Supply Chain Performance Measurement: An Integrated DEMATEL and Fuzzy-ANP Approach

Ozlem Senvar, Umut Rifat Tuzkaya and Cengiz Kahraman

Abstract Supply chain performance measurement is vital for the continuous improvement of supply chain management. Effective supply chain performance measurement is one of the most important aspects for supply chain management in which decision makers can analyze the historical performance and current status, and set future performance targets. This chapter provides a conceptual point of view to supply chain performance measurement. Inevitably, quantification of the values with precision in a complex supply chain performance measurement system is difficult. The supply chain performance measurement under fuzziness can consider the uncertainty and ambiguity surrounding the supply chain performance measurement. The aim of this chapter is to present a fuzzy decision making approach to deal with the performance measurement in supply chain systems. In this chapter, DEMATEL method is adapted to model complex interdependent relationships and construct a relation structure using measurement criteria for evaluation. F-ANP is performed to overcome the problem of dependence and feedback among each measurement criteria. The integrated DEMATEL and F-ANP approach provides an effective decision tool for the supply chain performance measurement.

Keywords Suppy chain management · Performance management · DEMATEL · ANP · Multi criteria decision making · Fuzzy logic

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1 Introduction

Supply chain is an important component in logistics development for all industries. It can improve efficiency and effectiveness of not only product transfer, but also information sharing between the complex hierarchies of all the tiers. Waters and Waters (2007) emphasized that supply chain comprises a key element in corporate competitiveness; some firms have come to view this function as the cornerstone of their differentiation strategy. The supply chain is a continuous process, from raw materials to finished goods. It contains different functions such as process design, products design, manufacturing, distribution, sales, purchasing, marketing and forecasting. Supply chain management defines a network of interdependent partners which are working extremely close together in order to accomplish a common goal of customer satisfaction. The success in the flow of supply chain management produces products of high quality at low cost and a good customer service (El-Baz 2011). Supply chain management involves integrating all key operational processes at any level between the final users and original suppliers of the products, services and information that offer added value to customers and other stakeholders (Cooper and Lambert 2000). Supply chain management creates value for customers, companies, and stakeholders interacting throughout a supply chain (Estampe et al. 2013). Inevitably, it is important to measure the performance of the complete supply chain as well as the individual processes. The performance measurement system should be based on the strategy, value drivers and important goals of the companies and the whole supply chain. Supply chain performance measurement is necessary for the continuous improvement of supply chain management (Chan 2003). In other words, supply chain performance measurement is essential for a company in order to survive in today's competitive business environment. Successful supply chain performance measurement relies on appropriate metrics that capture the entire essence of the supply chain process. Supply chain performance measurement should be a business-critical process, driven by metrics and supported by business intelligence. With increasing competition and changing market forces, tapping into this critical asset is essential in sustaining competitive advantage in the global space. Unfortunately, performance measurement in the supply chain field has not kept pace with today's world of interdependent business relationships. What companies need is a new performance measurement system that unifies different business elements, concepts, technologies and tools (Stefanović and Stefanović 2011).

For measuring performance the most widely used method is the balanced scorecard. Kaplan and Norton (1992) presented balanced scorecard model in order to evaluate corporate performance in four types of approaches: the financial, the internal business process, the customer as well as learning and growth. Balanced scorecard method has been widely used in strategy formulation with clearly defined missions, targets, suitable performance measures and metrics (Gunasekaran and Kobu 2007). Several researchers have proposition using balanced scorecard for measuring supply chain management capability (Forker et al. 1997; Yamin et al. 1999; Brewer and Speh 2000; Lapide 2000; Gunasekaran et al. 2001; Mehrjerdi 2009).

Inevitably, quantification of the values with precision in a complex supply chain performance measurement system is difficult. As a matter of fact, fuzzy logic is a technique suitable for dealing with uncertainty and subjectivity. Hence, the supply chain performance measurement under fuzziness can be a new direction in measuring the uncertainty and ambiguity surrounding the supply chain performance measurement.

From this standpoint, the aim of this chapter is to present a fuzzy decision making approach to deal with the performance measurement in supply chain systems. The complex supply chain performance measurement system can be partitioned into separate subsystems in order to facilitate the evaluation of each partition. In this chapter, a decision-making trial and evaluation laboratory (DEMATEL) method is used to develop interrelations among each measurement criterion. That is, DEMATEL method is adapted to model complex interdependent relationships and construct a relation structure using measurement criteria for evaluation. Afterwards, the weight of each criterion is evaluated using fuzzy analytic network process (F-ANP). The F-ANP is performed in order to overcome the problem of dependence and feedback among each measurement criteria.

The rest of the chapter can be summarized as follows: Sect. 2 reviews the selected studies regarding fuzzy supply chain performance measurement in brief. Section 3 explains the methodology used in this chapter. Section 4 provides an illustrative example. Section 5 provides conclusion, discussions as well as recommendations for further studies.

2 Fuzzy Supply Chain Performance Measurement

The supply chain performance measurement under fuzziness can be a new direction in measuring the uncertainty and ambiguity surrounding supply chain performance measurement.

Chen (2002) proposed an algorithm for external performance evaluation of distribution centers in logistics from retailers' viewpoint under fuzzy environment. In this regard, the concepts of factor analysis, eigenvector method, fuzzy Delphi method, fuzzy set theory, and multi criteria decision making method have been adopted.

Lau et al. (2002) considered a framework of supply chain management that involves the principles of fuzzy logic for analysis and monitoring performance of suppliers based on the criteria of product quality and delivery time. The proposed system recommends the quantity should be placed in the next purchase order by identifying the possible issues to be considered prior to final confirmation with the relevant suppliers.

Chan and Qi (2003) proposed an innovative performance measurement method for supply chain management. They employed process-based systematic perspective in order to build an effective method for measuring holistic performance of complex supply chains. They used fuzzy set theory to address the real situation in judgment and evaluation processes.

Chang et al. (2006) proposed a fuzzy multiple attribute decision making (FMADM) method based on the fuzzy linguistic quantifier. They tried to ensure that the evaluation results satisfy the current product competition strategies, and also improve the effectiveness and efficiency of the entire supply chain. They used the fuzzy concept to both the ordinal and cardinal information. Furthermore, they used the fuzzy linguistic quantifier guided order-weighted aggregation (FLQG-OWA) operator to satisfy the enterprise product development strategy based on different phases of product life cycle.

Kahraman et al. (2007) constructed a multi-attribute decision making model for evaluation and selection of logistic information technologies consisting of 4 main and 11 sub criteria. They developed a hierarchical fuzzy TOPSIS method to solve the complex selection problem with vague and linguistic data.

Ganga and Carpinetti (2011) proposed a supply chain performance model based on fuzzy logic to predict performance based on causal relationships between metrics, which are performance metrics levels 1 and 2 of the Supply Council Operations Reference model (SCOR) model. They adopted a prediction model based on fuzzy logic and on metrics of the SCOR model that seems to be a feasible technique to help managers in the decision making process of managing performance of supply chains.

Performance measurement is based on different quantitative and qualitative factors. Some of these factors may have a larger effect on the performance measure than others. Units of measure of the quantitative factors are different such as time, money, percentage, ratio, and counts. El-Baz (2011) presents a performance measurement approach based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP), which ensures the consistency of the designer's assignments of importance of one factor over another to find the weight of each of the manufacturing activity in the departmental organization. In the proposed model, various input factors have been selected, and treated as a linear membership function of fuzzy type. The fuzzy decision making approach provided an effective tool for the performance measurement in supply chain systems of manufacturing environment.

Seyedhosseini et al. (2011) developed a systematic and logical method for the auto part manufacturing organizations to enable them to extract and set leanness criteria for being lean by using the concept of balance scorecard. For determining the lean performance measurement through the company's lean strategy map, a set of objectives should be driven based on the balanced scorecard concept. To determine the company's lean strategy map, they used DEMATEL approach to identify the cause and effect relationships among objectives as well as their priorities. In addition, by combining this method and other group decision making methods such as Delphi, Nominal Group Technique, they come up with a cause and effect relationship among the objectives and draw a lean strategy map for the organization, which can improve the criteria selection strategy by using the higher weighted lean objectives indicating the degree of improved leanness in the manufacturing or service operations. Their study may be a reference point for auto part manufacturing companies to identify their production weaknesses, and help them to focus on their improvement based on their most important and suitable selected objectives and criteria.

Buyukozkan and Ciftci (2012) examined green supply chain management as well as capability dimensions to propose an evaluation framework for green suppliers. Since the nature of supplier selection is known as a complex multi-criteria problem including both quantitative and qualitative factors which may be in conflict and may also be uncertain, they integrated the identified components into a novel hybrid fuzzy multiple criteria decision making (MCDM) model combining the fuzzy Decision Making Trial and Evaluation Laboratory Model (DEMATEL), the Analytical Network Process (ANP), and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) in a fuzzy context.

Yang and Tzeng (2011) proposed an integrated multiple criteria decision making (MCDM) techniques combining with the decision making trial and evaluation laboratory (DEMATEL) and a novel cluster-weighted with ANP method in which the DEMATEL method is used to visualize the structure of complicated causal relationships between criteria of a system and obtain the influence level of these criteria. Then, they adopted these influence level values as the base of normalization supermatrix for calculating ANP weights to obtain the relative importance.

3 Methodology

3.1 DEMATEL Method

The Decision Making Trial and Evaluation Laboratory (DEMATEL) method is developed by Science and Human Affairs Program of the Battelle Memorial Institute through Geneva Research Centre between 1972 and 1976 (Tzeng and Huang 2011). It is used for evaluating complicated and intertwined multi-criteria decision problems (Wu et al. 2010). DEMATEL uses a graph theory to discover mutual impressible and effective relations of elements. Additionally, in this method, the importance and weight of each element are influenced by all factors such as upstream and downstream (Herat et al. 2012).

The following steps can be followed to apply DEMATEL method (Tzeng and Huang 2011; Hung 2011; Herat et al. 2012; Tuzkaya et al. 2012).

Step 1: Calculating the direct-relation matrix.

Pairwise comparisons between each i factor/criterion and each j factor/criterion should be done by giving integer numbers range from 0 to 4 which imply no influence, low influence, medium influence, high influence and very high influence, respectively. Then, a direct-relation $n \times n$ matrix denoted by X_{ij} is formed and it implies the effect of criterion i on criterion j.

Step 2: Calculating the normalized direct-relation matrix.

The normalized direct-relation matrix can be computed by normalizing the direct-relation matrix X.

$$Y = k \cdot X \tag{1}$$

where

$$k = min\left[\frac{1}{\max\limits_{1<i<n} \sum_{i=1}^{n} x_{ij}}, \frac{1}{\max\limits_{1<j<n} \sum_{j=1}^{n} x_{ij}}\right] \quad i,j = 1, 2, \ldots, n \tag{2}$$

In direct-relation matrix, the diagonal is assigned to zero.

Step 3: Calculating total-relation matrix.

The total-relation matrix T, which is the infinite series of direct and indirect impacts of each factor, can be calculated by this formula:

$$T = Y + Y^2 + Y^3 + \ldots + Y^m = Y(I - Y)^{-1} \tag{3}$$

Where, I represents identity matrix.

Step 4: Obtaining R and C values.

$$T = \left[t_{ij}\right]_{n \times n} \quad i, j = 1, 2, \ldots, n \tag{4}$$

$$R = [R_i]_{n \times 1} = \sum_{j=1}^{n} t_{ij} \tag{5}$$

which represents row sum of matrix T and lower than 1.

$$C = \left[C_j\right]_{1 \times n} = \sum_{i=1}^{n} t_{ij} \tag{6}$$

which represents column sum of matrix T and lower than 1.

In T matrix, rows point out direct and indirect impacts over other criteria and columns point out influences from other criteria. $j = i(r_i + c_i)$ represents the "influence" or degree of which ith factor/criterion affects or is affected by jth factor/criterion. R_i–C_j represents the effect of factors/criteria on the system. When R–C is positive, the criterion/factor affects their criteria/factors and assigned to "cause" group. If R–C is negative, the criterion/factor is affected by the other criteria/factors and assigned to "effect" group.

Step 5: Setting a threshold value and obtaining impact-digraph diagram.

Impact-digraph diagram should be obtained in order to determine structural relationship among criteria. This helps to reduce the complexity of the system. Moreover, a threshold value should be assigned by experts or decision makers. Higher values than this threshold value are chosen and included in impact-digraph-map. The other ones are eliminated (Tzeng and Huang 2011; Hung 2011). When the threshold value is too low, many elements are included in the impact-digraph-map. This result in a complex map and essential information may not be differentiated. When the threshold value is too high, many factors are not represented in the map. Therefore, it is vitally important to determine an appropriate threshold value to apply DEMATEL method efficiently (Tzeng and Huang 2011).

3.2 The ANP Method

The ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved. The elements in a cluster may influence other elements in the same cluster and those in other clusters with respect to each of several properties. The main objective is to determine the overall influence of all the elements. In that case, first of all properties or criteria must be organized and they must be prioritized in the framework of a control hierarchy. Then the comparisons must be performed and synthesized to obtain the priorities of these properties. Additionally, the influence of elements in the feedback system with respect to each of these properties must be derived. Finally, the resulting influences must be weighted by the importance of the properties and added to obtain the overall influence of each element (Saaty 1996, 2003; Onut et al. 2011).

Before performing pairwise comparisons, all criteria and clusters compared are linked to each other. There are three types of connections, namely one-way, two way and loop. The pairwise comparisons are made depending on the 1–9 scale recommended by Saaty.

All of these relations are evaluated as pairwise comparisons. To obtain global priorities, the local priority vectors are entered in the appropriate columns of a matrix of influence among the elements, known as a supermatrix. The supermatrix is raised to limiting powers to calculate the overall priorities and consequently the cumulative influence of each element on every other element with which it interacts is determined (Saaty and Vargas 1998). The supermatrix representation of a hierarchy with three levels is given as follows

$$W = \begin{matrix} Goal(G) \\ Criteria(C) \\ Alternatives(A) \end{matrix} \quad \begin{matrix} & G & C & A \\ & \end{matrix} \begin{pmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{pmatrix} \tag{7}$$

where W_{21} is a vector that represents the impact of the goal on the criteria, W_{32} is a vector that represents the impact of the criteria on each of the alternatives, and I is the identity matrix. W is referred to as a supermatrix because its entries are matrices. For example, if the criteria are dependent among themselves, then the (2, 2) entry of W given by W_{22} would be nonzero.

$$W = \begin{pmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{pmatrix} \tag{8}$$

The general form of the supermatrix is described in Eq. (9). C_m is the mth cluster, e_{mn} is the nth element in mth cluster, and W_{ij} is the principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. If the jth cluster has no influence to the ith cluster, then $W_{ij} = 0$. The influence of a set of elements belonging to a cluster, on any element from another component, can be represented as a priority vector by applying pairwise comparisons. All priority vectors in the network are combined into appropriate positions in a supermatrix, in which each entry indicates the influence of the row element on the column element (Chung et al. 2005).

$$W = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11}\cdots e_{1n_1} & e_{21}\cdots e_{2n_2} & \cdots & e_{m1}\cdots e_{mn_n} \end{array} \\ \begin{array}{cc} & e_{11} \\ & \vdots \\ C_1 & e_{1n_1} \\ & e_{21} \\ & \vdots \\ C_2 & e_{2n_2} \\ \vdots & \vdots \\ C_m & e_{m1} \\ & \vdots \\ & e_{mn_m} \end{array} & \begin{pmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{pmatrix} \end{array} \tag{9}$$

Since W is a column stochastic matrix, it is known that the synthesis of all the interactions among the elements of this system is given by W^{∞}. Limiting priorities of the supermatrix depend on the reducibility, primitivity, and cyclicity of that matrix. But there are different forms of the limit depending on the multiplicity of its principal eigenvalue, which must be equal to one or is a complex root of one, and on whether the matrix is reducible and cycles or not (Saaty 2004). If the matrix is irreducible and primitive, the limiting value is obtained by raising W to powers (Saaty and Vargas 1998).

$$W^{\infty} = \lim_{k \to \infty} W^k \tag{10}$$

In this situation, the limit is unique, and there is a column vector w^{∞} for W^{∞}. If there are other roots of unity and the supermatrix has the effect of cyclicity (irreducible and imprimitive), the limiting supermatrix is not only one. There are two or more limiting supermatrices in this situation and the Cesaro sum would be calculated to get the average priority.

$$W^{\infty} = \lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{j=1}^{N} W_j^k \tag{11}$$

where W_j is the jth limiting supermatrix. The Cesaro sum is mostly used for taking the limits when they are not unique. Otherwise, the supermatrix would be raised to large powers to get the priority weights (Yu and Tzeng 2006). In another words, it must be computed the limit priorities of the stochastic supermatrix according to whether it is irreducible or it is reducible with one being a simple or a multiple root and whether the system cyclic or not. If the matrix is reducible, then the multiplicity of the roots (m_i) of the principal eigenvalue has to be considered to obtain limit priorities from a reducible stochastic matrix with the principal eigenvalue being a multiple root. As an illustration, when $m_i = 1$, W^{∞} for a hierarchy with three levels is given by (Saaty and Vargas 1998; Onut et al. 2011):

$$W^{\infty} = \lim_{k\to\infty}\begin{pmatrix} 0 & 0 & 0 \\ W_{22}^k W_{21} & W_{22}^k 0 & 0 \\ W_{32}\left(\sum_{h=0}^{k-2} W_{22}^h\right) W_{21} & W_{32}\left(\sum_{h=0}^{k-1} W_{22}^h\right) & I \end{pmatrix} \tag{12}$$

Because $(W_{22})^k$ tends to zero as k tends to infinity for $|W_{22}| < 1$, W^{∞} is found as follows.

$$W^{\infty} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Z = W_{32}(I - W_{22})^{-1} W_{21} & W_{32}(I - W_{22})^{-1} & I \end{pmatrix} \tag{13}$$

Thus, the impact of the goal on the ranking of the alternatives is given by the (3, 1) entry of W^{∞}. According to Neumann series, if $\lim_{k\to\infty} W^k = 0$, then $I - W$ is nonsingular and

$$(I - W_{22})^{-1} = I + W_{22} + W_{22}^2 + W_{22}^3 + \cdots = \sum_{k=0}^{\infty} W_{22}^k. \tag{14}$$

It provides approximations of $(I - W_{22})^{-1}$ when W_{22} has entries of suitable magnitude. If the first several terms of Neumann series are approximately substituted to the Z,

$$Z = W_{32}\left(I + W_{22} + W_{22}^2 + W_{22}^3 + \cdots\right) W_{21} \tag{15}$$

Hence the vector *Z* can be used for evaluating and ordering the alternatives. In another words, after forming the supermatrix, if it is column stochastic, we can simply raise it to powers to obtain an answer. Otherwise, the weighted supermatrix is generated first and then raised it to limiting powers to get the global priority vector. Because the supermatrix is not column stochastic in generally, the limiting matrix does not exist. Hence, stochasticity of the supermatrix can be saved by additional normalization of the columns of the sub-matrices (Ramik 2006). For this reason, this normalization approach can be used to obtain new sub-matrices as mentioned in Eqs. (12–15) and especially with the vector Z, fuzzy evaluations of the alternatives can be executed effectively. The detailed discussion of the mathematical processes of the ANP can refer to Saaty (1996), Saaty and Vargas (1998), and Ramik (2006).

3.3 Fuzzy ANP

The fuzzy set theory introduced by Zadeh (1965, 1976) is suitable for dealing with the uncertainty and imprecision associated with information concerning various parameters (Tuzkaya and Onut 2008). Human judgment is generally characterized by vague language, like 'equally', 'moderately', 'strongly', 'very strongly', 'extremely' and a 'significant degree'. Using such language, decision makers quantify uncertain events and objects. Generally, the fuzzy sets are defined by the membership functions. The fuzzy sets represent the grade of any element x of X that have the partial membership to A. The degree to which an element belongs to a set is defined by the value between 0 and 1. An element x really belongs to A, if $\mu A(x) = 1$ and clearly not, if $\mu A(x) = 0$. Higher is the membership value, $\mu A(x)$, greater is the belongingness of an element x to a set A. Some main arithmetic operations can be extended to fuzzy numbers by the extension principle in the case of triangular fuzzy numbers (Chen et al. 1992).

Fuzzy-ANP method has been used to solve the problem of supply chain performance measurement. It is convenient in situations where there is a high degree of interdependence between various attributes of the alternatives. In this approach, pair-wise comparison matrices are formed between various attributes of each level with the help of triangular fuzzy numbers. Fuzzy-ANP can easily accommodate the interrelationships existing among the functional activities (Mohanty et al. 2005). The concept of supermatrices is employed to obtain the composite weights that overcome the existing interrelationships. Most of the supply chain performance measurement studies generally employ crisp data for evaluation of criteria and alternatives. However, a large amount of uncertainty is associated with various parameters of supply chain performance measurement models, and thus there is a need for fuzzy theory. The values of parameters such as supplier rejection rate, delivery performance, quality of delivered goods, capacity utilization, etc. are transformed into triangular fuzzy numbers and are used to calculate fuzzy values.

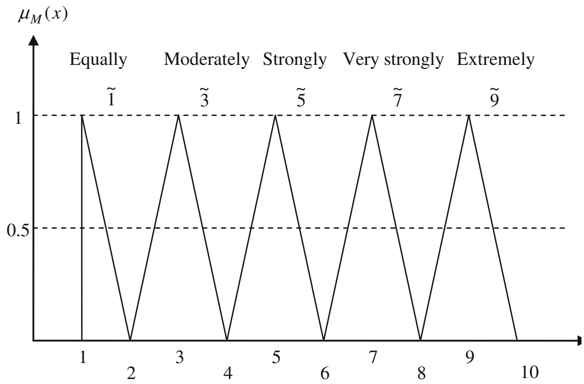

Fig. 1 Fuzzy membership function scale

In the pairwise comparison of attributes, decision maker can use triangular fuzzy numbers to state their preferences. Even though the discrete scale of 1–9 has the advantages of simplicity and easiness for use, it does not consider the uncertainty associated with the mapping of one's perception or judgment to a number. For these reasons a scale of $\tilde{1} - \tilde{9}$ can be defined for triangular fuzzy numbers instead of the scale of 1–9, When comparing attribute i with attribute j, $\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$ and $\tilde{9}$ indicate equal importance among the compared attributes, moderate importance of i over j, strong importance of i over j, very strong importance of i over j and extreme importance of i over j, respectively, where $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. This scale is shown in Fig. 1. To evaluate of the decision maker preferences, pairwise comparison matrices are structured by using triangular fuzzy numbers (l, m, u). The $m \times n$ triangular fuzzy matrix can be given as follows (Tuzkaya and Onut 2008).

$$\tilde{A} = \begin{pmatrix} (a_{11}^l, a_{11}^m, a_{11}^u) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (a_{21}^l, a_{21}^m, a_{21}^u) & (a_{22}^l, a_{22}^m, a_{22}^u) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \vdots & \vdots \\ (a_{m1}^l, a_{m1}^m, a_{m1}^u) & (a_{m2}^l, a_{m2}^m, a_{m2}^u) & \cdots & (a_{mn}^l, a_{mn}^m, a_{mn}^u) \end{pmatrix} \tag{16}$$

The element a_{mn} represents the comparison of component m (row element) with component n (column element). If $\tilde{A}$ is a pairwise comparison matrix, it is assumed that it is reciprocal, and the reciprocal value, i.e. $1/a_{mn}$, is assigned to the element a_{nm}

$$\tilde{A} = \begin{pmatrix} (1,1,1) & (a_{11}^l, a_{11}^m, a_{11}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (\frac{1}{a_{11}^u}, \frac{1}{a_{11}^m}, \frac{1}{a_{11}^l}) & (1,1,1) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \vdots & \vdots \\ (\frac{1}{a_{1n}^u}, \frac{1}{a_{1n}^m}, \frac{1}{a_{1n}^l}) & (\frac{1}{a_{2n}^u}, \frac{1}{a_{2n}^m}, \frac{1}{a_{2n}^l}) & \cdots & (1,1,1) \end{pmatrix} \tag{17}$$

$\tilde{A}$ is also a triangular fuzzy pairwise comparison matrix. There are several methods for getting estimates for fuzzy priorities $\tilde{w}_i$, where $\tilde{w}_i = \left(w_i^l, w_i^m, w_i^u\right)$, $i = 1, 2, \ldots, n$, from the judgment matrix $\tilde{A}$ which approximate the fuzzy ratios $\tilde{a}_{ij}$ so that $\tilde{a}_{ij} \approx \tilde{w}_i / \tilde{w}_j$. One of these methods, logarithmic least squares method (Chen et al. 1992), is reasonable and effective, and it is used in this study. Hence the triangular fuzzy weights for the relative importance of the criteria, the feedback of the criteria and the alternatives according to the individual criteria can be calculated. The logarithmic least squares method for calculating triangular fuzzy weights can be given as follows:

$$\tilde{w}_k = \left(w_k^l, w_k^m, w_k^u\right) \qquad k = 1, 2, 3, \cdots, n. \tag{18}$$

where

$$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}}, \quad \mathrm{s} \in \{l, m, u\}. \tag{19}$$

After calculating triangular fuzzy weights, the aggregated triangular fuzzy evaluations of the alternatives are obtained using the approximate Eq. (15) which is applied to the triangular fuzzy matrices as follows (Ramik 2006):

$$\tilde{Z} = \tilde{W}_{32}\left(I \tilde{+} \tilde{W}_{22} \tilde{+} \tilde{W}_{22}^2 \tilde{+} \tilde{W}_{22}^3 \tilde{+} \cdots\right)\tilde{W}_{21} \tag{20}$$

After finding the alternatives described as triangular fuzzy numbers, they must be ordered from the best to the worst using the one of the ordering methods. The ordering methods transform the fuzzy numbers to crisp numbers by defuzzification. There are different defuzzification methods such as, centroid average, maximum center average, mean of maximum, smallest of maximum, largest of maximum. Here, the centroid average method is used because of its easiness and being one of the most commonly used defuzzification techniques. This method determines the centre of the area of the aggregated membership functions.

4 An Illustrative Example

As a common methodology for identifying the production or service performance criteria, the performance measurement systems (PMS) are considered and developed to some extent. Reviewing the state-of-the arts, various systems and approaches used for measuring performance of supply chains have been examined. In this study, the concept of balanced scorecard approach has been extended for

Table 1 Main and sub-criteria for supply chain performance evaluation

C1	Financial criteria	F1	Supplier rejection rate
		F2	Buyer–supplier partnership level
		F3	Variations against budget
C2	Customer criteria	C1	Level of customer perceived value of product
		C2	Range of products and services
		C3	Flexibility of service systems to meet particular customer needs
C3	Business criteria	B1	Total supply chain cycle time
		B2	Capacity utilization
		B3	Total cash flow time
C4	Innovation and learning criteria	I1	Supplier assistance in solving technical problems
		I2	Supplier ability to respond to quality problems
		I3	Supplier's booking in procedures
C5	Logistics criteria	L1	Delivery performance
		L2	Responsiveness to urgent deliveries
		L3	Total distribution cost
		L4	Total inventory cost as:
C6	Planning criteria	P1	Effectiveness of distribution planning schedule
		P2	Effectiveness of master production schedule
		P3	Accuracy of forecasting techniques
C7	Quality criteria	Q1	Quality of delivered goods
		Q2	Delivery reliability
		Q3	Achievement of defect free deliveries

determining and selecting the above main and sub-performance criteria given in Table 1. Textile sector is chosen as the application area and two alternative supply chain types are considered to measure their supply chain performance. First alternative has a producer that relatively small, procures raw material to stock and also produce to stock and tries to pump it to the distribution channel. In the second supply chain, all the actors try to apply just-in-time approach from supplier to point of sales. The production facilities produce according to the order quantities and also supply raw material and components considering the production schedule.

In the first step of the illustrative example, DEMATEL is applied to determine cause and effect groups by categorizing the influencing factors. It starts with calculating the initial direct relation matrix which is given in Table 2. And then the normalized direct relation matrix is given in Table 3.

After generating the total-relation matrix given in Table 4, the cause and effect groups are determined (Table 5) and the threshold value, 0.64, is adopted. It means that the row criteria, which have an under threshold value, are not strongly affecting the column criteria. Therefore, these values of the total-direct matrix can be eliminated in the Fuzzy-ANP evaluation process.

Thanks to the DEMATEL method, the number of Fuzzy-ANP evaluations decreases to prevent intractably complex systems. Considering the results of DEMATEL, Fuzzy-ANP initial supermatrix for supply chain performance measurement is prepared. All paired comparisons are carried out by using the

Table 2 The initial direct relation matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0.0	1.5	3.5	1.5	2.5	3.0	4.0
C2	3.0	0.0	1.5	1.5	3.5	3.5	4.0
C3	3.5	1.0	0.0	2.0	2.0	3.5	3.0
C4	1.0	3.0	1.5	0.0	1.5	1.5	3.5
C5	2.0	3.5	2.5	2.5	0.0	2.5	2.5
C6	3.5	1.5	3.5	3.5	3.5	0.0	1.0
C7	1.0	3.5	1.5	2.0	1.5	2.5	0.0

Table 3 The normalized direct relation matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	0.08	0.19	0.08	0.14	0.17	0.22
C2	0.17	0.00	0.08	0.08	0.19	0.19	0.22
C3	0.19	0.06	0.00	0.11	0.11	0.19	0.17
C4	0.06	0.17	0.08	0.00	0.08	0.08	0.19
C5	0.11	0.19	0.14	0.14	0.00	0.14	0.14
C6	0.19	0.08	0.19	0.19	0.19	0.00	0.06
C7	0.06	0.19	0.08	0.11	0.08	0.14	0.00

Table 4 The total-relation matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0.571	0.652	0.740	0.620	0.709	0.805	0.881
C2	0.750	0.618	0.692	0.657	0.797	0.869	0.928
C3	0.706	0.597	0.550	0.615	0.658	0.790	0.803
C4	0.488	0.593	0.508	0.412	0.530	0.585	0.706
C5	0.662	0.732	0.682	0.652	0.582	0.772	0.813
C6	0.757	0.670	0.763	0.725	0.773	0.682	0.786
C7	0.506	0.621	0.524	0.525	0.547	0.642	0.552

Table 5 The sum of the influences on criteria

	Di	Ri	$Di + Ri$	$Di - Ri$
C1	4.98	4.44	9.42	0.54
C2	5.31	4.48	9.79	0.83
C3	4.72	4.46	9.18	0.26
C4	3.82	4.21	8.03	−0.39
C5	4.89	4.60	9.49	0.30
C6	5.16	5.14	10.30	0.01
C7	3.92	5.47	9.39	−1.55

triangular fuzzy numbers. The calculation details of local priority vectors (W_{21}) and matrices (W_{22} and W_{32}) which are the parts of the supermatrix are explained below.

Table 6 Normalized fuzzy weights of the sub-criteria according to the goal

	Lower	Mean	Upper
F1	0.039	0.077	0.116
F2	0.029	0.058	0.087
F3	0.034	0.068	0.101
C1	0.080	0.123	0.216
C2	0.018	0.027	0.048
C3	0.062	0.096	0.168
B1	0.023	0.042	0.060
B2	0.018	0.032	0.047
B3	0.010	0.018	0.027
I1	0.009	0.020	0.038
I2	0.010	0.023	0.044
I3	0.001	0.003	0.005
L1	0.036	0.045	0.081
L2	0.051	0.063	0.114
L3	0.029	0.036	0.065
L4	0.022	0.027	0.049
P1	0.031	0.042	0.084
P2	0.027	0.036	0.072
P3	0.022	0.030	0.060
Q1	0.018	0.044	0.097
Q2	0.015	0.038	0.084
Q3	0.020	0.051	0.111

W_{21} comparisons are related with the top of the hierarchy in the network. There is not any feedback or inner loop in these comparisons. Firstly the main criteria are compared by the decision maker and the weights of the clusters are obtained. Then, the sub-criteria in each cluster are compared with respect to the goal to determine their own weights. At last, weights of the sub- criteria are multiplied by the main criteria weights to get a column stochastic vector. The obtained vectors are given in Table 6 which is constituted from the fuzzy triangular numbers.

The evaluation time of the W_{22} matrix is decreased by eliminating some of the criteria evaluations that are belong to the same or different clusters. There are 22 sub-criteria and 484 comparisons in W_{22}. However, the number of evaluations is decreased to the 295 according to the chosen threshold value in DEMATEL. The normalized version of result matrix (W_{22}) with triangular fuzzy numbers is given as an appendix, since it is too large.

The last part of the Fuzzy-ANP supermatrix (W_{32}) is the comparison of the alternative supply chains according to the each sub-criterion. After these comparisons are realized by the decision makers, the last weights of the alternatives are calculated by Eq. (15). Table 7 shows the fuzzy weights of the alternatives with respect to the sub-criteria.

In the aggregating stage of the parts of supermatrix, W_{22} and W_{32} matrices will have importance values denoted w_1 and w_2, respectively. It is assumed that both

Table 7 Corresponding fuzzy weight matrix of the alternatives according to the sub-criteria

	Financial criteria								
	F1			F2			F3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.375	0.667	1.500	0.281	0.500	1.125	0.188	0.333	0.750
Alt 2	0.188	0.333	0.750	0.281	0.500	1.125	0.375	0.667	1.500

	Customer criteria								
	C1			C2			C3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.300	0.500	0.625	0.400	0.667	0.867	0.200	0.333	0.417
Alt 2	0.300	0.500	0.625	0.200	0.333	0.433	0.400	0.667	0.833

	Business criteria								
	B1			B2			B3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.300	0.429	0.643	0.280	0.400	0.600	0.280	0.400	0.600
Alt 2	0.400	0.571	0.857	0.420	0.600	0.900	0.420	0.600	0.900

	Innovation and learning criteria								
	I1			I2			I3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.250	0.333	0.467	0.150	0.200	0.280	0.250	0.333	0.467
Alt 2	0.500	0.667	0.933	0.600	0.800	1.120	0.500	0.667	0.933

	Logistics criteria											
	L1			L2			L3			L4		
	L	M	U	L	M	U	L	M	U	L	M	U
Alt 1	0.286	0.571	1.086	0.214	0.429	0.814	0.071	0.143	0.271	0.429	0.857	1.629
Alt 2	0.214	0.429	0.814	0.286	0.571	1.086	0.429	0.857	1.629	0.071	0.143	0.271

	Planning criteria								
	P1			P2			P3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.250	0.500	1.050	0.167	0.333	0.700	0.150	0.300	0.630
Alt 2	0.250	0.500	1.050	0.333	0.667	1.400	0.350	0.700	1.470

	Quality criteria								
	Q1			Q2			Q3		
	L	M	U	L	M	U	L	M	U
Alt 1	0.375	0.625	0.781	0.400	0.667	0.833	0.343	0.571	0.714
Alt 2	0.225	0.375	0.469	0.200	0.333	0.417	0.257	0.429	0.536

the sub-matrices have an equal importance as $w_1 = 0.5$ and $w_2 = 0.5$. A column stochastic matrix is obtained by multiplying w_1 with W_{22} and w_2 with W_{32}, respectively. The results are denoted by W_{22}* and W_{32}* matrices and inserted to the supermatrix. Then the approximation formula of Neumann series (Eq. 19) is used for the synthesis calculations and aggregated triangular fuzzy weights of the performance of supply chain alternatives are obtained (Table 8).

Table 8 Aggregated triangular fuzzy weights of the alternative supply chains' performance

Alternatives	Weights		
	Lower	Mean	Upper
Supply chain alternative 1	0.10776	0.39871	1.83697
Supply chain alternative 2	0.12254	0.43675	2.02579

The fuzzy weights give an idea about the performance values of the supply chain alternatives. However, defuzzification of the results and determining the rank of results is important. In this example, the centroid average method is used since it is easy applicable and practical one. At the end the defuzzified and normalized weights or performance values for alternative 1 and alternative 2 are determined as 47.5 % and 52.5 %, respectively.

5 Conclusion

As a matter of fact, supply chain is the upstream fraction of the value chain activities. The right materials, services as well as technologies should be purchased from the right sources at the right time and in the right quality. For this purpose, it is necessary to have good monitoring scheme for supply chain. Hence, effective supply chain performance measurement is the key issue towards efficient supply chain management. Current supply chain performance measurement systems still suffer from being too inward looking and not considering external environmental factors that might affect the overall supply chain performance. An effective overall supply chain performance evaluation model is necessary for suppliers as well as manufacturers to assess their companies under different supply chain strategies.

This chapter presents a fuzzy decision making approach to deal with the performance measurement in supply chain systems. In this chapter, DEMATEL method is adapted to model complex interdependent relationships and construct a relation structure using measurement criteria for evaluation. F-ANP is performed to overcome the problem of dependence and feedback among each measurement criteria.

For future directions, proposed integrated DEMATEL and Fuzzy-ANP approach can also be considered with different or extended criteria for the same problem. Furthermore, other convenient hybrid methodologies can be used for evaluating the same criteria, which are determined in this study. The comparison of these methodologies may be helpful for the decision makers.

Appendix

Normalized fuzzy weights of W22 part of the supermatrix

	Fnancial perspective									Customer perspective								
	F1			F2			F3			C1			C2			C3		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
F1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.12	0.16	0.08	0.13	0.17	0.07	0.12	0.16
F2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.08	0.05	0.09	0.11	0.02	0.04	0.05
F3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.10	0.03	0.04	0.06	0.06	0.10	0.13
C1	0.07	0.12	0.28	0.07	0.13	0.30	0.06	0.11	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.05	0.10	0.22	0.06	0.11	0.25	0.03	0.05	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.06	0.11	0.25	0.05	0.09	0.20	0.09	0.16	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B1	0.04	0.08	0.17	0.01	0.02	0.05	0.03	0.05	0.10	0.03	0.05	0.06	0.02	0.04	0.05	0.04	0.06	0.08
B2	0.02	0.03	0.06	0.02	0.04	0.09	0.02	0.04	0.09	0.02	0.04	0.05	0.04	0.06	0.08	0.01	0.02	0.03
B3	0.01	0.02	0.04	0.03	0.06	0.14	0.02	0.04	0.08	0.02	0.03	0.04	0.01	0.02	0.03	0.02	0.04	0.05
I1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.01	0.02	0.03	0.02	0.03	0.03
I2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.03	0.04	0.02	0.03	0.04
I3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.01	0.01	0.00	0.00	0.00
L1	0.04	0.08	0.17	0.03	0.05	0.11	0.03	0.05	0.12	0.04	0.07	0.09	0.05	0.09	0.11	0.04	0.06	0.08
L2	0.03	0.05	0.11	0.04	0.07	0.15	0.02	0.03	0.07	0.04	0.07	0.08	0.04	0.07	0.09	0.04	0.07	0.09
L3	0.03	0.06	0.13	0.05	0.08	0.18	0.05	0.08	0.19	0.03	0.06	0.07	0.03	0.05	0.06	0.03	0.06	0.07
L4	0.02	0.04	0.10	0.02	0.03	0.07	0.04	0.06	0.14	0.02	0.03	0.04	0.01	0.02	0.03	0.02	0.04	0.05
P1	0.04	0.07	0.16	0.03	0.05	0.11	0.02	0.04	0.09	0.04	0.07	0.08	0.03	0.05	0.06	0.04	0.06	0.07
P2	0.02	0.03	0.06	0.02	0.04	0.08	0.03	0.05	0.11	0.03	0.04	0.05	0.03	0.06	0.07	0.03	0.05	0.06
P3	0.02	0.04	0.10	0.03	0.06	0.13	0.03	0.05	0.12	0.02	0.03	0.04	0.02	0.04	0.05	0.02	0.04	0.04
Q1	0.03	0.06	0.13	0.03	0.06	0.13	0.03	0.05	0.11	0.04	0.07	0.09	0.04	0.06	0.07	0.04	0.07	0.09
Q2	0.03	0.05	0.12	0.02	0.04	0.09	0.03	0.06	0.13	0.03	0.05	0.06	0.02	0.03	0.04	0.03	0.05	0.06
Q3	0.04	0.07	0.15	0.04	0.08	0.18	0.04	0.07	0.15	0.04	0.06	0.07	0.05	0.09	0.11	0.04	0.06	0.07

(continued)

Normalized fuzzy weights of W22 part of the supermatrix

	Business perspective									Innovation and learning perspective								
	B1			B2			B3			I1			I2			I3		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
F1	0.12	0.16	0.25	0.11	0.15	0.23	0.08	0.11	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F2	0.03	0.04	0.05	0.05	0.07	0.10	0.05	0.07	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F3	0.09	0.13	0.19	0.08	0.11	0.16	0.11	0.15	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L1	0.05	0.07	0.11	0.08	0.11	0.17	0.07	0.09	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L2	0.06	0.08	0.13	0.02	0.03	0.04	0.04	0.06	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L3	0.05	0.07	0.10	0.04	0.06	0.08	0.05	0.08	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L4	0.04	0.06	0.08	0.06	0.08	0.13	0.03	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P1	0.06	0.09	0.13	0.04	0.06	0.09	0.05	0.07	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P2	0.02	0.03	0.05	0.05	0.07	0.10	0.04	0.06	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P3	0.04	0.05	0.08	0.03	0.05	0.07	0.03	0.04	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.06	0.09	0.14	0.05	0.08	0.12	0.03	0.05	0.07	0.28	0.38	0.53	0.28	0.38	0.53	0.13	0.17	0.23
Q2	0.04	0.05	0.08	0.03	0.04	0.06	0.05	0.07	0.11	0.22	0.29	0.41	0.22	0.29	0.41	0.38	0.50	0.70
Q3	0.05	0.07	0.11	0.07	0.10	0.15	0.07	0.10	0.14	0.25	0.33	0.47	0.25	0.33	0.47	0.25	0.33	0.47

(continued)

Normalized fuzzy weights of W22 part of the supermatrix

	Logistics perspective												Planning perspective					
	L1			L2			L3			L4			P1			P2		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
F1	0.06	0.11	0.21	0.06	0.11	0.21	0.03	0.07	0.13	0.04	0.08	0.16	0.05	0.09	0.19	0.04	0.08	0.18
F2	0.02	0.05	0.09	0.03	0.06	0.12	0.02	0.04	0.08	0.03	0.06	0.12	0.02	0.05	0.09	0.02	0.05	0.10
F3	0.04	0.09	0.16	0.04	0.07	0.14	0.07	0.13	0.25	0.05	0.10	0.19	0.03	0.07	0.14	0.04	0.07	0.15
C1	0.07	0.13	0.25	0.06	0.12	0.23	0.09	0.17	0.32	0.07	0.15	0.28	0.04	0.08	0.17	0.04	0.08	0.17
C2	0.02	0.05	0.09	0.01	0.02	0.04	0.02	0.04	0.08	0.02	0.05	0.09	0.03	0.07	0.14	0.05	0.10	0.20
C3	0.06	0.12	0.22	0.08	0.16	0.30	0.04	0.09	0.16	0.05	0.10	0.19	0.05	0.10	0.21	0.03	0.07	0.14
B1	0.03	0.06	0.11	0.02	0.05	0.09	0.02	0.05	0.09	0.03	0.06	0.12	0.02	0.05	0.10	0.02	0.03	0.06
B2	0.01	0.02	0.04	0.01	0.03	0.05	0.01	0.02	0.05	0.01	0.01	0.02	0.01	0.03	0.05	0.02	0.04	0.08
B3	0.02	0.04	0.07	0.02	0.04	0.07	0.02	0.04	0.07	0.02	0.04	0.08	0.01	0.02	0.04	0.01	0.03	0.05
I1	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.03	0.05	0.01	0.03	0.05	0.01	0.02	0.05	0.01	0.02	0.04
I2	0.01	0.02	0.04	0.01	0.03	0.05	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.03
I3	0.01	0.01	0.03	0.00	0.01	0.02	0.00	0.01	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.02
L1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.12	0.03	0.05	0.11
L2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.07	0.02	0.05	0.10
L3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.13	0.02	0.04	0.08
L4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.02	0.03	0.07
P1	0.03	0.05	0.10	0.02	0.04	0.08	0.03	0.05	0.10	0.03	0.06	0.11	0.03	0.05	0.11	0.03	0.05	0.11
P2	0.02	0.03	0.06	0.02	0.04	0.07	0.02	0.04	0.07	0.02	0.03	0.06	0.02	0.04	0.08	0.02	0.04	0.08
P3	0.02	0.05	0.09	0.03	0.05	0.10	0.02	0.04	0.08	0.02	0.04	0.08	0.01	0.02	0.04	0.01	0.02	0.04
Q1	0.02	0.05	0.09	0.03	0.05	0.10	0.04	0.07	0.14	0.04	0.08	0.15	0.02	0.04	0.09	0.02	0.04	0.09
Q2	0.02	0.04	0.08	0.02	0.04	0.08	0.02	0.04	0.07	0.01	0.03	0.05	0.02	0.04	0.08	0.02	0.04	0.08
Q3	0.04	0.07	0.14	0.03	0.07	0.13	0.03	0.05	0.10	0.03	0.05	0.10	0.03	0.05	0.11	0.02	0.05	0.10

(continued)

Normalized fuzzy weights of W22 part of the supermatrix

				Quality Perspective								
	P3			Q1			Q2			Q3		
	L	M	U	L	M	U	L	M	U	L	M	U
F1	0.03	0.06	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F2	0.03	0.06	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F3	0.04	0.08	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.05	0.10	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.01	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3	0.06	0.12	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B1	0.02	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2	0.02	0.03	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B3	0.01	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I1	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I2	0.01	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I3	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L1	0.03	0.05	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L2	0.02	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L3	0.02	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L4	0.02	0.03	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P1	0.03	0.05	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P2	0.02	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P3	0.01	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q1	0.02	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q2	0.02	0.04	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q3	0.03	0.05	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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