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SELECTION OF SUPPLY CHAIN PERFORMANCE MEASUREMENT SYSTEM USING FUZZY APPROACH

Parikshit Charan*, Ravi Shankar and Rajat K. Baisya*****

ABSTRACT

This paper is aimed to present a fuzzy decision-making approach to deal with the selection of supply chain performance measurement system (SCPMS) in supply chain system. During recent years, how to determine suitable SCPMS in the supply chain has become a key consideration. However, the nature of these decisions usually is complex and unstructured. In general, many quantitative and qualitative factors must be considered to determine suitable SCPMS. In this paper, linguistic values are used to assess the ratings and weights for these factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy multiple criteria decision-making (MCDM) model based on fuzzy-sets theory is proposed to deal with the SCPMS selection in the supply chain system. According to the concept of the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), a closeness coefficient is defined to determine the ranking order of all SCPMS by calculating the distances to the both fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) simultaneously. This paper shows that the proposed model is very well suited as a decision making tool for SCPMS selection decisions.

Keywords: *Supply chain performance measurement system (SCPMS); Multi-criteria decision making (MCDM); Technique for Order Performance by Similarity to Ideal Solution (TOPSIS); Fuzzy Set Theory.*

Introduction

With the opening up of the Indian economy, the Indian automobile industry is flooded with automobile manufacturing giants like General Motors Corp., Honda, Toyota Motor Corp., Volkswagen AG, Daimler Chrysler etc. India has become one of the most sought after destination where these companies are interested in setting up there manufacturing base. This sudden and quick transformation in the mindset of the foreign companies is due to vast Indian market. On the other hand, liberalization have fueled the growth of Indian automobile industry along with its supply chain partners, which according to Automotive Mission Plan (AMP) 2006-16 envisages

* Department of Management Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India. Email: parikshitcharan@yahoo.co.in, pcharan@gmail.com, Phone: 91-11-26591171 (O); 91-9811137045 (Mobile), Fax: 91-11-26862620 (O)

** Department of Management Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India. , Currently he is also associated with, School of Management, Asian Institute of Technology (AIT), Bangkok , Thailand, Email: ravi1@dms.iitd.ernet.in, r.s@rediffmail.com, rshankar@ait.ac.th, Phone: 91-11-26596421(O), 26591991(R), Fax: 91-11-26862620 (O)

*** Department of Management Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India., Email: rkbaisya@dms.iitd..ernet.in, rkbaisya@hotmail.com,
Phone: 91-11-26596395 (O); 91-124-2355378 (R), Fax: 91-11-26862620 (O)

an investment of $ 40 billion. As projected in the document, the turnover of the automobile industry would increase to $145 billion by 2016 from the current $35 billion, accounting for 10 percent of the GDP (Ministry of Heavy Industries and Public Enterprises, Government of India, 2007). Thus, the competition among the firms is very intense, prompting them to be innovative in order to reduce costs, enhance quality, and improve their performance and responsiveness to customers' demand. To achieve these goals, existing firms as well as new entrants needs to improve their supply chains performance. Gunasekaran et al. (2004) have suggested that in order to evolve an efficient and effective supply chain, SCM needs to be assessed for its performance. Similar views were put forward by Ren et al. (2004) when they stated that design, implementation and use of adequate performance management system (PMS) can play an important role if supply chains are to succeed in an increasingly complex, interdependent and changing world because "You cannot manage what you cannot measure". For that selecting supply chain performance measurement system which is appropriate for a particular supply chain is of paramount importance. Performance measurement selection is a critical step in the design and evaluation of any system. While there is an ever increasing number of supply chain models presented in the literature, there is very little available in supply chain performance measure selection (Wu and Song, 2005).

In considering supply chain performance measurement system (PMS) for future, two major requirements emerge (Morgan, 2004).

1. Performance measures must be linked with the strategy of an organization, be part of an integrated control system, have internal validity and enable proactive management; and
2. The performance measurement system must be dynamic, intra-connectable, focused and usable.

The first requirement is an important requisite for internal stability, economy, efficiency and effectiveness. The second requirement raises the operational problem of making a performance measurement system (PMS) dynamic from both an internal and supply chain perspective (Morgan, 2004).

Beamon (1998) concludes that a single performance measure will be inadequate for an entire supply chain, and that a system of performance measures is required for accurate measurement of supply chain systems. An evaluation framework, which incorporates determinants of supply chain performance measurement system, would be useful in selecting appropriate SCPMS for the Indian automobile industry. One such approach, with an application of a systemic analysis technique is presented in this paper. This technique evaluates the various determinants of supply chain performance measurement system selection through fuzzy model.

The fuzzy TOPSIS model presented in this paper structures the problem related to selection of a supply chain performance measurement system in a hierarchical form. One of the important issues for any strategic planning would be how the organization should prioritize the determinants and what policy elements or initiatives impact them (Wheelwright, 1978). Section 2 provides a brief discussion of the determinants for selecting supply chain performance measurement system and alternatives to be evaluated in this model. These characteristics are then used to structure the model. Later, the proposed methodology for evaluating the decision model is presented and applied to a decision-making problem faced by an automobile industry. This is followed by a discussion and managerial implications of this research. Finally, we conclude the work with the limitations of this work and directions for further research.

Determinants of Supply Chain Performance Measurement System

There are three determinants of supply chain performance measurement system, namely, these are intra functional measurement system, inter functional measurement system and inter organizational measurement system. These are briefly described below:

Intra Functional Measurement System

A measurement system which develops excellence within each of its operating units such as the manufacturing, marketing, or logistics departments Metrics for a company in this system will need to focus on individual functional departments. Most companies have focused their performance measurement on achieving functional excellence. Simatupang and Sridharan (2004) observed that as we move from functional excellence towards external integration, supply chain will be able to attain cost reductions while increasing efficiency and productivity. Hull et al. (1999) observed that problem with functional excellence is that as each department tries to optimize its own performance, but the overall performance is suboptimized.

Inter Functional Measurement System

A measurement system which develops excellence in its cross-functional processes rather that within its individual functional departments. Metrics for a company in this system will need to focus on cross-functional processes. This involves coordinated management of a company's internal operational activities like production scheduling, labour allocation, inventory holding, job sequencing, shipping, etc. (Copacino,1997). Basu (2001) observed that, extending intra-organizational PM systems into the domain of inter-organizational PM has meant paying lip service only to the concept of supply chain PM. Intra-organizational PM systems are not designed to measure beyond the boundaries of the organisation (beyond simple measures such as delivery time, etc.), and using them to try to do this over-simplifies the inter-organizational perspective. Daugherty et al. (1996) observed that early discussions of integration were, for the most part, limited to integration within the firm. Staude (1987) posited the need for two types of organizational integration-interdepartmental and intradepartmental. In such situations, a systems approach suggest that the objectives of the firm as a whole should be considered more important than those of individual departments. Udomleartprasert and Jungthirapanich (2003) highlighted the fact that although most of the organizations are managing the supply chains successfully, yet they have only achieved improvement in organizational performance. The organizations still have not achieved the desired results ascribed to supply chain management.

Inter Organization Measurement System

A measurement system which develops excellence in inter-enterprise processes. Metrics for a company in this system will focus on external and cross-enterprise metrics. This refers to integration of activities external to the company across the supply chain. Less than 5 percent of companies have achieved total integration with others (Copacino,1997). Successful SCM requires a change from managing individual functions to integrating activities into key supply chain processes (Lambert and Cooper, 2000). Ballou et al. (2000) have shown that supply chain management has moved us from an intrafunctional vision of the channel toward an interfunctional and even inter-organizational one. This requires three things: A new type of metrics beyond normal accounting procedures for capturing inter-organizational data and expressing them in terms that facilitate benefits analysis; An information sharing mechanism for transferring information about cooperative benefits among channel members; An allocation method for redistributing the rewards of cooperation in a way that all parties benefit fairly.

Collaboration is the key ingredient to attain external integration with other chain members (Simatupang and Sridharan,2004), thereby, allowing to benchmark from a single company level to an interorganizational level (Simatupang and Sridharan,2004a). Supply chain collaboration requires a reasonable amount of effort from all participating members to ensure the attainment of potential benefits (Barratt and Oliveira, 2001; Corbett et al., 1999).

Alternatives for the Supply Chain Performance Measurement System

After review of literature and discussion with fifteen experts in the field of supply chain, both from industry and the academia, some of the important supply chain performance measurement system are identified. For the purpose of illustration of our model, we analyze seven distinct alternatives. The seven alternatives are Supply chain balanced scorecard (SCBS), Hierarchical based measurement system (HBMS), Function based measurement system (FBMS), Perspective based measurement system (PBMS), Supply chain operations reference model (SCOR), Dimension based measurement system (DBMS) and Interface based measurement system (IBMS). These alternatives have been used in the proposed framework for the development of a fuzzy TOPSIS model. A brief description of these seven alternatives is given below.

Supply Chain Balanced Scorecard (SCBS)

Brewer and Speh (2000) have developed a model where supply chain point of view is embedded within the balanced scorecard framework. This model describes the links of different perspectives to goals of SCM and then what are the measures to be adopted in each. The internal perspective of the scorecard is extended to include both the inter-functional and inter-organizational partnership perspectives. SCBS emphasizes the interdependent as well as independent nature of supply chain and reorganizes the need to ascertain the extent to which effectively work together and function are coordinated and integrated. It also stimulates management to create other measures appropriate to their unique circumstances but it lacks in aligning overall supply chain objectives with objectives for the companies. This was the first significant framework to move beyond traditional logistics performance measures.

Hierarchical Based Measurement System (HBMS)

Gunasekaran et al. (2001) gave HBMS in which measures are classified into strategic, tactical and operational levels of management. This is done to assign them where they can be best dealt with by the appropriate management level, and quick decisions can be made. The metrics are further distinguished as financial and non-financial.

HBMS ties together the hierarchical view of supply chain performance measurement and maps the performance measures specific to organization goals. A clear guide cannot be made in such a system to put the measures into different levels that can lead to low level of conflicts among the supply chain partners.

Function Based Measurement System (FBMS)

Christopher (1992) developed a FBMS in which the measures are aggregated to cover the different processes in the supply chain. FBMS covers the detailed performance measures applicable at different linkages of supply chain. Approach is easy to implement and targets can be dedicated to individual departments. It dose not provide the top level measures to cover the entire supply chain with the company strategy. It looks at the supply chain in isolation, which gives the localized benefits that may harm the total supply chain benefits.

Perspective Based Measurement System (PBMS)

PBMS developed by Otto and Kotzab (2002) looks at supply chain in all the possible perspectives and provides measures to evaluate each perspective. The six perspectives are system dynamics, operations research, logistics, marketing, organization and strategy. It presents six unique sets of metrics to measure performance of SCM. This system provides a different vision to look supply chain. There can be trade off between measures of one perspective with the measures of other perspectives.

Supply Chain Operations Reference Model (SCOR)

The supply chain council created the SCOR model which is a framework for examining a supply chain in detail, defining and categorizing the processes that make up the supply chain, assigning metrics to the processes, and reviewing comparable benchmarks. The SCOR model is the only supply chain framework that links performance measures, best practices and software requirements to a detailed business process model. It integrates business process reengineering, benchmarking and process measurement into a cross-functional framework. In Supply Chain Operation Reference Model (SCOR), performance of most processes is measured from five perspectives: reliability, responsiveness, flexibility, cost, and asset (Supply chain council).

SCOR defines supply chain as the integrated process of plan, source, make, deliver and return spanning suppliers' supplier to customers' customer, aligned with operational strategy, material, work and information flows. The heart of SCOR is a pyramid of four levels that represent the path a company takes for supply-chain improvement. It requires a well defined infrastructure, resources and project based completion approach. Implementation of such an exhaustive system requires fully dedicated managerial resources and continuous business process reengineering to align the business with the best practices.

Dimension Based Measurement System (DBMS)

DBMS suggests that any supply chain can be measured on three key dimensions: service, assets and speed (Hausman, 2000). Service relates to the ability to anticipate, capture and fulfill customer demands with personalized products and on-time delivery; Assets involve anything with commercial value, primarily inventory and cash; and Speed includes metrics which are time related, they track responsiveness and velocity of execution.

Every supply chain should have at least one performance measure on each of these three critical dimensions.

Interface Based Measurement System (IBMS)

This framework aligns performance of each link within the supply chain. The framework begins with linkages at the focal company and moves outward a link at a time. The link by link approach provides a means for aligning performance from point-of-origin to point-of-consumption with the overall objective of maximizing shareholder value for the total supply chain as well as for each company (Pohlen and Lambert, 2001).

IBMS looks at the supply chain as a series of different links and to optimize the total supply chain a win-win approach is required at all linkages. Conceptually it looks good but in actual business setting it requires openness and total sharing of information at every link of the chain, which seems to be difficult to implement.

The Decision Environment

A graphical representation of the fuzzy TOPSIS model and decision environment is shown in Figure1

Measurement System

It can be seen that the overall objective is to select SCPMS. The determinants for selecting SCPMS (Intra functional measurement system, Inter functional measurement system and Inter organization measurement system) are described in Section 2. The SCPMS alternatives in this model are the specific SCPMS that a decision maker wishes to evaluate, given the various attribute levels of the SCPMS. The various alternatives available to the decision maker in this example include Supply chain balanced scorecard (SCBS), Hierarchical based measurement system (HBMS), Function based measurement system (FBMS), Perspective based measurement system (PBMS), Supply chain operations reference model (SCOR), Dimension based measurement system (DBMS) and Interface based measurement system (IBMS). In Section 5, we briefly describe the fuzzy TOPSIS approach and in section 6, apply it to an automobile company example to explain the fuzzy TOPSIS methodology.

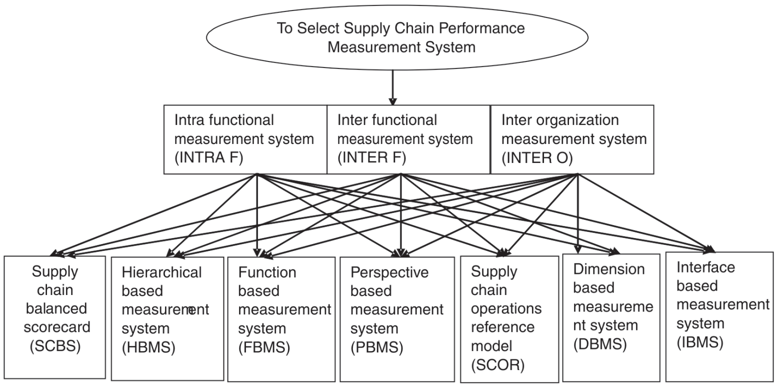

Figure 1: Fuzzy TOPSIS Based Framework for Selecting Supply Chain Performance

Fuzzy TOPSIS

In classical MCDM methods, the ratings and the weights of the criteria are known precisely (Delgado et al., 1992; Hwang and Yoon, 1981; Kaufmann and Gupta, 1991). A survey of the methods has been presented in Hwang and Yoon (1981). Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), one of the known classical MCDM methods, may provide the basis for developing supply chain performance measurement system selection models that can effectively deal with these properties. It bases upon the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). Under many conditions, crisp data are inadequate to model real-life situations. Since human judgements including preferences are often vague and cannot estimate his preference with an exact numerical value. A more realistic approach may be to use linguistic assessments instead of numerical values. In other words, the ratings and weights of the criteria in the problem are assessed by means of linguistic variables (Ross, 2007; Klir and Folger, 2006; Bellman and Zadeh, 1970; Chen, 2000; Delgado et al., 1992; Herrera et al., 1996; Herrera and Herrera-Viedma, 2000). In this paper, we further extended to the concept of TOPSIS to develop a methodology for solving supply chain performance measurement system selection problems in fuzzy environment (Chen, 2000). Considering the fuzziness in the decision data and group decision-making process, linguistic variables are used to assess the weights of all criteria and the ratings of each alternative with respect to each criterion. We can convert the decision matrix into a fuzzy decision matrix and construct a weighted-normalized fuzzy decision matrix once the decision-makers' fuzzy ratings have been pooled. According to the concept of TOPSIS, we define the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). And then, a vertex method is applied in this paper to calculate the distance between two fuzzy ratings.

Using the vertex method, we can calculate the distance of each alternative from FPIS and FNIS, respectively. Finally, a closeness coefficient of each alternative is defined to determine the ranking order of all alternatives. The higher value of closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS simultaneously (Chen et al.., 2006).

Proposed Method for SCPMS Selection

A systematic approach to extend the TOPSIS is proposed to solve the supply chain performance measurement system selection problem under a fuzzy environment in this section. In this paper the importance weights of various determinant / criteria and the ratings of qualitative determinant / criteria are considered as linguistic variables. Because linguistic assessments merely approximate the subjective judgment of decision-makers, we can consider linear trapezoidal membership functions to be adequate for capturing the vagueness of these linguistic assessments (Delgado et al., 1998; Herrera et al., 1996; Herrera and Herrera-Viedma, 2000). These linguistic variables can be expressed in positive trapezoidal fuzzy numbers, as in Figures 2 and 3. The importance weight of each criterion can be by either directly assigning or indirectly using pairwise comparison (Cook, 1992). It is suggested in this paper that the decision-makers use the linguistic variables shown in Figs. 2 and 3 to evaluate the importance of the determinant and the ratings of alternatives with respect to qualitative criteria. For example, the linguistic variable "Medium High (MH)" can be represented as (0.5, 0.6, 0.7, 0.8), the membership function of

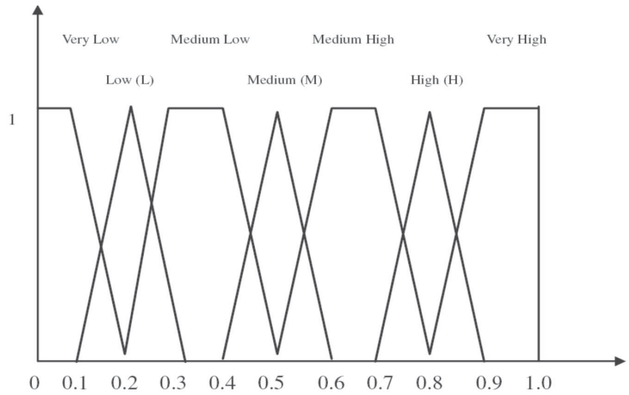

Figure 2: Linguistic variables for importance weight of each determinant.

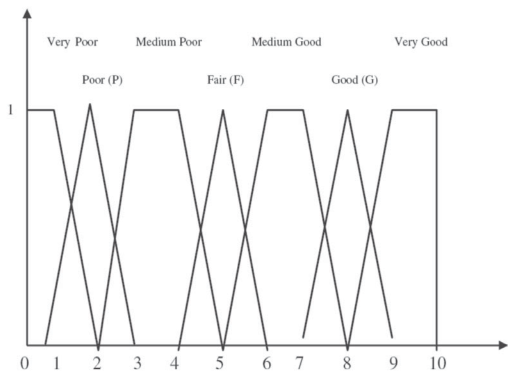

Figure 3: Linguistic variables for ratings.

which is

$$\mu_{Medium\ High}(x) = \begin{cases} 0, & x < 0.5, \\ (x-0.5)/(0.6-0.5), & 0.5\ d\leq x\ d\leq 0.6, \\ 1, & 0.6d\leq x\ d\leq 0.7, \\ (x-0.8)/(0.7-0.8), & 0.7\ d\leq x\ d\leq 0.8, \\ 0, & x > 0.8. \end{cases}$$

The linguistic variable "Medium Good (MG)" can be represented as (5,6,7,8), the membership function of which is

$$\mu_{Very\ Good}(x) = \begin{cases} 0, & x < 5 \\ (x-5)/(6-5), & 5\ d\leq x\ d\leq 6, \\ 1, & 6\ d\leq x\ d\leq 7 \\ (x-8)/(7-8), & 7\ d\leq x\ d\leq 8, \\ 0, & x > 8. \end{cases}$$

In fact, supply chain performance measurement system selection in supply chain system is a group multiple-criteria decision-making (GMCDM) problem, which may be described by means of the following sets:

i. a set of K decision-makers called $E = (D_1, D_2, \ldots, D_K)$;

ii. a set of m possible SCPMS alternatives called $A = (A_1, A_2, \ldots, A_m)$;

iii. a set of n determinants, $C = (C_1, C_2, \ldots, C_n)$, based on which supply chain performance measurement system is selected;

iv. a set of performance ratings of A_i ($i = 1, 2, \ldots, m$) with respect to determinant C_j ($j = 1, 2, \ldots, n$), called $X = (x_{ij}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n)$.

Assume that a decision group has K decision makers, and the fuzzy rating of each decision-maker D_k ($k = 1,2, \ldots, K$) can be represented as a positive trapezoidal fuzzy number $\tilde{R}_k$($k=1,2, \ldots, K$) with membership function $\mu_{\tilde{R}_k}(x)$. A good aggregation method should be considered the range of fuzzy rating of each decision-maker. It means that the range of aggregated fuzzy rating must include the ranges of all decision-makers' fuzzy ratings. Let the fuzzy ratings of all decision makers be trapezoidal fuzzy numbers $\tilde{R}_k = (a_k, b_k, c_k, d_k)$, $k = 1, 2, \ldots, K$. Then the aggregated fuzzy rating can be defined as

$\tilde{R} = (a,b,c,d), \quad k = 1,2,\ldots\ldots\ K$

where

$a = \min_k\{a_k\},\ b = 1/K\ \Sigma_{k=1}^{k} b_k,\ c = 1/K\ \Sigma_{k=1}^{k} c_k,\ d = \max_k\{d_k\}$

Let the fuzzy rating and importance weight of the kth decision maker be $\tilde{X}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk})$ and $\tilde{W}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4})$; $i = 1,2,\ldots.m$, $j = 1, 2, \ldots, n$, respectively. Hence, the aggregated fuzzy ratings ($\tilde{X}_{ij}$) of alternatives with respect to each criterion can be calculated as

$\tilde{X}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$, where

$a_{ij} = \min_k\{a_{ijk}\}$, $b_{ij} = 1/K\ \Sigma_{k=1}^{k}\ b_{ijk}$, $c_{ij} = 1/K\ \Sigma_{k=1}^{k}\ c_{ijk}$, $d_{ij} = \max_k\ \{d_{ijk}\}$

The aggregated fuzzy weights ($\tilde{w}_j$) of each criterion can be calculated as

$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$,

where

$w_{j1} = \min_k\{w_{jk1}\}$, $w_{j2} = 1/K\ \Sigma_{k=1}^{k}\ w_{jk2}$, $w_{j3} = 1/K\ \Sigma_{k=1}^{k}\ w_{jk3}$, $w_{j4} = \max_k\ \{d_{jk4}\}$

As stated above, a supply chain performance measurement system selection problem can be concisely expressed in matrix format as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{2n} \\ . & . & . \\ . & . & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x}_{mn} \end{bmatrix}$$

where $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$; i = 1,2,….m, j = 1, 2, . . .,n, can be approximated by positive trapezoidal fuzzy numbers.

To avoid complexity of mathematical operations in a decision process, the linear scale transformation is used here to transform the various criteria scales into comparable scales. The set of criteria can be divided into benefit criteria (the larger the rating, the greater the preference) and cost criteria (the smaller the rating, the greater the preference). Therefore, the normalized fuzzy-decision matrix can be represented

as

$\tilde{R} = [\tilde{r}_{ij}]_{mxn}$

where B and C are the sets of benefit criteria and cost criteria, respectively, and

$\tilde{r}_{ij} = (a_{ij} / d^*_j, b_{ij} / d^*_j, c_{ij} / d^*_j, d_{ij} / d^*_j)$, $j \in B$,

$\tilde{r}_{ij} = (a^-_j / dij, a^-_j / cij, a^-_j / bij, a^-_j / aij)$, $j \in C$,

$d^*_j = \max d_{ij}$, $j \in B$

$a^-_j = \min_i a_{ij}$, $j \in C$,

The normalization method mentioned above is designed to preserve the property in which the elements $\tilde{r}_{ij}$, $\forall i,j$ are standardized (normalized) trapezoidal fuzzy numbers.

Considering the different importance of each criterion, the weighted normalized fuzzy-decision matrix is constructed as

$\tilde{V} = [\tilde{v}_{ij}]_{mxn}$, i = 1,2,…….,m, j = 1,2,…………,n, where

$\tilde{v}_{ij} = \tilde{r}_{ij} (\bullet) \tilde{w}_j$

According to the weighted normalized fuzzy decision matrix, normalized positive trapezoidal fuzzy numbers can also approximate the elements $\tilde{v}_{ij}$, $\forall$i,j. Then, the fuzzy positive-ideal solution (FPIS, A*) and fuzzy negative-ideal solution (FNIS, A^-) can be defined as

$A^* = (\tilde{v}^*_1, \tilde{v}^*_2, \ldots\ldots\ldots\ldots\ldots\ldots \tilde{v}^*_n),$

$A^- = (\tilde{v}^-_1, \tilde{v}^-_2, \ldots\ldots\ldots\ldots\ldots \tilde{v}^-n),$

where

$\tilde{v}^*_j = \max_i \{v_{ij4}\}$ and $\tilde{v}^-_j = \min_i \{v_{ij1}\},$

$i = 1,2,\ldots\ldots,m, \quad j = 1,2,\ldots\ldots\ldots\ldots,n.$

The distance of each alternative (SCPMS) from A* and A^- can be currently calculated as

$d^*_i = \Sigma^n_{j=1} d_v(\tilde{v}_{ij}, \tilde{v}^*_j), \quad i = 1,2,\ldots\ldots,m,$

$d^-_i = \Sigma^n_{j=1} d_v(\tilde{v}_{ij}, \tilde{v}^-_j), \quad i = 1,2,\ldots\ldots,m,$

where dv(·,·) is the distance measurement between two fuzzy numbers.

A closeness coefficient is defined to determine the ranking order of all possible SCPMS once d^*_i and d^-_i of each SCPMS A_i(i =1, 2, . . . ,m) has been calculated. The closeness coefficient represents the distances to the fuzzy positive-ideal solution (A*) and the fuzzy negative-ideal solution (A^-) simultaneously by taking the relative closeness to the fuzzy positive-ideal solution. The closeness coefficient (CC_i) of each alternative (SCPMS) is calculated as

$CC_i = d^-_i / (d^*_i + d^-_i), \ i = 1,2,\ldots\ldots,m$

It is clear that $CC_i = 1$ if $A_i = A^*$ and $CC_i = 0$ if $A_i = A^-$. In other words, SCPMS A_i is closer to the FPIS (A*) and farther from FNIS (A^-) as CC_i approaches to 1. According to the descending order of CC_i, we can determine the ranking order of all SCPMS and select the best one from among a set of SCPMS.

In summation, an algorithm of the fuzzy decision-making method for dealing with the

Supply chain performance measurement system selection is given as follows.

Step 1: Form a committee of decision-makers, and then identify the determinants.

Step 2: Choose the appropriate linguistic variables for the importance weight of the determinants and the linguistic ratings for SCPMSs'.

Step 3: Aggregate the weight of determinants to get the aggregated fuzzy weight $\tilde{w}_j$ of determinant C_j, and pool the decision-makers' ratings to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of SCPMS Ai under determinant C_j .

Step 4: Construct the fuzzy-decision matrix and the normalized fuzzy-decision matrix.

Step 5: Construct weighted normalized fuzzy decision matrix.

Step 6: Determine FPIS and FNIS.

Step 7: Calculate the distance of each SCPMS from FPIS and FNIS, respectively.

Step 8: Calculate the closeness coefficient of each SCPMS.

Step 9: According to the closeness coefficient, we can determine the ranking order of all the SCPMS

An Example of Automobile Manufacturing Company

An automobile company desires to select a suitable supply chain performance measurement system. After preliminary screening, seven alternatives (A_1, A_2, A_3, A_4, A_5, A_6 and A_7) remain for further evaluation. A committee of three decision-makers, D_1, D_2 and D_3, has been formed to select the most suitable SCPMS. Three determinants / criteria are considered:

(1) Intra functional measurement system-INTRA F (C_1),

(2) Inter functional measurement system-INTER F (C_2),

(3) Inter organization measurement system-INTER O (C_3),

The hierarchical structure of this decision problem is shown in Fig. 1. The proposed method is currently applied to solve this problem, the computational procedure of which is summarized as follows:

Step 1: Three decision-makers use the linguistic weighting variables shown in Fig. 2 to assess the importance of the determinants. The importance weights of the determinants determined by these three decision-makers are shown in Table 1.

Step 2: Three decision-makers use the linguistic rating variables shown in Fig. 3 to evaluate the ratings of alternatives with respect to each determinants. The ratings of the seven alternatives by the decision-makers under the various determinants are shown in Table 2.

Table 1: Importance Weight of Determinants from three Decision-makers

Determinants	Decision-makers		
	D1	D2	D3
INTRA F (C_1)	ML	ML	ML
INTER F (C_2)	MH	MH	MH
INTER O (C_3)	VH	VH	VH

Table 2: Ratings of the Seven Alternatives by Decision-makers under Various Determinants.

Determinants	SCPMS Alternatives	Decision-makers		
		D1	D2	D3
INTRA F (C_1)	SCBS (A_1)	G	G	G
	HBMS (A_2)	G	MG	G
	FBMS (A_3)	VG	VG	VG
	PBMS (A_4)	F	F	F
	SCOR (A_5)	MG	MG	MG
	DBMS (A_6)	G	VG	G
	IBMS (A_7)	MG	MG	G
INTER F (C_2)	SCBS (A_1)	VG	VG	VG
	HBMS (A_2)	G	G	VG
	FBMS (A_3)	MP	MP	MP
	PBMS (A_4)	MG	MG	G
	SCOR (A_5)	VG	G	VG
	DBMS (A_6)	G	MG	G
	IBMS (A_7)	F	F	F
INTER O (C_3)	SCBS (A_1)	G	G	G
	HBMS (A_2)	G	VG	G
	FBMS (A_3)	P	P	P
	PBMS (A_4)	MG	MG	MG
	SCOR (A_5)	VG	VG	VG
	DBMS (A_6)	MG	MG	MG
	IBMS (A_7)	MP	MP	MP

Step 3: Then the linguistic evaluations shown in Tables 1 and 2 are converted into trapezoidal fuzzy numbers to construct the fuzzy-decision matrix and determine the fuzzy weight of each criterion, as in Table 3.

Table 3: Fuzzy-decision Matrix and Fuzzy Weights

	INTRA F (C_1)	INTER F (C_2)	INTER O (C_3)
SCBS (A_1)	(7,8,8,9)	(8,9,10,10)	(7,8,8,9)
HBMS (A_2)	(5,7.3,7.7,9)	(7,8.3,8.7,10)	(7,8.3,8.7,10)
FBMS (A_3)	(8,9,10,10)	(2,3,4,5)	(1,2,2,3)
PBMS (A_4)	(4,5,5,6)	(5,6.7,7.3,9)	(5,6,7,8)
SCOR (A_5)	(5,6,7,8)	(7,8.7,9.3,10)	(8,9,10,10)
DBMS (A_6)	(7,8.3,8.7,10)	(5,7.3,7.7,9)	(5,6.7,7.3,9)
IBMS (A_7)	(5,6.7,7.3,9)	(4,5,5,6)	(2,3,4,5)
Weight	(0.2,0.3,0.4,0.5)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)

Step 4: The normalized fuzzy-decision matrix is constructed as in Table 4.

Table 4: Normalized Fuzzy-decision Matrix

	INTRA F (C_1)	INTER F (C_2)	INTER O (C_3)
SCBS (A_1)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
HBMS (A_2)	(0.5,0.73,0.77,0.9)	(0.7,0.83,0.87,1.0)	(0.7,0.83,0.87,1.0)
FBMS (A_3)	(0.8,0.9,1.0,1.0)	(0.2,0.3,0.4,0.5)	(0.1,0.2,0.2,0.3)
PBMS (A_4)	(0.4,0.5,0.5,0.6)	(0.5,0.67,0.73,0.9)	(0.5,0.6,0.7,0.8)
SCOR (A_5)	(0.5,0.6,0.7,0.8)	(0.7,0.87,0.93,1.0)	(0.8,0.9,1.0,1.0)
DBMS (A_6)	(0.7,0.83,0.87,1.0)	(0.5,0.73,0.77,0.9)	(0.5,0.67,0.73,0.9)
IBMS (A_7)	(0.5,0.67,0.73,0.9)	(0.4,0.5,0.5,0.6)	(0.2,0.3,0.4,0.5)

Step 5: Weighted normalized fuzzy-decision matrix is constructed as in Table 5.

Table 5: Weighted Normalized Fuzzy-decision Matrix

	INTRA F (C_1)	INTER F (C_2)	INTER O (C_3)
SCBS (A_1)	(0.14,0.24,0.32,0.45)	(0.40,0.54,0.7,0.8)	(0.56,0.72,0.8,0.9)
HBMS (A_2)	(0.10,0.219,0.308,0.45)	(0.35,0.498,0.609,0.8)	(0.56,0.747,0.87,1.0)
FBMS (A_3)	(0.16,0.27,0.4,0.5)	(0.10,0.18,0.28,0.40)	(0.08,0.18,0.2,0.3)
PBMS (A_4)	(0.08,0.15,0.20,0.30)	(0.25,0.402,0.511,0.72)	(0.40,0.54,0.7,0.8)
SCOR (A_5)	(0.10,0.18,0.28,0.40)	(0.35,0.522,0.651,0.8)	(0.64,0.81,1.0,1.0)
DBMS (A_6)	(0.14,0.249,0.348,0.5)	(0.25,0.438,0.539,0.72)	(0.40,0.603,0.73,0.9)
IBMS (A_7)	(0.10,0.201,0.292,0.45)	(0.20,0.30,0.35,0.48)	(0.16,0.27,0.4,0.5)

Step 6: Determine FPIS and FNIS as

$A^* = [(0.5,0.5,0.5,0.5), (0.8,0.8,0.8,0.8), (1.0,1.0,1.0,1.0)]$,

$A^- = [(0.08, 0.08, 0.08, 0.08), (0.10, 0.10, 0.10, 0.10), (0.08, 0.08, 0.08, 0.08)]$.

Step 7: Calculate the distance of each SCPMS from FPIS and FNIS with respect to each determinant, respectively, as Tables 6 and 7.

Table 6: Distances between A_i(i= 1,2,…….7) and A* with respect to each determinant

	INTRA F (C_1)	INTER F (C_2)	INTER O (C_3)
$d(A_1,A^*)$	0.24	0.24	0.28
$d(A_2,A^*)$	0.26	0.29	0.26
$d(A_3,A^*)$	0.21	0.57	0.81
$d(A_4,A^*)$	0.33	0.37	0.42
$d(A_5,A^*)$	0.28	0.27	0.20
$d(A_6,A^*)$	0.23	0.36	0.39
$d(A_7,A^*)$	0.27	0.48	0.68

Table 7: Distances between A_i(i= 1,2,.......7) and A^- with respect to each determinant

	INTRA F (C_1)	INTER F (C_2)	INTER O (C_3)
d(A_1, A^-)	0.24	0.53	0.68
d(A_2, A^-)	0.23	0.49	0.73
d(A_3, A^-)	0.28	0.18	0.13
d(A_4, A^-)	0.13	0.41	0.55
d(A_5, A^-)	0.20	0.51	0.80
d(A_6, A^-)	0.26	0.42	0.61
d(A_7, A^-)	0.22	0.25	0.28

Step 8: Calculate the closeness coefficient of each SCPMS alternative

Calculate d^*_i , d^-_i and CC_i of seven SCPMS Ai (i= 1, 2, . . . ,7) as Table 8.

Table 8: Computations of d^*_i , d^-_i and CC_i

	d^*_i	d^-_i	$d^*_i + d^-_i$	CC_i (Closeness Coefficient)
SCBS (A_1)	0.76	1.45	2.21	0.66
HBMS (A_2)	0.81	1.45	2.26	0.64
FBMS (A_3)	1.59	0.59	2.18	0.27
PBMS (A_4)	1.12	1.09	2.21	0.49
SCOR (A_5)	0.75	1.51	2.26	0.67
DBMS (A_6)	0.98	1.29	2.27	0.57
IBMS (A_7)	1.43	0.75	2.18	0.34

Step 9: According to the closeness coefficient, we can determine the ranking order of all the SCPMS

$CC_1 = 0.66$, $CC_2 = 0.64$, $CC_3 = 0.27$, $CC_4 = 0.49$, $CC_5 = 0.67$, $CC_6 = 0.57$, $CC_7 = 0.34$

$CC_5 > CC_1 > CC_2 > CC_6 > CC_4 > CC_7 > CC_3$

From the closeness coefficient calculation it is observed that SCOR is the most-suited alternative for the supply chain performance measurement system for the case company. SCBS, HBMS, DBMS, PBMS IBMS and FBMS follow this alternative. These results should be seen in the light of the characteristics of the case company and the inputs provided by its decision-makers.

Discussion and Managerial Implications

In this section, we first discuss the results of the model. Later, we present few suggestions to the prospective users of this model. Finally, we discuss the managerial implications of this model and some generalization of results.

The major contribution of this research lies in the development of a comprehensive model, which incorporates diversified issues for selecting supply chain performance measurement system. The proposed fuzzy TOPSIS model in this paper guides the decision makers in the selection of the supply chain performance measurement system.

For the case undertaken in this study, the results indicate that SCOR is the first choice of the case company, which is followed by SCBS, HBMS, DBMS, PBMS, IBMS and FBMS. The choice of the case company towards SCOR may be attributed to the fact that it links performance measures, best practices and software requirements to a detailed business process model. It integrates business process reengineering, benchmarking and process measurement into a cross-functional framework which can lead to enhanced competitiveness. Inter organizational measurement system has forced the companies to look beyond their own companies and towards supply chain in a holistic way.

Table 8 shows the closeness coefficient for the alternatives. It is observed from the table, that SCOR excels over the other six alternatives. Though, in the illustrated example, the model has been described for seven distinct alternatives, it can accommodate more than seven at the cost of complexity. In the light of the results obtained for the case company, it is to be noted that the results obtained are valid for the case company in its own decision environment. It is the decision environment of the user, which makes one alternative superior to other.

Conclusion

The implementation of supply chain performance measurement system may cost in millions of dollars for company. The implementation of these may be a risky endeavor for the top management as it involves financial and operational aspects, which can determine the performance of the company in the long run. And no longer do the companies compete against each other, it is the supply chains which compete. So the question now is not whether to go for it or not, but which framework to pick up. This research is relevant in this sense. The fuzzy TOPSIS model presented in this paper structured the problem of selection of supply chain performance measurement system in a hierarchical form.

Thus, a fuzzy TOPSIS approach proposed in this paper can provide to the decision maker a more realistic and accurate representation of the problem for selection of supply chain performance measurement system. This study aids the decision makers in the complex task of prioritizing their options.

The model developed in this paper has a few limitations as well. The results reported in this research are based on the opinion of the decision-makers from the case company. Thus, assigning weights and ranking to various determinants and alternatives always depends on the user's knowledge and familiarity with the firm, its operations, and its industry. Therefore, the biasing of the experts to some determinant / criteria might have influenced the results.

Experts in the case automobile company considered that this approach lead to an objective analysis of the situation and is currently implementing SCOR for performance measurement of the supply chain.

A possible extension of this research study might be to study the preferences of the user companies corresponding to different sizes and sectors, where these determinant /criteria may be modeled as per the choice of companies.

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