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A SW application system for measuring supply chain operations' performance using SCOR FAHP technique

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Abstract. This paper proposes a new software (SW) application utilising the SCOR FAHP technique which incorporates the Fuzzy Analytic Hierarchy Process (FAHP) method in the Supply Chain Operations Reference-Model (SCOR) for the purpose of evaluating and improving supply chain operations' performance. An application in an Egyptian natural bottled water company is illustrated.

Keywords: Supply chain performance, SCOR model, FAHP method, SQL database.

1. Introduction

Performance measurement is defined as the process of quantifying the effectiveness and efficiency of action (Neely et al., 2005). 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).

In this paper a SW application system based on Structured Query Language (SQL) database is introduced which enables the application of the SCOR FAHP technique to SCM. Applying this system allows management of the effectiveness and the efficiency of supply chain (SC) operations' performance in meeting supply chain goals and in contributing to overall improvement in the company's performance through identifying core competence SC operations and those operations which need improvement. To demonstrate the applicability of the proposed system, an application in an Egyptian natural bottled water company was conducted.

The organization of this paper is as follows: In Section 2, an introduction to the SCOR FAHP technique is given. In Section 3, the framework of the SCOR FAHP technique for measuring SC operations' performance is presented. In Section 4, the SW application system is introduced and discussed, including description and illustration of data entry, analysis and results of the case study. Finally, conclusions are presented in section 5.

2. The SCOR FAHP technique

The 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. The model is based on five core processes (plan, source, make, deliver, and return) and is 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 (Supply Chain Council Supply Chain Council Supply Chain CounLockamy and McCormack, 2004).

This model assists companies to select the right performance measures as it includes ten performance metrics to measure the performance of SC processes (perfect order fulfilment, order fulfilment cycle time,

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upside supply chain flexibility, upside supply chain adaptability, downside supply chain adaptability, supply chain management cost, cost of goods sold, cash to cash cycle time, return on supply chain fixed assets; and return on working capital) which fall into five standard performance categories: reliability, responsiveness, flexibility, cost and asset metrics. These ten performance metrics are designed to provide a view of overall SC performance at the top level while the SCOR model levels 2 and 3 (configuration level and process element level) supporting metrics are keys to the top level metrics (Huang et al., 2004; Hwang et al, 2008).

Chan (2003) used a multi-attribute decision-making technique, called an analytic hierarchy process (AHP), to make SCM decisions based on the priority of SC performance measures. The AHP is a tool for solving multi-criteria decision-making problems involving quantitative and qualitative aspects. In the AHP technique, the complex problem is broken down into sub-problems in a hierarchy of different levels of elements, then priorities among the elements are determined and combined to establish the final decision. To use AHP as a tool for measuring the performance of a supply chain, all relevant performance measures are defined and quantified, then a pair wise comparison matrix is used to determine priorities among elements of performance measurement. The weights of each element at each hierarchical level are aggregated to the next level. However, the weightings can be altered according to different industries.

In most cases in real life, 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 methods have been developed to handle this kind of uncertainty in preferences and to deal with this type of inexact data using fuzzy set theory and the application of fuzzy set theory to multiple criteria evaluation methods by assigning to each element a grade of membership ranging between zero and one (Kuo et al., 2006).

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 performance measures are obtained by using a questionnaire survey and the survey respondents are asked to rank the components of a given layer by giving interval judgements rather than fixed value judgements according to their comparative importance (Kunadhamraks and Hanaoka, 2008).

Although FAHP appears to be an appropriate tool for analyzing complex multi-criteria decision-making problems, it doesn't specify relevant measures for measuring SC operations' performance. The use of SCOR performance metrics allows the decision makers to deal with a limited number of critical measures to evaluate supply chain performance (Theeranuphattana and Tang, 2008). However; there is a debate about how SCOR performance metrics can be used to derive a quantifiable supply chain performance measure. SC performance measures should be linked with strategies, which may need a quantitative tool to link SCOR metrics to SC strategies. By using AHP measurement methodology managers can quantify – from their judgements – the weights of influence of SC strategy on individual performance measures (Huang et al., 2004). Combining the SCOR model with the FAHP method can overcome some limitations of using each approach separately offering a better alternative for measuring SC operations' performance.

3. The framework of the SCOR FAHP technique for measuring SC operations' Performance

Firstly, Supply chain processes and sub processes were identified and then mapped to the SCOR Model's 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 measures was established.

To determine the relative weight of each performance measure at different levels of SCOR hierarchy, structured interviews were conducted with a group of experts - who had a good understanding of the day to day operations of the company's supply chain as well as an overview of the company's strategic vision and goals- to rank the importance weight of the supply chain performance measures. A fuzzy pair-wise questionnaire was used to facilitate comparison of these measures. The importance of the two measures related to each other 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.

To aggregate the experts' responses, a fuzzy prioritization method - derived from Chang et al. (2009) – was adopted. Based on this fuzzy prioritization method, the experts' comparison judgements are 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 (L, M, U) was used in expressing the consolidated opinions of the experts. 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.

As the preferences of experts were relatively subjective, their responses could differ depending on the degree of environmental uncertainty and depending on whether the experts adopted a conservative or optimistic attitude when determining their preferences. Therefore, the degree of experts' confidence in their preference should be taken into consideration. To determine that, α was used to express the 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 defuzzification of the triangular fuzzy numbers derived from the fuzzy pair-wise comparison matrix was performed; consequently the aggregate pair-wise comparison matrix was established and its consistency was verified.

Finally, the Eigenvector method was used for weight (W) calculation and the relative weights of the supply chain performance measures were determined.

A performance rating scale was established and a performance rate (R) was assigned for each of the supply chain performance measurement attributes.

By multiplying the relative importance weight of each measure (W) by its performance rate (R), the weighted rate (WR) of each performance measure was determined. The weighted rates of all performance measures were then aggregated to determine the company's supply chain index (SCI) to evaluate SC operations' performance.

4. The SW application system

To develop the SW application system, a database management system (DBMS) was required. DBMS environment allows a flexible representation and aggregation of raw data. It provides the ability to create tables to house data and establish links between tables offering easy access and maintenance of data observations and their relationships. In addition to numeric data manipulation, it allows parsing of textual strings for distinct words (types) and different occurrences of words (tokens) (Wolfram, 2006). Structured Query Language (SQL) database is used to develop the SW application system. SQL is a DBMS that allows the ability to view data in different ways through SQL data grouping. SQL as a standardised query language enables the requesting of information from a database making it possible to analyse data from different perspectives. The SW application system comprises four major stages namely; setting up the application in SQL; enabling the departments to enter daily SC operations data; aggregating SC operations annual performance; and calculating SC index. The application will be illustrated using the following case study of an Egyptian natural bottled water company.

4.1. Setting up the application in SQL

The main processes and sub processes for the 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 (normalise)
- Creating workflow with these SCOR processes
- Adding description to workflows to reflect inputs, outputs, and the responsible department for each process

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

Structured interviews were conducted with a group of four experts to determine the relative importance weight of each performance measure at different levels using the pair-wise questionnaire form. Using the Eigen vector method, the relative importance weights of the performance measurement attributes were then determined and aggregated throughout the hierarchy.

A five point performance rating scale (very poor, poor, good, very good, and excellent) was established for the leaf nodes of SC performance measures. A leaf node is a node of a tree data structure that has zero child nodes. For this SW application, leaf nodes are these performance measures at the lowest levels in the SCOR hierarchy which are not aggregated from sub performance measures. The leaf nodes were classified into two groups: newly developed measures that will be applied for the first time in the company and existing measures that are already applied in the company.

For the existing measures, the performance rating scale was established based on the historical performance of the company over the last five years. Since there is no historical data available in the company about the newly developed measures, a focus group comprising the group of experts was conducted to establish the performance rating scale for the newly developed measures. According to the established performance rating scale, SC performance measures can be internally benchmarked, where [0.2] denotes very poor performance, [0.4] denotes poor performance, [0.6] denotes good performance, [0.8] denotes very good performance, and [1] denotes excellent performance.

4.2. Enabling the departments to enter daily SC operations data

The leaf nodes of performance measures were classified according to the responsible department based on the description of the mapped SC processes. A data entry screen was designed for each department (Commercial, Engineering, Financial, Follow up, Planning, Production, and Quality) including the leaf nodes allocated to this department. For each leaf node, the data of the corresponding SC processes was entered on a daily or monthly basis according to the process. This data was then aggregated at the end of the year to establish an annual measure. Each department had a result sheet summarising the values of leaf nodes measures allocated to the department. Fig.1 illustrates an example in the commercial department to evaluate source agility. Data is entered for direct material (DM) orders agility (upside flexibility, upside adaptability, and downside adaptability) on a monthly basis and then aggregated for the year to reflect the agility of DM orders.

Fig. 1: SC source agility.

4.3. Aggregating SC operations annual performance

Based on the annual value of each leaf node, a performance rate (0.2, 0.4, 0.6, 0.8, or 1) was assigned with respect to the performance rating scale. As illustrated in fig. 2, by multiplying the rate of each leaf node by its weight, the annual weighted rate of leaf nodes were calculated and aggregated throughout the hierarchy of SC performance measures to determine the performance index of the company's supply chain.

Performance Attribute Code	Attribute Name	MIN	MAX	Weight	Annual performance	Rate	Rate Value	Weighted Rate
Node : AG								
AG 1.1	Upside Supply Chain Flexibility		1	.28		P	.2	.056
AG 1.2	Upside Supply Chain Adaptability		1	.53		E	.874	.463
AG 1.3	Downside Supply Chain Adaptability		1	.19		VG	.608	.116
AG 2.1	Upside Source Flexibility	15	2	.33	15.717	VP	.2	.066

Fig. 2: SC annual performance

4.4. Calculating SC index

The results were displayed in a dash board summarising and analysing the annual SC performance. As shown in fig. 3, the SCI for this Egyptian natural bottled water company at the end of the period was .616 revealing that the company's SC performance at this period was relatively good. Through analysing the weighted rate of each SC performance measure (see fig.2), the company can trace the contribution of each SC process in this performance and highlight processes which need improvement.

Attribute Name	Weighted Rate
Reliability	.143
Responsiveness	.123
Agility	.127
Costs	.089
Asset Management	.134
SCI	.616

Fig. 3: Supply chain index (SCI).

5. Conclusion

In this paper a new software (SW) application utilising the SCOR FAHP technique was proposed. Applying this SW allows companies to evaluate and enhance SC operations' performance. Since each performance measure corresponds to specific processes in the supply chain, companies can use this SW to identify these processes that are working well and those processes which need improvement resulting in more control on daily SC operations.

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