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An integrated model for sustainable performance measurement in supply chain

Fahriye Uysal [a*]

[a] *Assist. Prof. Dr., Akdeniz University, Ayşe Sak School of Applied Sciences, Poyraz Sok. No:55, Yeşilbayır, Döşemealtı, 07190 Antalya, Turkey*

Abstract

There is an ongoing importance to the sustainable supply chain performance measurement due to the shifting competitiveness between individual organizations of which supply chains competing against each other. Thus, evaluating the supply chain and improving supply chain performance require the development of sustainable supply chain performance measurement system. Once the performance measurement system only consist of the economical criterion, with the addition of sustainability now its measurement scope includes social, environmental and resource criteria. In this study, The Decision Making Trial and Evaluation Laboratory (DEMATEL) Method was applied to deal with the importance and causal relationships between the sustainable performances measurements criteria by considering the interrelationships among them. To analyze the abovementioned graph structure, a relatively new and multi-criteria decision making methods of graph theory and matrix approach are used. The proposed frameworks are tested using data obtained from three different manufacturing companies that take place on the same supply chain.

Keywords: sustainable supply chain, performance measurement, DEMATEL method, graph theory and matrix approach

1. Introduction

A focus on supply chains is a step towards the broader adoption and the development of sustainability, since the supply chain considers the product from initial processing of raw materials to delivery to the customer. However, sustainability must also integrate issues and flows that extend beyond the core of supply chain management: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life (Linton et al., 2007). Sustainable development is defined as a process of achieving human development in an inclusive, connected, equitable, prudent and secure manner (Hart and Milstein, 2003). A sustainable organization is one that contributes to sustainable development by simultaneously delivering economic, social and environmental benefits – or what has been termed "the triple bottom line" or 3BL. Sustainability is the ability of a firm to meet the needs of the present without compromising the ability of future generations to meet their needs (Norman and MacDonald, 2004).
Neely et al. (1995) define performance measurement as the process of quantifying the effectiveness and efficiency of action. Effectiveness is the extent to which a customer's requirements are met and efficiency measures how

* Fahriye Uysal, Tel: 00 90 242 4432067
E-mail address: fahriyeuysal@akdeniz.edu.tr

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economically a firm's resources are utilized while providing a pre-specified level of customer satisfaction. Discussions of sustainability are driven by the basic notion that a supply chain's performance should be measured not just by profits, but also by the impact of the chain on ecological, social systems, economics and resources (Gladwin, Kennelly and Krause 1995; Starik and Rands 1995; Jennings and Zandbergen 2005; Keeble, 2003). What is essential to supply chain performance is improving the effectiveness of materials management – the set of business processes that support the complete cycle of material flows from purchasing and internal control of production materials, through the planning and control of work-in-process, to the warehousing, shipping, and distribution of finished products (Markley and Davis, 2007).

Evaluating the performance of the firms in a supply chain is a very difficult and sophisticated task. Although there are many different models and indicators used for supply chain performance measurement in literature (Kaplan and Norton, 1992, Tangen, 2004, Pariada and Cattopadhyay, 2007), in view of the sustainable development this number decreases drastically (Singh et al., 2007, Labuschagne et al., 2005). 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 imply 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 (Erol et al, 2011).

In this study, a multi-criteria decision making method to select the best performance in a sustainable supply chain within the alternatives is given. For this reason, DEMATEL method is used to highlight the relations between the performance criteria with graph theory and matrix approach which are used to visualize the relations and calculate the index value for the numerical function.

2. Sustainable performance indicators

In this study, sustainability criteria which are usually seen as economic, social and environmental aspects are evaluated under the performance measurement view with the addition of the business dimension. Resource usage criterion which is evaluated under the environment dimension is taken as a discrete sustainability criterion for the performance evaluation of the firms.

Criteria used for the evaluation of sustainability of the firms in a supply chain are given:

Sustainable economic performance criteria: Innovations created through supplier partnerships, Total sales, The number of shareholders, Promoting new investments, Establishing new employment opportunities, Total tax paid, Competitiveness of the forward and reverse supply chain sub-criteria are used to evaluate the sustainable economic performance.

Sustainable social performance criteria: training time, applied innovative ideas generated by employees /employee, personnel turnover, recordable incidents with respect to harassment and violence/employee, recordable accidents/employee, recordable employee complaints/employee, customer complaints, Fraction of total sales invested for social projects / year, Effectiveness of discipline management, Effectiveness of compensation management, Effectiveness of Personnel Recruitment and Selection, Organization's openness to stakeholder involvement in decision making, Institutional efficiency, Effectiveness of performance management system sub-criteria are used to evaluate the sustainable social performance.

Sustainable environmental performance criteria: Waste minimization, Number of ISO standards developed, Fraction of facilities using renewable energy, Effectiveness of reverse logistics system, Effectiveness of supplier training in environmental issues, Fraction of suppliers certified in ISO 14001, Fraction of facilities using HFC powered units, Use of recycled materials, Effectiveness of the 3PL company, with which the company works, sub-criteria are used to evaluate the sustainable environmental performance.

Sustainable resource performance criteria: Total size of the stores, The number of stores, The number of people employed, Energy consumption, Water consumption, sub-criteria are used to evaluate the sustainable resource performance.

3. Methods

The following procedural diagram depicts the overview of the DEMATEL combined with Graph theory and matrix approach adopted in the present research. As shown in Figure 1, the various inputs have been collected from various sources for instance feedback from supply chain experts, supply chain mangers.

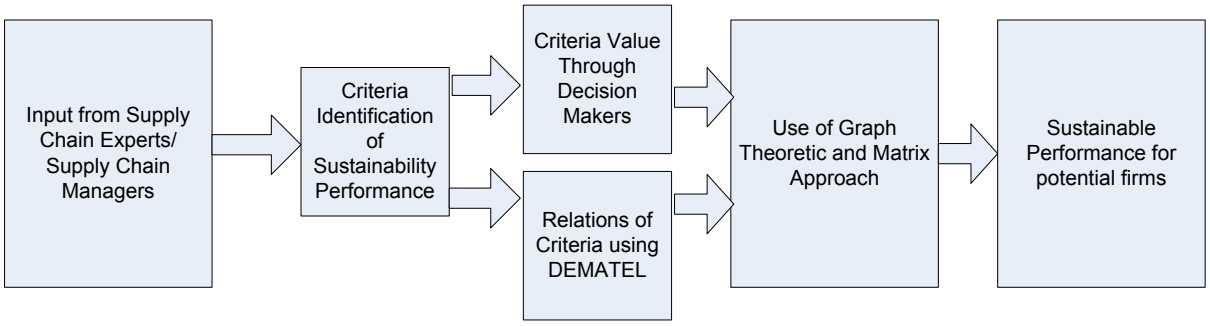


Figure 1 Procedural steps adopted for firm's selection

3.1. Dematel

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique is a comprehensive method for building and analyzing a structural model involving causal relationships between complex factors (Wu and Lee, 2007). DEMATEL has been built on the basis of graph theory, enabling analyzes and solves problems by visualization method. This structural modeling approach adopts the form of a directed graph, a causal effect diagram, to present the interdependence relationships and the values of influential effect between factors. Through analysis of visual relationship of levels among system factors, all elements are divided into a causal group and an effected group. And this can provide researchers with a better understanding of the structural relationship between system elements, and help find ways to solve complicated system problems (Herrera et al., 2000; Wang and Chuu, 2004). The relationships between cause and effect factors are converted into the DEMATEL. Suppose that a system composes a set of elements $C = (C_1, C_{2,} C_3, \dots C_n)$ and particular pair-wise relations are decided for modeling with respect to a mathematical relation. The major following steps are:

1. Generating the direct relation matrix. Measuring the relationship between criteria requires that the comparison scale be designed into four levels: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), and 4 (very high influence). An initial direct relation matrix A is a nxn matrix obtained by pair-wise comparisons, in which T_{ij} is denoted as the degree to which the criterion i affects the criterion j, i.e.,

$$T = [t_{ij}]_{nxn} \quad T = \begin{bmatrix} 0 & 3 & 1{,}7 & 1 \\ 3{,}2 & 0 & 2{,}5 & 2 \\ 1{,}7 & 2{,}2 & 0 & 1{,}8 \\ 1 & 1{,}5 & 1{,}8 & 0 \end{bmatrix}$$

2. Normalizing the direct relation matrix. On the base of the direct relation matrix A, the normalized direct relation matrix I can be obtained through the equation.

$$S = kxA$$

$$k = \frac{1}{max 1 \le i \le n \sum_{j=1}^{n} a_{ij}} \quad S = \begin{bmatrix} 0{,}00 & 0{,}39 & 0{,}22 & 0{,}13 \\ 0{,}42 & 0{,}00 & 0{,}32 & 0{,}74 \\ 0{,}22 & 0{,}29 & 0{,}00 & 0{,}23 \\ 0{,}13 & 0{,}19 & 0{,}23 & 0{,}00 \end{bmatrix}$$

3. Attaining the total relation matrix. Once the normalized direct relation matrix S is obtained, the total relation matrix I is denoted as the identity matrix.

$$T = S(I - S) - 1$$

4. Producing a causal diagram. The sum of rows and the sum of columns are separately denoted as vectors D and R within the total relation matrix M. A cause and effect graph can be acquired by mapping the dataset of (D+R, D-R). The horizontal axis vector (D+R) named "Prominence" is made by adding D to R, which reveals how much importance the criterion has. Similarly, the vertical axis (D-R) named "Relation" is made by subtracting D from R, which may group criteria into a cause group. Or, if the (D-R) is negative, the criterion is grouped in the effect group.

$$T = \left[t_{ij}\right]_{nxn} \qquad i, j = 1,2, \dots, n$$

$$D = \left[\sum_{i=1}^{n} t_{ij}\right]_{ixn} = \left[t_j\right]_{nx1}$$

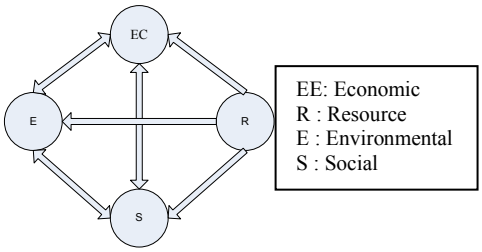
$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{ixn} = \left[t_j\right]_{nx1}$$

D+R	D-R
12,10056	0,513467
15,82013	3,013241
11,90484	-0,11232
12,59498	-3,41438

5. Obtaining the inner dependence matrix. In this step, the sum of each column in total relation matrix is equal to 1 by the normalization method, and then the inner dependence matrix can be acquired.

3.2. Graph Theory and Matrix Approach

Graph theory is a logical and systematical approach. The advanced theory of graphs and its applications are very well documented. Graph/digraph model representations have proved to be useful for modeling and analyzing various kinds of systems and problems in numerous fields of science and technology (Chen, 1997, Jense and Gutin, 2000, Rao, 2006). The matrix approach is useful in analyzing the graph/graph models expeditiously to derive the system function and index to meet the objectives.
The main steps of the methodology are as follows:
• Step-I
Identify the firm selection attributes for the given product or part and short-list the firms on the basis of the identified attributes satisfying the requirements. A quantitative or qualitative value or its range may be assigned to each identified attribute as a limiting value or threshold value for its acceptance for the considered application. A firm with each of its attribute, meeting the criterion, may be short-listed.
• Step-II
1. After short-listing the firms, find out the relative importance (*rij*) relations between the attributes and normalize the values of attributes (*Ai*) for different alternatives.
2. Develop the firm selection attributes digraph considering the identified selection attributes and their relative importance. The number of nodes must be equal to the number of considered attributes in Step 1 above. The magnitude of the edges and their directions will be determined from the relative importance between the attributes.



3. Develop the firm selection attributes matrix for the firm selection attributes diagraph. This will be an $N \times N$ matrix with diagonal elements of Ai and off-diagonal elements of rij.

$$Per(S) = A1A2A3A4 + \{(r12r21A3A4 + r13r31A2A4 + r14r41A2A3 + r23r32A1A4 + r24r42A1A3 + r34r43A1A2)\} + \{(r12r23r31A4 + r13r32r21A4 + r12r24r41A3 + r14r42r21A3 + r13r34r41A2 + r14r43r31A2 + r23r34r42A1 + r24r43r32A1)\} + \{(r12r21r34r43 + r13r31r24r42 + r14r41r23r32 + r12r23r34r41 + r14r43r32r21 + r13r34r42r21 + r12r24r43r31 + r14r42r23r31 + r13r32r24r41)\}$$

4. Obtain the firm selection attributes function for the firm selection attributes matrix.

Firms	1. Group	2.Group	3.Group	4.Group	5.Group	6.Group	Total
A	0	0	668	447	1051	369	2535
B	0	0	172	211	772	369	1524
C	0	0	0	0	972	369	1341

5. Substitute the values of rij and normalized values of Ai, obtained in step 1, in firm selection attributes function to evaluate the firm selection index for the considered firms.
6. Arrange the firm in descending order of firm performance selection index. The firm having the highest value of firm performance selection index is the best choice. Firm A>Firm B> Firm C

5. Conclusion

DEMATEL method does not require this assumption but further helps the decision makers in identifying the casual relationships among criteria. That is, by applying DEMATEL method, the importance of four criteria can be determined and the causal relations among the criteria can be constructed. This relation graph is used in the multi-criteria decision making process.
The proposed combine methodology will be used for the firm selection problem according to their performance in the supply chain. To evaluate firms, decision maker's expert opinions, firm alternatives and selection criteria are needed. Relational graph between criteria, matrix presentation and firm performance selection index are the components of the evaluation process. In this process, selection graph models the importance weight, matrix approach is the functional presentation of the graph model and numerical value of the selection criterion function is the firm performance selection index.
By combining DEMATEL, graph theory and matrix approach, the firm with the best performance according to the sustainable performance criterion in the supply chain will be selected. Any changes in the related environment, economics, and social or resource criteria will affect the selection process. It's also possible to expand this study through the years.

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