Qi's methodology. Chan and Qi's model was developed in 2003 based on the concept of performance of activity (POA) to identify and employ performance measures. In this model, the SC is represented by six core business processes: supplying, inbound logistics, manufacturing, outbound logistics, marketing and sales, and end customer processes. To assess the performance of these processes, the model suggested seven performance categories: cost, time, capacity, capability (including effectiveness, reliability, availability, and flexibility), productivity, utilization, and outcome. In Theeranuphattana and Tang proposed model, the rationale beyond the combination of the SCOR model and Chan and Qi's methodology is that they share similar characteristics and complement each other in terms of measuring SC performance; a combination of both methods allows their limitations to be overcome and offers an ideal alternative. Eliciting from this methodology, it is possible to combine Fuzzy AHP technique with SCOR model to construct an overall objective function; overall supply chain efficiency; for network optimization.

Combining the SCOR model and Fuzzy AHP technique allows managers to focus on the performance of the integrated supply chain through measuring SC performance at the high level by using a limited number of critical measures (Gunasekaran *et al.*, 2001).

The use of Fuzzy AHP technique with SCOR performance metrics will not cause the difficulty of constructing the processes and measures hierarchy (PMH) because the SCOR model offers users an array of standardized metrics as well as performance attributes.

In addition, SC performance measures should be linked with strategies; which may need a quantitative tool to link SCOR metrics to SC strategies. By using Fuzzy AHP measurement methodology managers can quantify – from their judgments – the weights of influence of SC strategy on individual performance measures. After applying this method to the SCOR model, managers can determine the degree to which performance metrics contribute towards the success of a particular strategy.

3. Framework for the proposed methodology:

First, supply chain characteristics, main members, structural dimensions, and strategy were described and analyzed. Supply chain processes and sub processes were identified and then mapped to the SCOR Model standard descriptions of supply chain processes.

The corresponding performance measurement attributes for the mapped processes were identified based on the SCOR Model standard performance metrics, and consequently the hierarchy framework for supply chain performance measurement attributes was established.

To determine the relative importance weight of each attribute at different levels, structured interviews were conducted with a group of experts who have a good knowledge and understanding of the processes under examination. A fuzzy pair-wise questionnaire, based on triangular fuzzy numbers, was used to facilitate comparison of attributes. For each expert response on the questionnaire, n-by-n reciprocal judgment matrixes were established. The pair-wise comparison matrix for the relative importance weights of the SC performance measurement attributes (W) can be expressed as follows:

$$A = [a_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \end{array}$$

where $a_{ij} = 1$ and $a_{ij} =, \frac{1}{a_{ij}}$ *i, j*= 1, 2,…,*n*.

(1)

To aggregate the experts' responses, a Fuzzy prioritization method, derived from Chang et al, 2009, was adopted. Based on this Fuzzy prioritization method, the expert's comparison judgments were represented as fuzzy triangular numbers where the uncertainty and imprecision of evaluations can be tackled.

A fuzzy pair-wise comparison matrix based on triangular fuzzy numbers was used in expressing the consolidated opinions of the experts. The triangular fuzzy numbers $\tilde{u}_{ij}$ were established as follows (L, M, U). Where L denotes the minimum numerical value, U denotes the maximum numerical value and M is the geometric mean which represents the consensus of most experts.

$$\tilde{u}_{ij} = (L_{ij}, M_{ij}, U_{ij}), L_{ij} \leq M_{ij} \leq U_{ij} \ and \ L_{ij}, M_{ij}, U_{ij} \in [1/9, 1] \cup [1,9]$$

(2)

$$L_{ij} = \min(B_{ijk}),$$

(3)

$$M_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}},$$

(4)

$$U_{ij} = \max(B_{ijk})$$.

(5)

where B_{ijk} represents a judgment of expert k for the relative importance of two criteria i-j.

$$\tilde{A} = [a_{ij}] = \begin{array}{c|c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} & \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix} \end{array}$$

(6)

where $\tilde{a}_{ij}$ denotes a triangular fuzzy matrix for the relative importance of two criteria C_1 and C_2. Meanwhile, $[\tilde{a}_{ij}]$ represents the triangular fuzzy numbers by the formulas (2)-(5).

As the preferences of experts are relatively subjective opinions, their responses could differ depending on the degree of environmental uncertainty and depending on whether the experts adopt a conservative or optimistic attitude when determining their preferences. Therefore, the degree of experts' confidence in their preference should be taken into consideration. For the questionnaire responses, α was used to express that environmental uncertainty; in addition, λ was used to express the degree of experts' confidence in their preference.

To establish the aggregate pair-wise comparison matrix, the defuzzication of the triangular fuzzy numbers derived from the fuzzy pair-wise comparison matrix was done using the following formula:

$$(a_{ij}^{\alpha})^{\lambda} = [\lambda . L_{ij}^{\alpha} + (1-\lambda) . U_{ij}^{\alpha}], 0 \leq \lambda \leq 1, 0 \leq \alpha \leq 1$$

(7)

where $L_{ij}^{\alpha} = (M_{ij} - L_{ij}).\alpha + L_{ij}$, represents the left-end value of α-cup a_{ij}, $U_{ij}^{\alpha} = U_{ij} - (U_{ij} - M_{ij}).\alpha$, represents the right-end of α-cup for α-cup for a_{ij}.

And consequently the aggregate pair-wise comparison matrix was established as follows:

$$[(A^{\alpha})^{\lambda} = [(a_{ij})^{\lambda}] = \begin{array}{c|cccc} & C_1 & C_2 & \cdots & C_n \\ \hline C_1 & 1 & (a^{\alpha}{}_{12})^{\lambda} & \cdots & (a^{\alpha}{}_{1n})^{\lambda} \\ C_2 & (a^{\alpha}{}_{21})^{\lambda} & 1 & \cdots & (a^{\alpha}{}_{2n})^{\lambda} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_n & (a^{\alpha}{}_{n1})^{\lambda} & (a^{\alpha}{}_{2n})^{\lambda} & \cdots & 1 \end{array}$$

(8)

The Eigenvector method was used for weight calculation. Eigen value and Eigenvector were calculated for each aggregate pair-wise comparison matrix at each level as follows:

$(A^{\alpha})^{\lambda} \cdot W = \bar{\lambda} \max . W,$

(9)

$[(A^{\alpha})^{\lambda} - \bar{\lambda} \max] . W,$

(10)

where W denotes the Eigenvector of $(A^{\alpha})^{\lambda}$, $0 \leq \lambda \leq 1, 0 \leq \alpha \leq 1$.

To verify the consistency of the comparison matrix, consistency index (C.I.) and consistency ratio (C.R.) were calculated for each aggregate pair-wise comparison matrix at each level.

One of the main issues that affect the validity and the credibility of prioritization is the consistency of decision maker's judgments. Lacking the mechanism to test the consistency of comparison matrix can lead to invalid priorities (Abdul Moneim, 2008).

A method has been proposed by Saaty to measure the inconsistency of the pair-wise comparison matrix. Based on Saaty's method, the consistency ratio (CR) is defined as a ratio between the consistency of a given evaluation matrix (consistency index CI) and the consistency of a random matrix (RI). The RI is the random index representing the consistency of a randomly generated pair-wise comparison matrix. The CR of a decision should not exceed 0.1. In the case CR exceeds 0.1; the comparison matrix is considered inconsistent and should be improved (Meixner, 2009).

C.I. and R.I. are calculated as follows:

$C.I. = \frac{\bar{\lambda}max - n}{n-1}$

(11)

$C.R. = \frac{C.I.}{R.I.}$

(12)

where R.I. represents the average consistency index over numerous random entries of same order reciprocal matrices.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

(Source: Al-Harbi, 2001)

Table 1: Random Consistency Index (RI) for different number of criteria (n)

For any metrics at any level, if the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, the pair-wise comparison processes should be repeated until the consistency index is less than 0.1.

Then, the relative importance weight of the performance measurements attributes were determined by aggregating the weights throughout the hierarchy.

A performance rating scale was established and then performance rate was assigned for each of the supply chain performance measurement attributes with respect to the established performance rating scale.

After determining the performance rate and the relative weight of each attribute, the weighted rate of each attribute was calculated. The weighted rates of all performance measurement attributes were then aggregated through the weighted averaging aggregation method to determine the performance index of the company's supply chain.

4. Case study:

To demonstrate the applicability of the proposed method, a case study on an Egyptian Natural Bottled Water Company was conducted. The measurement algorithm was carried out by means of the Microsoft Excel Spreadsheet. The brief illustrative procedures for applying the proposed method are divided into the following six major steps.

Step one: Identifying the characteristics and the structure of the existing supply chain

An overview about the company and the identification of its characteristics and structure were done through outlining briefly: what the company does, how it developed historically, the company's current situation, the problems it is experiencing, the main members and the structural dimensions of its supply chain, and its supply chain strategy.

Step two: Mapping the main processes and sub processes in the supply chain

The main processes and sub processes for company's supply chain were identified. Then an initial flowchart was drawn and reviewed to ensure that the processes were correctly identified and linked.

Then, these processes were mapped to the SCOR Model standard description of processes:

- Comprising supply chain processes in five hierarchical levels: top level, configuration level, process element level, and two process implementation levels.
- Mapping these generic descriptions of SC processes to SCOR process IDs (normalize)
- Creating workflow with these SCOR processes
- Adding description to workflows to reflect inputs/outputs of the processes
-

Step three: Determine the corresponding performance measures for the previous mapped processes

Based on the SCOR Model standard performance metrics, the corresponding performance measurement attributes for the previous mapped processes were identified. Then the hierarchy framework for supply chain performance measurement attributes was established.

Step four: Determine the relative importance weight of the supply chain performance measurement attributes

A group of four experts was assembled comprising the business planning manager, the commercial manager, the quality assurance manager, and Engineering division manager. Structured interviews were conducted with the experts group. A pair-wise questionnaire form was used to facilitate comparison of sub attributes at different levels up to level one. The relative importance of two elements was rated using a scale with the values 1, 3, 5, 7, and 9, where 1 denotes equally important, 3 for slightly more important, 5 for strongly more important, 7 for demonstrably more important, and 9 for absolutely more important. For this survey, 53 metrics including 229 pairs of comparison were established.

To aggregate the experts' responses, fuzzy pair-wise comparison matrix based on triangular fuzzy numbers (L, M, U) was used in expressing the consolidated opinions of the experts.

For the questionnaire responses, $\alpha = 0.5$ was used to express that environmental uncertainty is steady; in addition, $\lambda = 0.5$ was used to express that a future attitude is fair.

To establish the aggregate pair-wise comparison matrix, the defuzzication of the triangular fuzzy numbers derived from the fuzzy pair-wise comparison matrix was done. And consequently the aggregate pair-wise comparison matrix was established. Then, the Eigenvector method was used for weight calculation. Eigen value and Eigenvector were calculated for each aggregate pair-wise comparison matrix at each level.

Then Consistency index (C.I.) and consistency ratio (C.R.) were calculated for each aggregate pair-wise comparison matrix at each level to verify the consistency of the comparison matrix.

Finally, the relative importance weights of the performance measurement attributes were then determined by aggregating the weights throughout the hierarchy.

Step five: Determine the weighted rates of the supply chain performance measurement attributes

A performance rating scale was established based on the historical performance of the company. A performance rate was then assigned for each of the supply chain performance measurement attributes with respect to the established performance rating scale.

After determining the performance rate and the relative weight of each attribute, the weighted rate was calculated for each SC performance measurement attribute by multiplying the importance weight of each attribute by its performance rate.

Step six: Evaluate the performance of supply chain operations

As each performance measurement attribute corresponds to certain processes in the SC, based on the calculated weighted rate of each performance measurement attribute, the company can identify processes that are working well and processes that might need improvement.

The weighted rates of all performance measurement attributes were then aggregated through the weighted averaging aggregation method to determine the performance index of the company's supply chain. This index revealed the overall SC performance with respect to 5 intervals performance scale: [0.0-0.2], [0.2-0.4], [0.4-0.6], [0.6-0.8], [0.8-1]. Where [0.0-0.2] denotes very poor performance, [0.2-0.4] denotes unsatisfactory performance, [0.4-0.6] denotes fair performance, [0.6-0.8] denotes satisfactory performance, and [0.8-1] denotes highly satisfactory performance.

5. Conclusion:

This research proposed a Fuzzy - SCOR approach to evaluate and improve the performance of SC operations. This approach started by analyzing the supply chain and describing its processes. Then, supply chain processes were mapped to the SCOR Model and the corresponding performance measurement attributes of SC processes were identified based on this model. Using Fuzzy AHP technique, the weighted rate of each attribute was calculated and then aggregated across all SC performance measurement attributes using the weighted averaging aggregation method to determine the performance index of the company's supply chain.

Since each SC performance measurement attribute has a weighted rate and corresponds to certain processes in the SC, SC processes that need improvement can be identified and the overall SC performance, in terms of SC index, can be evaluated. Applying this method allows organizations to manage the effectiveness and efficiency of supply chain operations in meeting supply chain goals and to contribute to overall improvement in the company's performance.

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