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Analysis

A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain

Ismail Erol [a,*], Safiye Sencer [a,1], Ramazan Sari [b,2]

[a] Abant İzzet Baysal University, Department of Business Administration, 14280, Bolu, Turkey
[b] Middle East Technical University, Department of Business Administration, 06531, Ankara, Turkey

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ABSTRACT

Sustainable supply chain performance measurement is aimed at addressing environmental, social and economic aspects of sustainable supply chain management. It can be argued that it is not easy to reduce all dimensions of sustainable supply chain to a single unit. Then, the issue is that all valuations should somehow be reducible to a single one-dimensional standard. Multi-criteria evaluation introduces a framework to remedy this issue. As a consequence, multi-criteria evaluation seems to supply a proper and adequate assessment framework for sustainable supply chain assessment. In this study, a multi-criteria framework based on fuzzy entropy and fuzzy multi-attribute utility (FMAUT) is proposed in order to evaluate and compare the company performances in terms of sustainable supply chain. However, note that reducing all aspects of sustainable supply chain to a single unit using a multi-criteria framework may not be sufficient to satisfy all the needs of decision makers although it is used to evaluate sustainability performance of supply chains with respect to three aspects. Therefore, in this research, an alert management system is also developed to satisfy further requirements of users. The proposed frameworks are tested using data obtained from one of the middle sized Turkish grocery retailers.

1. Introduction

Sustainable supply chain management (SSCM) is defined as the management of material and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e. economic, environmental and social into account (Seuring and Müller, 2008a). In sustainable supply chains, environmental and social criteria need to be fulfilled by supply chain members to remain within the supply chain, while it is expected that competitiveness would be maintained through meeting customer needs and related economic criteria. This definition is rather wide and combines those given for sustainability and supply chain management. It is also able to integrate green/environmental supply chain management as one part of the wider field (Seuring and Müller, 2008a).

One implication of sustainability for companies and, therefore, for supply chains, is the wider set of criteria that have to be met, often called the triple bottom line approach (Kleindorfer et al., 2005; Carter and Rogers, 2008; Svensson, 2007; Seuring and Müller, 2008a). On the other hand, the comprehension of sustainable development is often rather simplistic. It is not discussed whether a more technical, positivist comprehension or a social science-based approach is taken, i.e., where sustainability is comprehended as a regulative idea. Consequently, the understanding of sustainable development is fragmented and mostly one-dimension, i.e., environmentally based. An integrated perspective is required for future research where social issues in particular and the interrelation of the three dimensions need to be investigated much further.

SSCM has emerged as a growing topic, receiving increasing interest in the sustainability and supply chain management area (Seuring and Müller, 2008b). Exerting such a major influence on sustainability of national economies, aside from studies dominated by either case or survey based research, measuring performances in the context of sustainable supply chain has not attracted researchers' attention.

With increasing pressure to act and report on sustainability strategies, an overwhelming number of principles, tools and reporting formats have emerged and some of which are adopted by corporations to demonstrate their commitment to sustainable development (Beloff et al., 2004). For example, indicators are used to represent a state of economic, social and environmental development in a defined system (Ness et al., 2007). However, in case of using too many indicators, it is quite difficult to assess sustainability. Further, since managing decisions, such as sustainable supply chain, properly implies involving various participants and perspectives, it is argued that it is impossible to reduce all dimensions to a single unity of measure. Then, the issue is that all valuations should somehow be reducible to a single one-dimension standard. Multi-criteria evaluation introduces a framework to remedy this issue. In fact, it accomplishes the goals of being inter-disciplinary,

* Corresponding author. Tel.: +90 3742541420.
E-mail addresses: erol_i@ibu.edu.tr (I. Erol), sencer_s@ibu.edu.tr (S. Sencer), rsari@metu.edu.tr (R. Sari).
[1] Tel.: +90 3742541000.
[2] Tel.: +90 312 210 3068.

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participatory and transparent (since all criteria are presented in their original form). Then, it is argued that multi-criteria methods yield a most constructive framework for evaluating sustainable development (Singh et al., 2007; Munda, 2004, 2005). Some of these researchers have worked on corporate sustainability. For example, Singh et al. (2007) introduce sustainability and present a conceptual decision model using Analytical Hierarchy Process (AHP) to assist in evaluating the impact of an organization's sustainability performance. They used AHP to determine the weights at various levels. The effectiveness of the model is evaluated in a case study for a major steel company in India. Ding (2007) identifies four sustainable determinants and develops a sustainability index, which is a multi dimensional approach to assess the complexity and importance of projects and facilities for sustainability and profitability. Krajnc and Glavic (2005) present a model for designing a composite sustainable development index that displays performance of companies along the economic, social, and environmental dimensions of sustainability. They also show the effectiveness of the model by comparing two companies in terms of their sustainability performances.

In this research, given the above-mentioned concerns and multiple criteria nature of the sustainable supply chain measurement problem, a new multi-criteria-based framework is proposed in order to evaluate sustainability performance of a supply chain. In such a problem, for some of criteria, while exact assessments can be obtained, for others, they cannot. Since human judgments and preferences are often vague and complex, and decision makers cannot estimate their preferences with an exact scale, linguistic assessments can only be given instead of exact assessments. Therefore, fuzzy set theory is introduced into the proposed Multi-Criteria Decision Method (MCDM) framework, which is put forward to solve such uncertainty problems. The developed framework is based on two proposed methodology: fuzzy entropy and fuzzy Multiple Attribute Utility Theory (FMAUT). Note that sole use of multi-criteria-based sustainable supply chain measurement is not sufficient to satisfy all the needs of decision makers although it is used to evaluate sustainability performance of supply chains with respect to three aspects. There may be three drawbacks of sole use of sustainable supply chain framework as follows: (1) it only measures sustainability performances in overall, (2) it is not capable of doing analysis as to each sustainability indicator independently, and (3) it does not consider the specific targets in terms of the aspects of sustainability.

In this research, it is suggested that developing an alert management system is one possible approach to eliminate the above-mentioned drawbacks.

The remainder of the paper is structured as follows: (1) the proposed methodology is developed, (2) an application is performed, and (3) discussion and some concluding remarks are provided.

2. Methodology

The proposed sustainable supply chain measurement system consists of four inter-connected sub-systems as displayed in Fig. 1.

The following sections demonstrate the details of the proposed framework.

2.1. Constructing indicator sets and collecting data

Each possible indicator should be considered in the analysis to cope with sustainability performance of a supply chain performance from a wide variety of viewpoints, which will help the decision makers better understand the problem and thus improve their confidence in the final evaluation outcome. In a similar way, a sustainability indicator is a specific expression that provides information about an organizations' sustainability performance, efforts to influence that performance, or sustainability conditions. A number of factors may be considered to select the most proper indicators for a particular company. Some of them are as follows: relevance to key objectives, measurability, data availability, administrative burden, reliability of information source and cost of collecting data and so on.

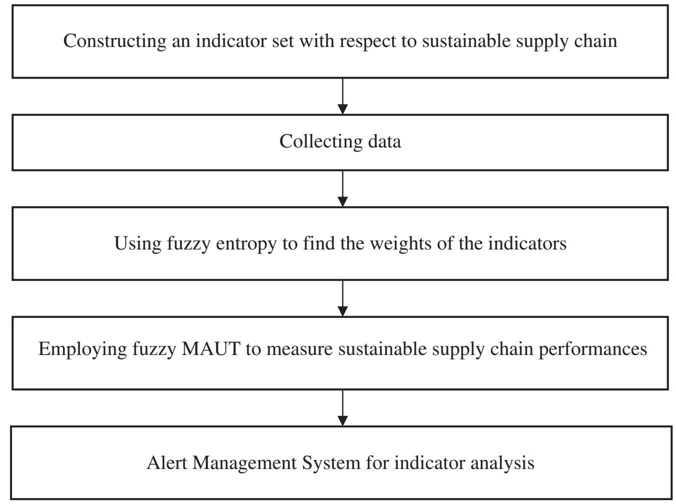


Fig. 1. Sustainable supply chain measurement system framework.

Once an indicator set has been established, decision makers should be surveyed to collect relevant data. Data collection process is invaluable since the reliability of the results is based on the accuracy of data.

2.2. Calculating the importance of criteria and ranking alternatives

Having too much data is the most common and most serious problem an organization can have with its measurement system. Therefore, once the indicator lists have been selected, they should be prioritized for use. Next, the final rankings of the alternatives are calculated. In this research, entropy and MAUT were employed to generate the importance weights of criteria and the final rankings of the alternatives, respectively. However, since human judgments and preferences are often vague and complex, and decision makers cannot estimate their preferences with an exact scale, linguistic assessments can only be given instead of exact assessments. Therefore, fuzzy entropy and fuzzy MAUT are proposed to solve such uncertainty problems in this research.

However, no matter what method is used to solve Fuzzy MCDM problems, first providing an introduction to fuzzy numbers is necessary.

2.2.1. Fuzzy set theory

A fuzzy set is a class of objects, with a continuum of membership grades, where the membership grade can be taken as an intermediate value between 0 and 1. A fuzzy subset A of a universal set X is defined by a membership function $f[A(x)]$ which maps each element x in X to a real number [0, 1]. When the grade of membership for an element is 1, it means that the element is absolutely in that set. When the grade of membership is 0, it means that the element is absolutely not in that set. Ambiguous cases are assigned values between 0 and 1.

In this study, triangular fuzzy numbers are used as membership functions, corresponding to the elements in a set as shown in Fig. 2. The reason for using a triangular fuzzy number is that it is intuitively easy for the decision makers to use and calculate. Fuzzy number A is a triangular fuzzy number if its membership function can be denoted as follows (Kaufmann and Gupta, 1988):

$$\mu_A(X) = \begin{cases} 0 & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0 & x > u \end{cases}$$

where l, m, and u are real numbers and $l = m = u$.

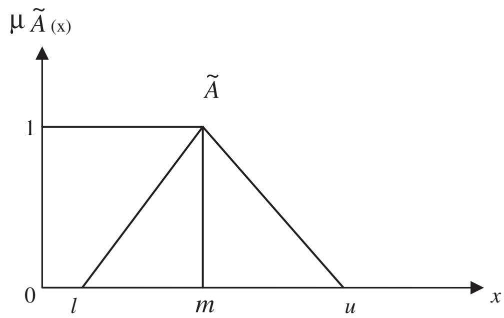


Fig. 2. A triangular fuzzy number.

A triangular fuzzy number can be shown as (l, m, u). The parameters l, m, and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. Triangular fuzzy membership functions and the linguistic terms defined are shown in Fig. 3 and Table 1, respectively.

Each triangular fuzzy number has linear representations on its left and right sides such that its membership function can be defined as displayed in Zimmermann (2001). Defining two triangular fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$ by the triplets as $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the addition, multiplication, division, negative and reciprocal operations of $\tilde{A}_1$ and $\tilde{A}_2$ can be expressed as follows:

Addition: $\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$

Multiplication: $\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$

Division: $\tilde{A}_1 \Phi \tilde{A}_2 = (l_1 / u_2, m_1 / m_2, u_1 \times l_2)$

Negative: $-\tilde{A}_1 = (-l_1, -m_1, -u_1)$

Reciprocal: $\tilde{A}_1^{-1} = 1 / \tilde{A}_1 = (1 / l_1, 1 / m_1, 1 / u_1)$.

Then, the distance between fuzzy number $\tilde{A}_1$ and $\tilde{A}_2$ is calculated as

$$d\left(\tilde{A}_1, \tilde{A}_2\right) = \sqrt{\frac{1}{3}\left[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2\right]}.$$

Table 1
Linguistic terms used by the decision matrix.

Linguistic terms	Linguistic values
Very Low (VL)	(0.00; 0.15; 0.25)
Low (L)	(0.15; 0.30; 0.45)
Medium (M)	(0.35; 0.50; 0.65)
High (H)	(0.55; 0.70; 0.85)
Very High (VH)	(0.75; 0.90; 1.00)

2.3. Fuzzy entropy

Quite a few methods for determining weights of criteria have been proposed. However, no single method can guarantee a more accurate result, and the same decision makers may obtain different weights, and there are no criteria for determining what the true weight is (Chang and Yeh, 2000; Weber and Borcherding, 1993; Yeh et al., 1999).

In this research, entropy is used to calculate the weights of indicators. Entropy method is particularly useful for assigning a weight to each criterion because of the fact that (Chen and Hwang, 1992; Hwang and Yoon, 1981; Zeleny, 1982; Xu et al., 2004; Zou et al., 2006; Sopadang et al., 2002): (1) this method does not require an individual decision maker to rank the criteria, and (2) the relative weight of each criterion can be obtained using rather simple calculations. In other words, decision makers can use the real performance values of companies for calculating the weights. Therefore, it is argued that entropy method is an objective weighting technique. Thus, inherent subjectivity in calculating weights is mostly handled.

The entropy concept suggests that if values for alternatives as to a criterion are the same, the criterion can be eliminated from further consideration. Alternately, the weight assigned to a criterion can be smaller if all the alternatives have similar values for a criterion. On the other hand, when the differences between a criterion's values across particular alternatives are greater, the criterion is viewed as more important. The entropy concept has been shown to be particularly useful to investigate contrasts between sets of data.

Note that since some of criteria consist of linguistic values, in this study, traditional entropy method is empowered using fuzzy arithmetic. The extended fuzzy entropy is based on fuzzy hamming distance function. Since the approach takes into account both subjective and objective factors, it retains the merits of both subjective and objective approaches.

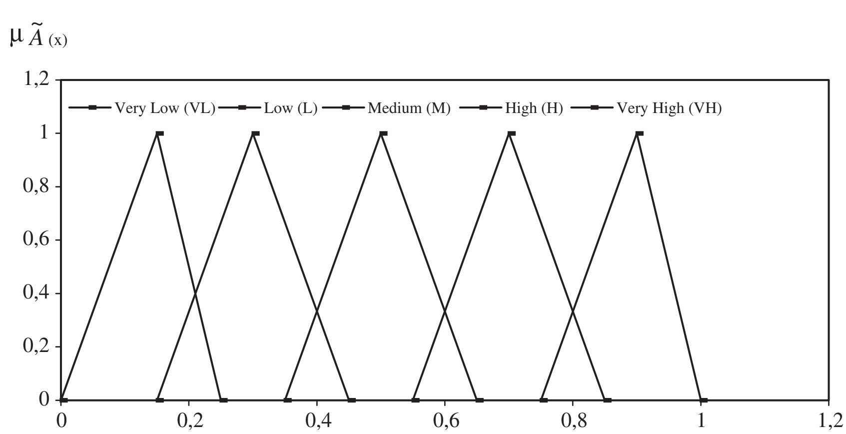


Fig. 3. Fuzzy membership functions.

Deciding matrix D of m alternatives and n attributes (criteria)

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ A_i \\ \cdot \\ \cdot \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} X_1 & X_2 & & X_j & & X_n \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & \dots & X_{ij} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2j} & \dots & X_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ X_{i1} & X_{i2} & \dots & X_{ij} & \dots & X_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ X_{m1} & X_{m2} & \dots & X_{mj} & \dots & X_{mn} \end{bmatrix} \end{array} \qquad (1)$$

Where

A_i the ith alternative considered,

x_{ij} the numerical outcome of the ith alternative with respect to the jth criterion. The calculation of the entropies is very straightforward. The entropy E_j of the set of attribute j is defined as given in Eq. (10): $E_j = -k\sum_{j=1}^{m} r_{ij}\, lnr_{ij}$

where value of r_{ij} is defined as the following probability:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}. \qquad (2)$$

Fuzzy entropy algorithm for determining the evaluation criteria weights can be summarized as follows:

Step 1: Calculate the normalized fuzzy decision matrix, $\tilde{R}$.

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n} \quad i = 1,2,\dots,m; \quad j = 1,2,\dots n. \qquad (3)$$

The benefit criteria, the normalized value $\tilde{r}_{ij}$ is calculated as

$$\tilde{r}_{ij} = \left(\frac{x_{ij}-l_{ij}^{-}}{u_{ij}^{+}-l_{ij}^{-}}\right) \text{ where } u_j^{+} = max_i x_{ij}. \qquad (4)$$

Similarly, the normalized value of $\tilde{r}_{ij}$ for the cost criteria is calculated as

$$\tilde{r}_{ij} = \left(\frac{u_{ij}^{+}-x_{ij}}{u_{ij}^{+}-l_{ij}^{-}}\right) \text{ where } l_j^{-} = min_i x_{ij}. \qquad (5)$$

Step 2: Determination of fuzzy weights

$$W_j = \left(w_j^l, w_j^m, w_j^u\right), \quad j = 1,2,\dots,n \qquad (6)$$

$$w_j^m = \frac{\frac{1}{x_{ij}^m}-1}{\sum_{k=1}^{n}\left(\frac{1}{x_{1k}^m}-1\right)}, \quad k = 1,2,\dots,n \qquad (7)$$

$$w_j^l = \frac{\frac{1}{x_{ij}^l}-1}{\frac{1}{x_{ij}^l}-1+\sum_{k\neq j}\left(\frac{1}{x_{1k}^r-1}\right)}, \quad k = 1,2,\dots,n \qquad (8)$$

$$w_j^u = \frac{\frac{1}{x_{ij}^u}-1}{\frac{1}{x_{ij}^u-1}+\sum_{k\neq j}\left(\frac{1}{x_{1k}^l-1}\right)}, \quad k = 1,2,\dots,n. \qquad (9)$$

Step 3: Calculate the distance based weights.

The entropy concept has been shown to be particularly useful to investigate contrasts between sets of data. It suggests that if a criterion's values with respect the alternatives are the same, the criterion can be eliminated from further consideration. Alternately, the weight assigned to a criterion can be smaller if all the alternatives have similar values for a criterion. On the other hand, when the differences between a criterion's values across particular alternatives are greater, the criterion is viewed as more important (Hwang and Yoon, 1981).

In this paper, we provide a fuzzy entropy weight. For crisp numbers, the calculation of the entropies is very straightforward. The entropy E_j of the set of attribute j is

$$E_j = -k\sum_{j=1}^{m} r_{ij}\, lnr_{ij} \qquad (10)$$

where k represents a constant $k = \frac{1}{ln\, m}$, which guarantee that $0 \le E_j \le 1$.

In the proposed method, the fuzzy entropy of the criterion is calculated using fuzzy hamming distance function as follows:

Hamming distance:

$$\begin{aligned} d(x,y) &= \sum_{i=1}^{n}\left|x_i - y_i\right| \\ F_{ij} &= \frac{1}{3}[|l_1-l_2|+|m_1-m_2|+|u_1-u_2|]. \end{aligned} \qquad (11)$$

For fuzzy numbers, we would first transform the fuzzy numbers into crisp numbers, and then calculate their respective entropies. Although there are many methods to transform fuzzy numbers, most of these methods did not take into account the decision-maker's preferences for the degree of uncertainties. The following formula can be used to consider these factors:

$$F\left(x_{ij}\right) = \frac{\int xu\left(x_{ij}\right)dx}{\int u\left(x_{ij}\right)} \qquad (12)$$

where $F(x_{ij})$ represents the ranking index of the jth attribute of the ith alternative.

$$f_{ij} = \frac{F\left(x_{ij}\right)}{\sum_{i=1}^{n} F\left(x_{ij}\right)} \qquad (13)$$

$$\tilde{E}_j = -k\sum_{i=1}^{m} f_{ij}\, lnf_{ij} = -\frac{1}{ln\, m}\sum_{i=1}^{m} f_{ij}\, lnf_{ij} \qquad (14)$$

where k represents a constant $k = \frac{1}{ln\, m}$, which guarantee that $0 \le E_j \le 1$.

Now, calculate the fuzzy distance entropy weight with the following equation:

$$W_j^d = \frac{1-\tilde{E}_j}{\sum_{j=1}^{n}\left(1-\tilde{E}_j\right)}. \qquad (15)$$

Step 4: Determination of the final fuzzy entropy weights.
Ranking of the final weight value is obtained from defuzzification value with centroid method.

$$\tilde{W}_j = \left(\left(w_j^l\right) \times \left(\frac{w_j^d}{w_j^m}\right), \left(w_j^m\right) \times \left(\frac{w_j^d}{w_j^m}\right), \left(w_j^u\right) \times \left(\frac{w_j^d}{w_j^m}\right)\right) \tag{16}$$

2.4. Fuzzy MAUT

The Multiple Attribute Utility Theory (MAUT) combines the main advantages of simple scoring techniques and optimization models. Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine tangible and intangible criteria. The MAUT theory is developed to help decision makers assign utility values to devices in terms of single attribute utility functions and combine individual evaluations to obtain overall utility values. It considers the decision maker's preferences in the form of a utility function which is defined over a set of attributes (Hwang and Yoon, 1981). MAUT is intuitively a very useful method for formulizing and analyzing decision making problems. The MAUT provides a logical and tractable means to make tradeoffs among conflicting objectives. The advantages of the MAUT approach are that the involved judgments are made explicitly, the value information can be used in many ways to help clarify a decision process, and a decision maker, typically learns a great deal through these joint efforts to construct their views on their preferences (Pohekar and Ramachandran, 2006).

Given the above-mentioned advantages, in this research, MAUT approach is employed. However, in the traditional MAUT approach, the decision variables are deterministic and the utility values are crisp. Therefore, the general MAUT method is unable to handle problems with qualitative and uncertain data. In industrial practice, practitioners and experts often describe objects or events with uncertain and linguistic information. For instance, decision makers may use a "fuzzy" term such as "very difficult" to describe the degree of effectiveness in a certain performance measurement system. In other cases, they may give a range of a certain parameter for describing an object. Therefore, in applying the utility theory to sustainability assessment, the decision makers may provide a range of utility values for a specific indicator level. Therefore, it is desirable to use the fuzzy set theory to obtain a sensible result.

Based on the above-mentioned understanding, a new method, called the fuzzy Multiple Attribute Utility Theory (FMAUT), which combines MAUT and fuzzy set theories, is proposed in this research to deal with qualitative indicators in evaluating sustainable supply chain performances. The procedure for constructing an FMAUT model is as follows:

Step 1: Identify the fuzzy intermediate utility values for the benefit criteria. To do this, the normalized value $\tilde{r}_{ij}$ is calculated as

$$\tilde{r}_{ij} = d\left(\frac{x_{ij} - l_{ij}^-}{u_{ij}^+ - l_{ij}^-}\right) \text{ where } u_j^+ = max_i x_{ij}. \tag{17}$$

Similarly, the normalized value $\tilde{r}_{ij}$ for the cost criterion is calculated as

$$\tilde{r}_{ij} = d\left(\frac{u_{ij}^+ - x_{ij}}{u_{ij}^+ - l_{ij}^-}\right) \text{ where } l_j^- = min_i x_{ij}. \tag{18}$$

Step 2: Following the calculation of the above fuzzy normalization of evaluation matrix, the final fuzzy utility value is found by adding the utilities of alternatives on different criteria as follows:

$$\tilde{U}_i = \tilde{r}_{ij} \otimes \tilde{w}_j. \tag{19}$$

Step 3: Rank the reference order. Choose an alternative with maximum fuzzy utility i is the best rank value.

2.5. Alert management

In the proposed alert management system, first, indicator change variables, which are values identified by a decision maker to show target level for an indicator are determined. Then, alert levels using the indicator change variables are displayed. Alert levels generated enable a decision maker to take precautions in certain periods of a year to resolve the problems encountered.

There are five alert levels defined in this research. They are "Alert", "Critical", "Error", "Warning", "Notice" "Good" and "Very Good" (Table 2).

As to what these alert levels mean to any organization, in a certain year, for example, if alert level for an indicator is designated as "critical", it means the organization has a critical fulfillment condition with high negative impact. In order to convert this linguistic explanation into an algorithm, it is concluded that if the value of the indicator is equal to the minimum of the past year's values, it can be suggested that the company has showed no progress in current year. Therefore, precautionary policies should be adopted.

For converting the other alert level's linguistic explanations into algorithms, decision makers are needed to identify change variables. In other words, in alert management, sustainability indicator change variables must be identified by considering the fact if an indicator is "lower the better" or "greater the better" type. Given the above framework, inefficient performance in terms of any indicator is demonstrated by four alert messages based on fulfillment problems: alert, critical, error and warning. As long as change variables are identified by considering intended performance targets with respect to each indicator, then the proposed system handles the inefficient values of the indicators. Please note that in the process of identifying change variables, decision makers must consider what value of a certain indicator is inefficient.

There are five change variables based on the last five alert levels. Appendix 1 demonstrates the examples of decision loops for "lower the better" and "greater the better" types of indicators, respectively.

In alert management, besides generating indicator wise alert levels, it is necessary to yield alert levels for each aspect of sustainability as well. To achieve that, alert levels for sustainability rankings are identified by using decision loops. Environmental, social and economic sustainability performances of the current year should be better than the performances of the past years. In this respect, if the performance of the current year is better than the performance of the past years, then the alert management system provides the message "good". If the current year ranks second, then the system provides the message "critical". Finally, if the current year ranks third and worse, then the system displays the message "alert". As long as the sustainability performances of the current year are better than the past year's performances, the supply chain is qualified as "good", which suggests that it shows some progress compared to the

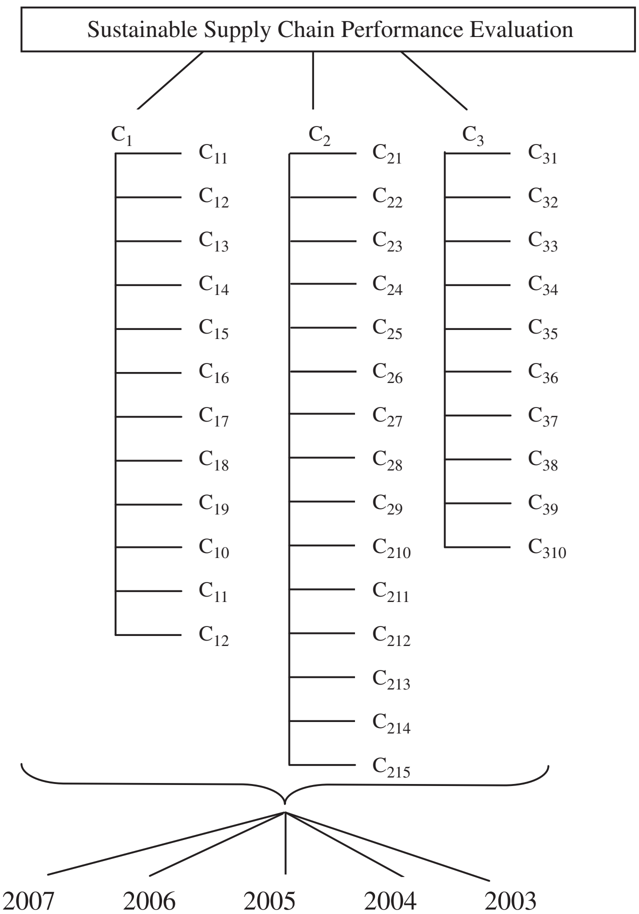
Table 2
Categories for alert index.

Alert levels	Explanations
Alert	Action must be taken immediately
Critical	Critical fulfillment condition with high negative impact
Error	Significant fulfillment problems with medium negative impact
Warning	Slight fulfillment problems with low negative impact
Notice	Mainly normal fulfillment without negative impact
Good	Successful fulfillment with positive impact
Very good	Successful fulfillment with high positive impact

performances of the past years. Getting messages “critical” and “alert” means the supply chain is in trouble and therefore should take preventive precautions. Appendix 2 shows the code developed for each sustainability rankings to generate alert levels.

3. Application

Achieving sustainable supply chains are naturally not a goal that an organization can reach alone. Rather, it entails the participation of



C_1: Environmental Sustainability C_2: Social Sustainability C_3: Economic Sustainability

C_{11}: Water consumption
C_{12}: Energy consumption
C_{13}: Waste minimization
C_{14}: Fraction of suppliers certified in ISO 14001
C_{15}: Number of ISO standards developed
C_{16}: Fraction of facilities using HFC powered units
C_{17}: Fraction of facilities using renewable energy
C_{18}: Use of recycled materials
C_{19}: Effectiveness of reverse logistics system
C_{110}: Effectiveness of the 3PL company that the company works with.
C_{111}: Effectiveness of supplier training in environmental issues
C_{112}: Effectiveness of supplier monitoring

C_{21}: Average annual training time, h/a
C_{22}: Annual number of applied innovative ideas generated by employees /employee
C_{23}: Annual personnel turnover
C_{24}: Annual number of recordable incidents with respect to harassment and violence/employee
C_{25}: Annual number of recordable accidents/employee
C_{26}: Average annual areic number of recordable employee complaints/employee
C_{27}: Average annual areic number of customer complaints, 1/ (m2 a)
C_{28}: Gender diversity
C_{29}: Fraction of total sales invested for social projects / year
C_{210}: Effectiveness of discipline management
C_{211}: Effectiveness of compensation management
C_{212}: Effectiveness of Personnel Recruitment and Selection
C_{213}: Organization’s openness to stakeholder involvement in decision making
C_{214}: Institutional efficiency
C_{215}: Effectiveness of performance management system.

C_{31}: Innovations created through supplier partnerships
C_{33}:Total size of the stores
C_{32}: The number of stores
C_{34}: Total sales kTRY
C_{35}: The number of people employed
C_{36}: Total tax paid kTRY
C_{37}: The number of shareholders
C_{38}: Establishing new employment opportunities
C_{39}: Promoting new investments
C_{310}: Competitiveness of the forward and reverse supply chain

Fig. 4. Indicators used in the analysis.

each organization in a supply chain (Lozano, 2007). Such processes leading to sustainable development improvements often need a key actor that has specific power and motivation to introduce sustainable development initiatives. Retailing companies could play such a role because of the importance they have in the supply chain between supply and demand (Itterhus et al., 1999; Jones et al., 2005). Retailing companies assume SSCM efforts to manage upstream activities by integrating sustainability indicators and targets into supply strategies and to influence downstream activities through marketing and sale initiatives (Itterhus et al., 1999). It is argued that supply chain pressure from companies such as grocery retailers causes a multiplier effect since they often have thousands of suppliers. Therefore, it is suggested that retailers can exert tremendous power on their supply chains as a direct result of their sustainability strategies by determining what products to sell in stores, deciding how to develop human resources strategies, determining terms in supply contracts, defining production conditions, operating distribution systems, shaping packaging choices and *etc.* (Iles, 2005). Owing to these facts, it is argued that retailing companies have a capability to affect sustainability in their supply chain considerably.

In this example, therefore, a grocery retailer in Turkey was selected to test the methodology. The company, which made 112 MTRY (million Turkish Liras), 75 MUSD (million US $) at the end of 2007, has 32 stores. The proposed system displayed in Fig. 1 is followed using the sustainability data for years 2003–2007. Based on the framework, the following assessments are fulfilled.

3.1. Selecting the proper indicators

In this step, due to the fact that the data about the supply chain is obtained from the retailing company, it is of vital importance that the company approves the indicator lists in order to gather the data. This approval process was based on two criteria as follows: "an indicator's measurability" and "data availability for a particular indicator". First, to select a proper set of sustainable supply chain indicators, several studies were examined and shared with the company managers. For example, in an early study Erol et al. (2009) review available sustainability indicator frameworks comprehensively and perform a survey conducted with 20 grocery retailers, one of which is the one included in our current study, in Turkey to select a possible list of indicators for each sustainability aspect. Further, Svensson (2007), Seuring and Müller (2008a, b), Hervani et al. (2005) and Keating et al. (2008) also discuss SSCM and how to measure sustainability performance of a supply chain.

Once the above-mentioned researches have been analyzed, comprehensive lists of the indicators were generated. Next, the company managers selected the most proper indicator lists based on the criteria "an indicator's measurability" and "data available in either qualitative or quantitative form for a particular indicator". The selected lists are displayed in Fig. 4.

For example, in order for the environmental indicator "water consumption" to be assessed, measure "annual water consumption $m^3/(m^2\ a)$" is developed. In other words, "annual water consumption $m^3/(m^2\ a)$" should be calculated in order for a decision maker to properly compare yearly performances in terms of water consumption. The other indicators are measured in a similar manner as displayed in Fig. 4.

Even if not all the indicators used in this research seem to be related to the retailer's whole supply chain, it can be seen that most of them reflect the whole, consisting of the industrial stakeholders of the company. The whole supply chain data on some of the indicators, such as water and energy consumption, are not included because of the difficulties on the data collection process. In addition, it is argued that some of the indicators should be used because of the nature of retailing supply chains even if they seem to be only company related. Let us elaborate on those issues.

Table 3
Data for environmental sustainability indicators.

Environmental sustainability (C_1)	2007	2006	2005	2004	2003
Annual water consumption $m^3/(m^2\ a)$ (C_{11})	0.100	0.104	0.100	0.108	0.107
Annual energy consumption kW h/$(m^2\ a)$ (C_{12})	36.000	40.094	37.500	40.625	35.714
Waste minimization (recycling rates) kg/$(m^2\ a)$ (C_{13})	0.100	0.094	0.090	0.094	0.068
Fraction of suppliers certified in ISO 14001 (C_{14})	0.45	0.40	0.40	0.30	0.25
Number of ISO standards developed (C_{15})	2.000	1.000	1.000	1.000	1.000
Fraction of facilities using HFC powered units (C_{16})	0.100	0.060	0.050	0.050	0.010
Fraction of facilities using renewable energy (C_{17})	0.150	0.100	0.100	0.050	0.010
Use of recycled materials (C_{18})	VH	M	M	VL	VL
Effectiveness of reverse logistics system (C_{19})	VH	VL	VL	VL	VL
Effectiveness of the 3PL company that the company works with (C_{110})	VH	VH	VL	VL	VL
Effectiveness of supplier training in environmental issues (C_{111})	VH	VH	VH	VL	VL
Effectiveness of supplier monitoring (C_{112})	VH	M	M	VL	VL

The environmental indicators that have something to do with the whole supply chain are the ones other than the first three. That is, as the first three indicators are directly related to the retailing company, the rest of them reflect the data obtained from the other members of the supply chain along with the company.

For social sustainability, excluding annual personnel turnover and average annual areic number of customer complaints, the rest include the data from the whole chain. However, in general, it can be argued that personnel turnover rate and customer complaints in retailing sectors are the most important aspects of the social sustainability, which also have a huge impact on the social sustainability performances of their supply chains. Therefore, the company managers have decided to include them in the study along with the other indicators.

Table 4
Data for the social sustainability indicators.

Social sustainability (C_2)	2007	2006	2005	2004	2003
Average annual training time per employee, h/a (C_{21})	40	30	20	20	15
Number of applied innovative ideas generated by employees per employee per year (C_{22})	VH	VH	VH	VL	VL
Annual personnel turnover (C_{23})	0.500	0.550	0.650	0.600	0.650
Annual number of recordable incidents with respect to harassment and violence per employee (C_{24})	0.013	0.016	0.016	0.024	0.028
Annual number of recordable accidents per employee (C_{25})	0.088	0.074	0.104	0.119	0.144
Average annual areic number of recordable employee complaints per employee (C_{26})	M	M	VH	M	VL
Average annual areic number of customer complaints, $1/(m^2\ a)$ (C_{27})	0.512	0.429	0.308	0.250	0.287
Gender diversity (C_{28})	0.400	0.400	0.350	0.300	0.300
Fraction of total sales invested for social projects per year (C_{29})	0.005	0.007	0.002	0.003	0.004
Effectiveness of discipline management (C_{210})	VH	VH	VH	VL	VL
Effectiveness of compensation management (C_{211})	VH	M	M	VL	VL
Effectiveness of personnel recruitment and selection (C_{212})	VH	VH	VL	VL	VL
Organization's openness to stakeholder involvement in decision making (C_{213})	VH	VH	VL	VL	VL
Institutional efficiency (C_{214})	VH	M	M	VL	VL
Effectiveness of performance management system (C_{215})	VH	M	VL	VL	VL

Table 5
Data for the economic sustainability indicators.

Economic sustainability (C_3)	2007	2006	2005	2004	2003
Innovations created through supplier partnerships (C_{31})	VH	VH	M	M	VL
The number of stores (C_{32})	32	26	22	16	12
Total space (m^2 a) (C_{33})	25,000	21,200	20,000	16,000	9200
Total sales/kTRY (C_{34})	112,000	107,737	94,400	88,500	82,600
The number of people employed (C_{35})	850	700	625	420	320
Total tax paid/kTRY (C_{36})	28,000	25,000	22,000	18,000	17,000
The number of shareholders (C_{37})	L	VH	H	M	VL
Establishing new employment opportunities (C_{38})	VH	M	M	M	VL
Promoting new investments (C_{39})	VH	M	M	M	VL
Competitiveness of reverse and forward logistics system (C_{310})	VH	VH	VL	VL	VL

As for the economic sustainability, excluding the indicators "the total sales", "the number of people employed", "total space", "the number of stores" and "total tax paid", the rest are related to the whole chain. The indicator "the number of stores" is included since only retailers have stores in the supply chain.

3.2. Retrieving the data with respect to the indicators

In this section, the required data were retrieved based on the indicators given in Fig. 4. The data with qualitative and quantitative assessments consist of years 2003 to 2007 as displayed in Tables 3–5. The linguistic assessment results for qualitative criteria were obtained by guiding the decision makers through a subjective assessment process defined in Table 1. Then, all of the indicators were converted into linguistic scales using Table 1 as displayed in Table 6.

3.3. Calculating the importance weights

The importance weights of the indicators with respect to three aspects are calculated by using the data in Tables 3–6. To this end, the data is plugged into Eqs. (1)–(16). The calculated weights for upper, medium and lower levels based on fuzzy entropy are displayed in Table 7.

3.4. Calculating the performance indices

Once the fuzzy importance weights of the indicators have been calculated, the sustainable supply chain performance values were computed using fuzzy MAUT.

To achieve that, the data displayed in Tables 3–7 are plugged into Eqs. (17)–(19). First, we identified normalized values for environmental, social and economic sustainability as displayed in Table 8.

Finally, the reference order was ranked. It is observed from Table 9 that in environmental, social and economic sustainability, the supply chain has its best performances in 2007 as experiencing its worst performances 2004, 2003 and 2003 in terms of environmental, social and economic sustainability, respectively.

3.5. Alert management

In this step, based on the interviews with the company management, first change variables with respect to each sustainability indicator were identified as displayed in Table 10.

Then, the alert levels were computed using corresponding change variables. In this research, alert levels with respect to the indicators were generated by using an algorithm provided in the appendix.

For example, the algorithm is developed for the indicator "water consumption" to be minimized in Appendix 3. In 2007, based on the code, the alert level for the indicator "water consumption" is designated as "critical", meaning that the value of the indicator is equal to the minimum of the past year's values. In other words, the company showed no progress in 2007. Therefore, precautionary policies should be adopted to decrease the annual water consumption $m^3/(m^2$ a). Secondly, in 2006, the alert level for the indicator "water consumption" is designated as "alert" meaning that the value of the indicator is greater than the minimum of the past year's values, meaning that action must be taken immediately to decrease water consumption.

Secondly, the algorithm for the indicator "fraction of facilities using renewable energy" which is the greater the better type is exemplified (Appendix 4). In this example, the alert level for the indicator "the fraction of facilities using renewable energy" in 2007 is designated as "very good" meaning successful fulfillment with high positive impact by using change variable_4 and change variable_5.

Table 6
All linguistic assessments including the corresponding ones for quantitative indicators.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{110}	C_{111}	C_{112}
Decision matrix using fuzzy linguistic variables for environmental sustainability												
2007	VH	VH	VL	VH	VH	VH	VH	VH	VH	VH	VH	VH
2006	M	VL	VL	H	VL	M	M	M	VL	VH	VH	M
2005	VH	M	L	H	VL	L	M	M	VL	VL	VH	M
2004	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL
2003	VL	VH	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL

	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{210}	C_{211}	C_{212}	C_{213}	C_{214}	C_{215}
Decision matrix using fuzzy linguistic variables for social sustainability															
2007	VH	VH	VH	VH	H	M	VH	VH	M	VH	VH	VH	VH	VH	VH
2006	M	VH	M	H	VH	M	M	VH	VH	VH	M	VH	VH	M	M
2005	VL	VH	VL	H	M	VH	VL	M	VL	VH	M	VL	VL	M	VL
2004	VL	VL	L	VL	L	M	VL	VL	VL	VL	VL	VL	VL	VL	VL
2003	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL

	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	C_{39}	C_{310}
Decision matrix using fuzzy linguistic variables for economic sustainability										
2007	VH	VH	VH	VH	VH	VH	L	VH	VH	VH
2006	VH	H	H	H	H	H	VH	M	M	VH
2005	M	M	M	L	M	L	H	M	M	VL
2004	M	VL	L	VL	VL	VL	M	M	M	VL
2003	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Table 7
The fuzzy entropy weights.

Fuzzy entropy weights								
Environmental			Social			Economical		
Indicator	Fuzzy interval	Weights	Indicator	Fuzzy interval	Weights	Indicator	Fuzzy interval	Weights
C_{11}	U	0.20726	C_{21}	U	0.21176	C_{31}	U	0.25326
	M	0.08941		M	0.06627		M	0.14253
	L	0.00001		L	0.00001		L	0.00003
C_{12}	U	0.20726	C_{22}	U	0.15409	C_{32}	U	0.33807
	M	0.08941		M	0.07143		M	0.14253
	L	0.00001		L	0.00001		L	0.00002
C_{13}	U	0.30291	C_{23}	U	0.17014	C_{33}	U	0.28920
	M	0.08941		M	0.06407		M	0.14367
	L	0.00000		L	0.00001		L	0.00004
C_{14}	U	0.20220	C_{24}	U	0.14592	C_{34}	U	0.36711
	M	0.08876		M	0.06407		M	0.14253
	L	0.00000		L	0.00001		L	0.00003
C_{15}	U	0.36607	C_{25}	U	0.12967	C_{35}	U	0.33807
	M	0.09091		M	0.06442		M	0.14253
	L	0.00000		L	0.00002		L	0.00002
C_{16}	U	0.20106	C_{26}	U	0.12420	C_{36}	U	0.36711
	M	0.08887		M	0.06442		M	0.14253
	L	0.00000		L	0.00001		L	0.00003
C_{17}	U	0.21842	C_{27}	U	0.21176	C_{37}	U	0.28920
	M	0.08876		M	0.06627		M	0.14367
	L	0.00000		L	0.00001		L	0.00004
C_{18}	U	0.21842	C_{28}	U	0.15359	C_{38}	U	0.27479
	M	0.08876		M	0.06627		M	0.14367
	L	0.00000		L	0.00001		L	0.00003
C_{19}	U	0.35744	C_{29}	U	0.17014	C_{39}	U	0.27699
	M	0.08876		M	0.06407		M	0.14253
	L	0.00000		L	0.00001		L	0.00003
C_{110}	U	0.27262	C_{210}	U	0.15409	C_{310}	U	0.44109
	M	0.08876		M	0.07143		M	0.14367
	L	0.00000		L	0.00001		L	0.00002
C_{111}	U	0.19154	C_{211}	U	0.15762			
	M	0.08876		M	0.06407			
	L	0.00000		L	0.00001			
C_{112}	U	0.21842	C_{212}	U	0.21572			
	M	0.08876		M	0.07143			
	L	0.00000		L	0.00001			
			C_{213}	U	0.21572			
				M	0.07143			
				L	0.00001			
			C_{214}	U	0.13989			
				M	0.06407			
				L	0.00001			
			C_{215}	U	0.27651			
				M	0.06627			
				L	0.00001			

Alert levels with respect to the three aspects of sustainability are generated similarly and displayed in Table 11.

Finally, in alert management, alert levels for each SSCM ranking were obtained. Considering the code, since, for instance, 2007 ranked first in terms of environmental sustainability, the alert level generated turns out to be "good".

4. Discussion and implications

Based on the findings, year 2007 ranked first in environmental, social and economic sustainability. In terms of the worst performance, year 2004, 2003 and 2003 ranked fifth in environmental, social and economic sustainability, respectively.

Finally, since the sustainable supply chain measurement based on fuzzy framework is not capable of being able to satisfy all the needs of a decision maker, the alert management is also developed. Alert management displays the alert levels using the indicator change variables. With the alert levels generated, decision makers enable to take precautions in certain periods of a year to resolve the problems encountered.

With the above points in mind, it is argued that the proposed methodology has the potential to assist decision makers due to the following reasons: (1) it compares and ranks sustainable supply chain performance in indicator basis and as a system, (2) it seeks to take explicit account of multiple criteria in aiding the decision making and assists in indicating opportunities for improvement in sustainability, (3) it leads to better considered, justifiable decisions and can be used as a benchmark among supply chains, (4) it can be utilized by investors that consider acquisitions in an industry, (5) it demonstrates the progress of the supply chain to the industrial stakeholders if it is included in the annual report, and (6) it serves to complement and to challenge intuition (Belton and Stewart, 2002).

However, it is important to recognize that this methodology does not give an absolute number of how close a supply chain is to a sustainable development or when it will reach this goal even if the alert management paves the way for reaching sustainable supply chain by considering change variables. In other words, it is important not only

Table 8
Normalized decision matrix for environmental, social and economical sustainability aspect.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{110}	C_{111}	C_{112}
Normalized decision matrix for environmental sustainability												
2007	1	0.9418	0	1	1	1	1	1	1	1	1	1
2006	0.5460	0.1081	0.1761	0.7500	0	0.5556	0.6429	0.5000	0	1	1	0.5000
2005	1	0.6364	0.3111	0.7500	0	0.4444	0.6429	0.5000	0	0	1	0.5000
2004	0	0	0.1944	0.2500	0	0.4444	0.2857	0	0	0	0	0
2003	0.1407	1	1	0	0	0	0	0	0	0	0	0

	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{210}	C_{211}	C_{212}	C_{213}	C_{214}	C_{215}
Normalized decision matrix for social sustainability															
2007	1	1	1	1	0.7992	0.5000	1	1	0.6000	1	1	1	1	1	1
2006	0.6000	1	0.6667	0.8174	1	0.5000	0.6841	1	1	1	0.5000	1	1	0.5000	0.5000
2005	0.2000	1	0	0.7985	0.5722	1	0.2214	0.5000	0	1	0.5000	0	0	0.5000	0
2004	0.2000	0.2500	0.3333	0.2842	0.3556	0.5000	0	0	0.2000	0	0	0	0	0	0
2003	0	0	0	0	0	0	0.1411	0.0000	0.4000	0	0	0	0	0	0

	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	C_{39}	C_{310}
Normalized decision matrix for economical sustainability										
2007	1	1	1	1	1	1	0.3333	1	1	1
2006	1	0.7000	0.7595	0.8550	0.7170	0.7273	1	0.5000	0.5000	1
2005	0.5000	0.5000	0.6835	0.4014	0.5755	0.4545	0.8333	0.5000	0.5000	0
2004	0.5000	0.2000	0.4304	0.2007	0.1887	0.0909	0.5000	0.5000	0.5000	0
2003	0	0	0	0	0	0	0	0	0	0

simply to take these performance values as the final answer, but also to accept it as part of the overall learning and improvement process — another step in further understanding about the problem. In addition, note that subjectivity may be inherent in all decision making. Multi-criteria analysis does not dispel this subjectivity entirely. It simply seeks to make the need for subjective judgments explicit. Therefore, there is no such thing as the absolute right answer even within the context of the framework proposed in this study. The concept of an optimum does not exist in a multi-criteria framework, and thus multi-criteria analysis cannot be justified within the optimization paradigm even if fuzzy arithmetic is used. Instead, it should be perceived as an aid to decision making that facilitate decision makers' learning about understanding of the problem, organizational priorities and objectives to guide them in identifying preferred course of action (Belton and Stewart, 2002).

Table 9
Sustainable supply chain rankings.

Environment sustainability		Social sustainability		Economic sustainability	
Ranking	Index value	Ranking	Index value	Ranking	Index value
2007	0.2104	2007	0.1261	2007	0.2265
2005	0.0831	2006	0.0948	2006	0.2018
2006	0.0820	2005	0.0386	2005	0.1061
2003	0.0414	2004	0.0145	2004	0.0439
2004	0.0060	2003	0.0110	2003	0.0054

In this research, the following points were taken into consideration in line with Roy (1996): (1) the proper indicator lists were generated, (2) how to measure the indicators were identified and demonstrated, (3) an objective method was used to decrease the subjectivity in weighting the indicators, (4) a fuzzy method was used to rank the performances, and (5) what the results may mean to all the stakeholders were provided.

Table 10
Change variables for environmental, social and environmental indicators.

Change variables	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{110}	C_{111}	C_{112}
Change variables for environmental indicators												
Change Variable_1	0.01	0.01	0.11	0.1	0.1	0.02	0.02	0.1	0.1	0.1	0.1	0.1
Change Variable_2	0.03	0.04	0.21	0.2	0.2	0.06	0.06	0.2	0.2	0.2	0.2	0.2
Change Variable_3	0.05	0.07	0.31	0.3	0.3	0.11	0.11	0.3	0.3	0.3	0.3	0.3
Change Variable_4	0.07	0.11	0.41	0.4	0.4	0.16	0.16	0.4	0.4	0.4	0.4	0.4
Change Variable_5	0.10	0.16	0.50	0.5	0.5	0.20	0.20	0.5	0.5	0.5	0.5	0.5

Change variables	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{210}	C_{211}	C_{212}	C_{213}	C_{214}	C_{215}
Change variables for social indicators															
Change Variable_1	0.10	0.10	0.10	0.50	0.1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Change Variable_2	0.20	0.20	0.20	0.90	0.3	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Change Variable_3	0.30	0.30	0.30	1.30	0.5	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Change Variable_4	0.40	0.40	0.40	1.70	0.7	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Change Variable_5	0.50	0.50	0.50	2.00	1.0	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Change variables	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	C_{39}	C_{310}
Change variables for economic indicators										
Change Variable_1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Change Variable_2	0.20	0.20	0.20	0.30	0.20	0.20	0.20	0.20	0.20	0.20
Change Variable_3	0.30	0.30	0.30	0.50	0.30	0.30	0.30	0.30	0.30	0.30
Change Variable_4	0.40	0.40	0.40	0.70	0.40	0.40	0.40	0.40	0.40	0.40
Change Variable_5	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50	0.50	0.50

Table 11
Alert levels for environment sustainability indicators.

Years	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{110}	C_{111}	C_{112}
Alert levels for environmental indicators												
2007	Critical	Alert	Alert	Warning	Warning	Very Good	Very Good	Notice	Notice	Critical	Critical	Notice
2006	Alert	Alert	Alert	Critical	Critical	Very Good	Critical	Critical	Critical	Notice	Critical	Critical
2005	Good	Alert	Alert	Good	Critical	Critical	Very Good	Notice	Critical	Critical	Notice	Notice
2004	Alert	Alert	Alert	Notice	Critical	Very Good	Very Good	Critical	Critical	Critical	Critical	Critical

Years	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{210}	C_{211}	C_{212}	C_{213}	C_{214}	C_{215}
Alert levels for social indicators															
2007	Good	Critical	Error	Error	Alert	Alert	Alert	Critical	Alert	Critical	Very Good	Critical	Critical	Very Good	Very Good
2006	Very Good	Critical	Error	Error	Very Good	Alert	Alert	Warning	Very Good	Critical	Critical	Very Good	Very Good	Critical	Very Good
2005	Critical	Very Good	Alert	Error	Very Good	Warning	Alert	Warning	Alert	Very Good	Very Good	Critical	Critical	Very Good	Critical
2004	Good	Good	Error	Error	Very Good	Warning	Warning	Critical	Alert	Critical	Critical	Critical	Critical	Critical	Critical

Years	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	C_{39}	C_{310}
Alert levels for economic indicators										
2007	Critical	Notice	Warning	Notice	Notice	Warning	Alert	Very Good	Very Good	Very Good
2006	Notice	Warning	Error	Very Good	Warning	Warning	Warning	Very Good	Very Good	Very Good
2005	Critical	Good	Notice	Good	Very Good	Notice	Good	Very Good	Very Good	Very Good
2004	Good	Good	Very Good	Very Good	Good	Error	Very Good	Very Good	Very Good	Very Good

Finally, the results have some policy implications as well. Indicators used in the analysis may imply that sustainability in the supply chain is very sensitive to microeconomic and macroeconomic policies as well as the macroeconomic stability of the country. Any short run fluctuations in economic environment may increase uncertainties, which in turn may have undesirable transitory impacts on indicators such as R&D expenditures, payments to the employees and dividends, the number of social projects and the number of people employed. On the other hand, the results indicate that energy efficiency and environmental policy prescriptions, and improvement in the health and training system could assure the long run sustainable development in the supply chain. However, as stated by Harris (2007), there is little work on reforming macroeconomic theory and policy to take account of sustainability. In conclusion, the results obtained from the research may be utilized by practitioners and policy makers taking into account the above-mentioned points.

5. Conclusion

In this study, a sustainable supply chain measurement framework tool is developed to evaluate the sustainability performance of a supply chain. To this end, indicators were selected, and the importance levels for the indicators were calculated using fuzzy entropy method. Then, the aggregated performance indices with respect to each aspect of sustainability were computed by using fuzzy MAUT. Finally, the alert management provides alert levels for decision makers to satisfy their further needs.

The proposed tool was tested using data from a grocery retailer in Turkey because of the importance grocery retailers have in the value chain between supply and demand. Based on the results, year 2007 ranked first in environmental, social and economic sustainability. In terms of the worst performance, year 2004, 2003 and 2003 ranked fifth in environmental, social and economic sustainability, respectively.

Since the FMAUT/fuzzy entropy-based sustainable supply chain measurement is not capable of being able to satisfy all the needs of a decision maker, alert management is also developed. Alert management displays the alert levels using the indicator change variables. With the alert levels generated, decision makers enable to take precautions in certain periods of a year to resolve the problems encountered.

It is believed that the proposed framework (1) seeks to take explicit account of multi-criteria in aiding the decision making and assists in indicating opportunities for improvement in sustainability, (2) leads to better considered and justifiable decisions, and (3) can be utilized by investors that consider acquisitions in the industry.

It is argued that including similar analyses in sustainability reports using methodologies such as the one proposed in this research is of significant importance. The reports equipped with such analyses enable stakeholders to better evaluate the organizations. In addition, organizations can develop their overall strategies based on the results of such analyses.

Appendix 1

```
INPUT     : Indicator values to be minimized
OUTPUT: Alert message for an indicator
    For indicator initial indicator_value=1 to last_value do
            If current indicator value > min {past indicator values}
            then message = ALERT
                If current indicator value = min {past indicator
                values} then message = CRITICAL
        If min {past values} > current indicator value > min {past
indicator values}*(1- change variable_1) then message = ERROR
        If min {past values}*(1- change variable_1) >= current
indicator value > min{past indicator values}*(1- change variable_2)
then message = WARNING
              If min {past values}*(1- change variable _2) >= current
indicator value > min{past indicator values}*(1- change variable_3)
then message = NOTICE
              If min {past values}*(1- change variable_3) >= current
indicator value > min{past indicator values}*(1- change variable_4)
then message=GOOD
              If min {past values}*(1- change variable_4) >= current
indicator value > min{past indicator values}*(1- change variable_5)
then message = VERY GOOD
    end
```

INPUT : Indicator values to be maximized
OUTPUT: Alert message for an Indicator
For indicator initial_value = 1 to last_value do
If current indicator value < max {past indicator values} then message = ALERT
If current indicator value = max {past indicator values} then message = CRITICAL
If max {past values} < current indicator value <=max{past indicator values}*(1+ change variable_1) then message=ERROR
If max {past values}*(1+ change variable_1) <= current indicator value < max{past indicator values}*(1+ change variable_2) then message = WARNING
If max{past values}*(1+ change variable_2) <= current indicator value < max{past indicator values}*(1+ change variable_3) then message=NOTICE
If max{past values}*(1+ change variable_3) <= current indicator value < max{past indicator values}*(1+ change variable_4) then message = GOOD
If max{past values}*(1+ change variable_4) <= current indicator value < max{past indicator values}*(1+ change variable_5) then message=VERY GOOD
end

Appendix 2

```
INPUT : Sustainability rankings
OUTPUT: Sustainability alerts
attribute_number =0
For attribute_number = current_ year to starting_year
attribute_number = attribute_number +1
Next attribute_number

For (ranking =1 to attribute_number)
   For (i =1 to (attribute_number + 1)-attribute_number)
      If nom(i) > nom(i + 1) Then
         temp = nom(i)
         nom(i) = nom(i + 1)
         nom(i + 1) = temp
      End If
   Next i
Next ranking

For i = 1 to attribute_number

If nom(i) = 1 then message = "GOOD"
If nom(i) = 2 then message = "CRITICAL"
If nom(i)>=3 then message = "ALERT"
Next i
```

Appendix 3

For indicator initial indicator_value = 1 to last indicator_value do
If current indicator value > min {past indicator values} then message = ALERT
If current indicator value = min {past indicator values} then message = CRITICAL
If min{past indicator values} > current indicator value > min {past indicator values}*(1-0,01) then message = ERROR
If min{past indicator values}*(1-0,01) >= current indicator value > min{past indicator values}*(1-0,03) then message =WARNING
If min{past indicator values}*(1-0,03) >= current indicator value > min{past values}*(1-0,05) then message = NOTICE
If min{past indicator values}*(1-0,05) >= current indicator value > min{past indicator values}*(1-0,07) then message=GOOD
If min{past indicator values}*(1-0,07) >= current indicator value > min{past indicator values}*(1-0,1) then message = VERY GOOD
end

Appendix 4

For indicator initial indicator_value = 1 to last indicator_value do
If current indicator value < max {past values} then message = ALERT
If current indicator value = max {past values} then message = CRITICAL
If max {past values} < current indicator value <=max {past indicator values}*(1 + 0,01) then message = ERROR
If max{past indicator values}*(1 + 0,01) <= current indicator value < max{past indicator values}*(1+0,05) then message = WARNING
If max{past indicator values}*(1 + 0,05) <= current indicator value <max{past values}*(1+0,10) then message= NOTICE
If max{past indicator values}*(1 + 0,10) <= current indicator value < max{past indicator values}*(1 + 0,15) then message = GOOD
If max{past indicator values}*(1 + 0,15) <= current indicator value < max{past indicator values}*(1 + 0,20) then message = VERY GOOD
end

Appendix 5

Sustainability
: sender sustainability
: receiver alert management
: content min{past values}*(1-0,030) >= indicator value > min {past values}*(1-0,05) then message = NOTICE
: language XML

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