Expert Systems with Applications 38 (2011) 1850–1858

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Fuzzy DEMATEL method for developing supplier selection criteria

Betty Chang [a], Chih-Wei Chang [b], Chih-Hung Wu [c,*]

[a] Graduate Institute of Architecture and Sustainable Planning, National Ilan University, Ilan, Taiwan
[b] Graduate Institute of Management, National Ilan University, Ilan, Taiwan
[c] Department of Digital Content and Technology, National Taichung University, Taichung, Taiwan

ARTICLE INFO

Keywords:
Supply chain management (SCM)
Supplier selection
Fuzzy theory
DEMATEL

ABSTRACT

Supply chain management (SCM) practices have flourished since the 1990s. Enterprises realize that a large amount of direct and indirect profits can be obtained from effective and efficient SCM practices. Supplier selection has great impact on integration of the supply chain relationship. Effective and accurate supplier selection decisions are significant components for productions and logistics management in many firms to enhance their organizational performance. This study pioneers in using the fuzzy decision-making trial and evaluation laboratory (DEMATEL) method to find influential factors in selecting SCM suppliers. The DEMATEL method evaluates supplier performance to find key factor criteria to improve performance and provides a novel approach of decision-making information in SCM supplier selection. This research designs a fuzzy DEMATEL questionnaire sent to seventeen professional purchasing personnel in the electronic industry. Our research results find that stable delivery of goods is the most influence and the strongest connection to other criteria.

1. Introduction

A well-designed supply chain management (SCM) system is important for improving competitive advantage in an era of international economics and rapidly developing information technology (Li & Wang, 2007). The gap between product quality and performance is closing with intensifying competition in the global market. Scholars and industries consider how to manage enterprise operation more efficiently in this competitive arena (Sarmah, Acharya, & Goyal, 2006). Effective supplier decisions are significant components for productions and logistics management in many firms, and a correct forecast is crucial for the electronic related industry (Hsu, 2003). In other words, accurate supplier forecasts help enterprises find proper supply chain partners and consequently enhance organizational performance.

The success or failure of supply chain management depends upon a suitable SCM system and appropriate suppliers. Many firms apply collaborative commerce by establishing strategic partnerships with suppliers, and involve them in the early stages of product research and development (Araz & Ozkarahan, 2007). Experts agree that supplier selection is one of the most important functions of a purchasing department, helping businesses save material cost and increase competitive advantage (Saen, 2007).

Supplier selection also acts as the pivotal role in an enterprise's transport business development, with future competitive ability in an industrial environment (Jayaraman, Srivastava, & Benton, 1999). Only those suppliers who meet the firms' needs can provide material and parts with comparative low cost and high quality. In an effective supply chain, enterprises must first find outstanding suppliers, and then establish long-term partnerships with these suppliers to increase enterprises' competitive abilities (Shin, Collier, & Wilson, 2000). Today's business environment emphasizes supplier relationship development for sustainable enterprise management (Krause & Ellram, 1997). Considerable research supports supply chain performance as highly influential in enterprise competitiveness (Quayle, 2003; Sako, 2004). This finding has lead to considerable academic and real world interest, regarding supplier development strategies.

Many methods have been used in predicting industrial performance, including the Grey theory (Lin & Yang, 2003), and the two-stage fuzzy piecewise regression analysis method (Huang & Tzeng, 2008). Ni, Xu, and Deng (2007) applied a method with extended Quality Function Deployment (QFD) and data mining to investigate supplier selection (Ni et al., 2007). Li and Wang use a grey-based decision-making method to deal with fuzziness in supplier selection (Li & Wang, 2007). Pi and Low propose a supplier selection method that use Taguchi loss functions and the Analytic Hierarchy Process (AHP) to obtain weights of major criteria (Pi & Low, 2006). However, the method needs more data, such as customer data, maintenance records, and information from different marketing areas. Gencer and Gurpinar adopted the Analytic

---

* Corresponding author. Address: 140, Min-Shen Road, Tai Chung 40306, Taiwan, ROC. Tel.: +886 4 22183024; fax: +886 4 22183270.

E-mail addresses: ptchang@mail.niu.edu.tw (B. Chang), ckuo@mail.niu.edu.tw (C.-W. Chang), chwu@ntcu.edu.tw (C.-H. Wu).

0957-4174/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2010.07.114

Network Process (ANP) to investigate supplier selection implementation in an electronic firm. Compared with AHP, ANP includes interaction among criteria (Gencer & Gurpinar, 2007).

However, few methods and studies have capable of demonstrating the relationship between factors that might affect SCM performance. Therefore, this study pioneer in using the fuzzy decision-making trial and evaluation laboratory (DEMATEL) method to select which supplier suit enterprises. The advantage of the DEMATEL method is the capability of revealing the relationship between these factors which influence other factors in supplier selection. This study obtains direct and indirect influence among criteria using the DEMATEL technique, and computes the causal relationship and strength among supplier selection factors. The DEMATEL technique does not need large amounts of data.

This paper is organized as follows: In Section 2, we present a literature review of SCM and Supplier selection. Section 3 describes the methodologies of fuzzy DEMATEL. Section 4 outlines an empirical study to show the process of fuzzy DEMATEL method to determine selection criteria of SCM supplier. Section 5 carries our conclusions and suggestions.

2. Concepts of supply chain management and supplier selection

The economic environment from the late 1980s to early 1990s forced enterprises to face international market competition with greater competitive capability. Enterprises today must have better production technology internally and externally, such as supplier capability and customer requirement for competitive ability. Enterprises must change their attitudes toward the supplier from enemy to partner and view them as a resource in order to increase the supply chain to rapid response in a dog-eat-dog environment (Cousins & Menguc, 2006). Supply chain management is an essential enterprise activity under international market competition. A successful supply chain management must focus on several aspects, such as supplier selection and relationship management, information technology application, internaland external supply chain. The following section explores important literatures according to the points above, for systematic research.

2.1. Supply chain management (SCM)

SCM can apply an integrally systematic model to control information flow, material and service of enterprises to satisfy customer requirements. Managers have traditionally focused on managing internal operations to promote profits. SCM emphasizes integrating internal activities and decisions with external enterprise partners to promote competitive capability (Li & Wang, 2007). Supply chain management has attracted increasing attention from academics the past 20 years. Academic publications, seminars, professional development plans and school courses manifest the importance of SCM. Research adjusts constantly to create various technologies to assist implementing supply chain management for enterprise performance. Private enterprises and listed companies recognize that good SCM promotes success (Cousins, Lawson, & Squire, 2006).

SCM integrates with comprehensive managerial functions such as purchase, operational management, information technology and marketing (Tessarolo, 2007). External integration development of supply chain promotes large-scale product schedule performance. This performance increases when internal integration and internal group members combine with external customers and suppliers to enhance mutual product recognition (Lee & Rhee, 2007). Improper management of the supply chain relationship results in direct or indirect bad effects. For example, manufacturers in the wholesale or retail market face different marginal costs and uncertain situations, maximizing profit through a strategic decision rather than optimum profit. Hence, the retail dealer will price products higher, order smaller quantities or serve fewer customers (Choi & Krause, 2006).

Supplier selection greatly impacts the supply chain relationship. Improper management of the supply chain relationship affects SCM effect directly. Hence, this study uses a quantitative method to solve the problem and promote SCM performance through good supplier selection.

2.2. Supplier selection

Supplier differentiation refers to differences derived from supplier characteristics such as organizational culture, manufacturing procedure, technology capability and geographic location distribution (Chang, Wang, & Wang, 2007). Adopting the proper supplier group to promote competitive capability and supplier performance is the greatest task. Supply performance refers to valid and continuous action encompassing the past, present and future.

An effective and efficient supply performance evaluation method becomes increasingly important in supply chain subjects (Dickson, 1996). This research sorts through previous literatures to grasp which evaluation criteria draws the greatest attention in previous literatures (Chang et al., 2007; Kreng & Wang, 2005; Noorul & Kannan, 2006; Prahinski & Benton, 2004; Wang & Hu, 2005; Weber & Current, 1993; Weber, Current, & Benton, 1991; Zadeh, 1965). The criteria used in relevant literatures are listed in Table 1.

3. The fuzzy DEMATEL method

The DEMATEL method was first conducted by The Battelle Memorial Institute through its Geneva Research Centre in 1973 {Gabus, 1973, #17}. DEMATEL is an extended method for building and analyzing a structural model for analyzing the influence

Table 1
Criteria of supplier selection.

	Dickson	Weber	Current	Prahins-ki & Benton	Kreng & Wang	Wang	Noorul & Kannan	Chang et al.
Quality	X	X	X	X	X	X	X	X
Service		X		X		X		X
Flexible		X						
Price	X		X	X	X	X	X	X
Delivery	X	X	X	X	X	X	X	
Lead-time					X			
Reaction to demand change				X		X		X
Production capability							X	
Technical capability			X				X	
Reliability of delivery					X			

relation among complex criteria. However, making decisions is very difficulty in fuzzy environment to segment complex factors {Wu, 2007, #48}. The current study uses the fuzzy DEMATEL method to obtain a more accurate analysis.

3.1. DEMATEL method

The original DEMATEL method searched for integrated solutions to fragmented and antagonistic societies around the world. The DEMATEL method has recently become very popular in Japan, because of its ability to pragmatically visualize complicated causal relationships.

Specifically, the DEMATEL method is based on digraphs, which separate involved factors into cause group and effect group. Directed graphs, known as digraphs, are more useful than directionless graphs because digraphs demonstrate the directed relationships of sub-systems. The digraph may portray a basic concept of contextual relation among elements of a system, in which the values represent the strength of influence. Hence, The DEMATEL can convert the relationship between cause and effect factors into an intelligible structural model of the system. The DEMATEL can propose the most important criteria which affects other criteria.

The DEMATEL can reduce the number of criteria for evaluating factor effectiveness, concurrently; companies can improve effectiveness of specific factors based on the impact digraph map {Tzeng, 2007, #43}. Therefore, The DEMATEL evaluates supplier performance to find key factor criteria to improve performance and provide decision-making information in SCM supplier selection.

The DEMATEL method converts the relationship between cause and effect factors into an intelligent structural model of the system as stated in previous sections. Suppose a system contains a set of elements $K = \{k_1, k_2, \ldots, k_n\}$, and particular pair-wise relations are determined for modeling with respect to a mathematical relation E. Next, the method portrays the relation E as a direct-relation matrix that is indexed equally on both dimensions by elements from the set T. Then, besides the case where number 0 appears in the cell (i, j), if the entry is a positive integral that has the meaning of (1), the ordered pair (k_i, k_j) is in relation to E, and (2) there exists a relation in element k_i that effects element k_j. This investigation uses the DEMATEL method for analyzing the data in this study, and refines the essential DEMATEL steps below. First, the pair-wise comparison scale may be designated into four levels, where scores of 1, 2, 3, and 4 represent "very low influence", "low influence", "high influence", and "very high influence" respectively. An initial direct-relation matrix $\mathbf{T}$ is a $n \times n$ matrix obtained by pair-wise comparisons in terms of influences and directions between criteria, in which T_{ij} is denoted as the degree to which the criterion i affects the criterion j, i.e., $\mathbf{T} = [T_{ij}]_{n\times n}$. Then a normalized direct-relation matrix $\mathbf{S}$, i.e., $\mathbf{S} = [S_{ij}]_{n\times n}$ and $0 \leqq S_{ij} \leqq 1$ can be obtained through the formulas (1) and (2), in which all principal diagonal elements are equal to zero

$$K = \frac{1}{\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n} a_{ij}} \tag{1}$$

$$S = K \times T \tag{2}$$

A total-relation matrix $\mathbf{M}$ can be acquired by using the formula (3), in which the $\mathbf{I}$ is denoted as the identity matrix

$$\mathbf{M} = \mathbf{X}(\mathbf{I} - \mathbf{X})^{-1} \tag{3}$$

The sum of rows and the sum of columns are separately denoted as $\mathbf{D}$ and $\mathbf{R}$ within the total-relation matrix $\mathbf{M}$ through the formulas (4)–(6):

$$\mathbf{M} = m_{ij}, \quad i, j = 1, 2, \ldots, n \tag{4}$$

$$\mathbf{D} = \left[\sum_{j=1}^{n} m_{ij}\right]_{nx1} \tag{5}$$

$$\mathbf{R} = \left[\sum_{i=1}^{n} m_{ij}\right]_{1xn} \tag{6}$$

where $\mathbf{D}$ and $\mathbf{R}$ denote the sum of rows and the sum of columns, respectively. Finally, a causal and effect graph can be acquired by mapping the dataset of $(\mathbf{D}+\mathbf{R}, \mathbf{D}-\mathbf{R})$, where the horizontal axis $(\mathbf{D}+\mathbf{R})$ is made by adding $\mathbf{D}$ to $\mathbf{R}$, and the vertical axis $(\mathbf{D}-\mathbf{R})$ is made by subtracting $\mathbf{R}$ from $\mathbf{D}$.

3.2. Fuzzy theory

Fuzzy theory introduces the concept of membership function in order to deal with different linguistic variables (Zadeh, 1965, #49). A certain degree of fuzziness exists in terms of people's thoughts, inference and perception. The theory aims to solve uncertain or fuzzy data in the environment. Unlike traditional Boolean logic which defines whether or not an element belongs to a crisp set (1 or 0), a fuzzy set defines a degree of belonging by a membership function. According to the crisp set theory, an abrupt boundary is supposed to exist between geographic classes. A geographical entity fully belongs to one class, and is totally excluded from other classes. Inclusion or exclusion of an entity within classes is usually based on some chosen criteria. Two problems exist when trying to deal with spatial data. One is the difficulty to define an appropriate criterion {Burrough, 1996, #5}. For example, a groundwater system can be a criterion for identifying an aquifer; sandstone can belong to the aquifer class. However, several factors affect this criterion, such as grain size, grain size fraction, texture, and sandstone structure {Csillag, 2000, #11}. The other problem is the uncertainty of boundaries, as mentioned in the above section. The fuzzy set theory is a way of expressing uncertain or imprecise spatial data. We define X as a universe of discourse having its generic elements Y, or $Y = \{y\}$. A fuzzy set H in Y is characterized by a membership function, $u_H(y)$, which maps Y to the membership space $[0, 1]$.

Fuzzy set theory deals with sources of uncertainty or imprecision that are vague and non-statistical in nature {Zeng, 2001, #50}. For example, a traditional set might comprise the set of all tall people in the classroom. This would result in a binary where all people over 180 cm are classified as tall, and persons under 180 cm are not. The fuzzy set theory would instead assign degrees of membership in the tall set. A person who is 173 cm might be assigned a 0.96 degree of membership. The fuzzy set theory in this example allows more meaningful membership in a set {McNeil, 1993, #30}. The fuzzy set theory has the advantage of being closely linked to classical logic, but in many instances, it is difficult to determine how to assign membership {Duckham, 2001, #15}.

Since the beginning of the 1970s, the fuzzy set theory has been introduced and applied to classifying geographic entities due to ambiguous class definition {Cheng, 2002, #7}. Applications include regionalization {Leung, 1987, #25}, soil classification and definition of boundaries between soil classes {Banai, 1993, #3; Davidson, 1996, #12}, and boundaries in geographic space {Wang, 1996, #44}. Recently, the fuzzy set theory has been used to model uncertain geometric aspects of mapping units {Brown, 1998, #4}, and topology {Dijkmeijer, 1996, #14}. When 'object' became a buzz word in the world of computer science, the concept of fuzzy objects also appeared in GIS literature to represent objects with indeterminate boundaries {Cheng, 2002, #7}.

3.3. Triangular fuzzy numbers

Zadeh proposed the fuzzy set theory and introduced the concept of membership function (Zadeh, 1965, #49). The fuzzy

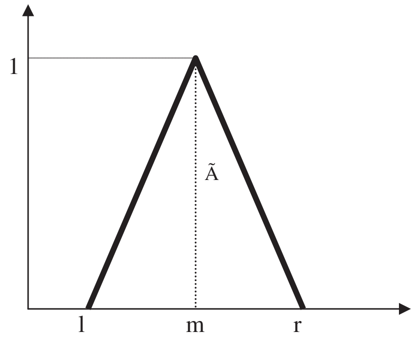

Fig. 1. A triangle fuzzy numbers $\tilde{A}$.

set theory deals with linguistic variable problems in the real world. A triangular fuzzy number $\tilde{A}$ is shown as a triplet (l, m, r) and a membership function $\mu_{\widehat{A}}$ is defined as Fig. 1.

The membership function is defined as

$$\mu_{\tilde{A}}(y) = \begin{cases} 0, & y < a \\ y - a/b - a, & a \leqslant y \leqslant b \\ c - y/c - b, & b \leqslant y \leqslant c \\ 0, & y > c \end{cases}$$

In assessing different projects, the satisfaction with different properties in the project is usually placed on a certain scale. If we signify it with a clear and precise number, it is less likely to reflect the reality. Therefore, in fuzzy multi-principle assessment, fuzzy numbers are used to show the degree of satisfaction {Arens, 2005, #2}. Fuzzy numbers refer to the fuzzy set on real line R and their membership function is $\mu_x(y) : R \to [0, 1]$, which has the following characteristics:

$\mu_x(Y)$ is piecewise continuous;
$\mu_x(Y)$ is convex fuzzy subset.

This study applies the triangular fuzzy number to obtain ideal solutions from group decision-making. Fuzzy linguistic variables are parts of human languages. Therefore, fuzzy numbers are used when dealing with human response. Fuzzy aggregation processes must include a defuzzification step. The defuzzification procedure considers the spread, height and shape of a triangular fuzzy number as important characteristics of the fuzzy number. The relative location on the x-axis is also an attribute of a fuzzy number {Opricovic, 2004, #34}. The centroid (Center-of-gravity, COA) method is widely used in defuzzification. However, it cannot distinguish between two fuzzy numbers with the same crisp value, if these two fuzzy numbers have different shapes. The CFCS (Converting Fuzzy data into Crisp Scores) defuzzification method {Opricovic, 2003, #33} is suitable for the fuzzy aggregation process. The CFCS method obtains a better crisp value {Opricovic, 2003, #33; Wu, 2007, #48}.

The CFCS method is based on determining the fuzzy maximum and minimum of the fuzzy number range. According to membership functions, the total score can be found out as a weighted average {Opricovic, 2003, #33}. Let $A_{ij} = (l_{ij}^n, m_{ij}^n, r_{ij}^n)$, mean the degree of criterion i that affects criterion j and fuzzy questionnaires n $(n = 1, 2, 3, \ldots, h)$. The CFCS method involves a five-step algorithm as follows:

Step 1. Normalization:

$$xr_{ij}^n = (r_{ij}^n - \min l_{ij}^n)/\Delta_{\min}^{\max} \tag{7}$$

$$xm_{ij}^n = (m_{ij}^n - \min l_{ij}^n)/\Delta_{\min}^{\max} \tag{8}$$

$$xl_{ij}^n = (l_{ij}^n - \min l_{ij}^n)/\Delta_{\min}^{\max} \tag{9}$$

where $\Delta_{\min}^{\max} = \max r_{ij}^n - \min l_{ij}^n$.

Step 2. Compute right (rs) and left (ls) normalized values:

$$xrs_{ij}^n = xr_{ij}^n/(1 + xr_{ij}^n - xm_{ij}^n) \tag{10}$$

$$xls_{ij}^n = xm_{ij}^n/(1 + xm_{ij}^n - xl_{ij}^n) \tag{11}$$

Step 3. Compute total normalized crisp values:

$$x_{ij}^n = [xls_{ij}^n(1 - xls_{ij}^n) + xrs_{ij}^n \times xrs_{ij}^n]/[1 - xls_{ij}^n + xrs_{ij}^n] \tag{12}$$

Step 4. Compute crisp values:

$$Z_{ij}^n = \min l_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max} \tag{13}$$

Step 5. Integrate crisp values:

$$Z_{ij} = 1/h(Z_{ij}^1 + Z_{ij}^2 + \cdots + Z_{ij}^h) \tag{14}$$

4. Data analysis

Data analysis is divided into five sub-sections: (1) fuzzy DEMATEL questionnaire design, (2) the calculation process of Fuzzy DEMATEL method, (3) analyzing the evaluation criteria of significance, (4) analyzing the degree of central role and relation, and (5) the strategy map and the causal diagram.

4.1. Fuzzy DEMATEL questionnaire design

This study uses 10 evaluation criteria and symbols as follows: (1) product quality, (2) product price, (3) technology ability, (4) service, (5) delivery performance, (6) stable delivery of goods, (7) lead-time, (8) reaction to demand change in time, (9) production capability and (10) financial situation. The fuzzy DEMATEL method is also used to evaluate the influence of each criterion in supplier selection. This research first designed a questionnaire for fuzzy DEMATEL composed of three parts. The first part outlines each criteria definition for easy understanding and response. Then, respondents were asked to compare the importance of each criterion using scores 1, 2, 3 and 4 to represent the degree of significance. Scores of 1, 2, 3, and 4 represent “no importance”, “low importance”, “high importance”, and “very high importance”, respectively.

The second part is a pair-wise comparison to evaluate the influence of each score, where scores of 0, 1, 2, 3 and 4 represent “no influence”, “low influence”, ”normal influence”, “high influence”, and “very high influence”, respectively. The finally part is personal data.

4.2. The calculation process of fuzzy DEMATEL method

This study uses an expert interview method. The objects were professional experts working in purchasing departments of electronic industries in Taiwan. The evaluation criteria symbols in this study are as follows: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9) and financial situation (A10). Data collected from the experts was analyzed with the fuzzy DEMATEL method. The major nine steps were conducted as the following.

Step 1. Set up Direct-Relation Matrix **T**

The first step of the fuzzy DEMATEL analysis sets up a direct-relation matrix **T** from the data collected as Table 2.

Step 2. Design the fuzzy linguistic variables

The study addresses response to the human logic variable, according to the linguistic variable (Li, 1999): no influence, very

Table 2
Direct-relation matrix **T**.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
A_1	0	3	4	3	1	1	1	1	1	0
A_2	3	0	1	1	1	0	1	1	1	1
A_3	4	3	0	3	1	1	1	3	1	1
A_4	1	1	1	0	3	4	3	3	1	1
A_5	0	0	0	3	0	4	1	3	1	1
A_6	3	1	3	3	3	0	3	3	3	3
A_7	1	1	1	1	3	3	0	3	1	1
A_8	1	1	3	3	3	3	0	0	3	1
A_9	3	1	1	1	3	3	1	3	0	3
A_{10}	1	1	1	1	1	1	1	1	3	0

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

Table 3
The fuzzy linguistic scale.

Linguistic terms	Influence score	Triangular fuzzy numbers
No influence (No)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.50)
Low influence (L)	2	(0.25, 0.50, 0.75)
High influence (H)	3	(0.50, 0.75, 1.00)
Very high influence (VH)	4	(0.75, 1.00, 1.00)

low influence, low influence, high influence and very high influence, and shows positive triangular fuzzy numbers $(l_{ij}^n, m_{ij}^n, r_{ij}^n)$ as Table 3. The study transforms direct-relation matrix **T** into triangular fuzzy numbers as Table 4.

Step 3. Transform triangular fuzzy numbers into the initial direct-relation matrix **F**.

The study computes triangular fuzzy numbers by the CFCS method. The questionnaires are defuzzified as a crisp value which obtains the Z_{ij}.

The logistic formula computes the initial direct-relation matrix F according to formulas (7)–(14), thereby obtaining the initial direct-relation matrix **F** as Table 5.

Step 4. Obtain average value.

The study obtains the average value of initial direct-relation matrixes **F** from the total amount of all initial direct-relation matrixes **F** divided by 17 (the number of respondents).

Step 5. Set up the generalized direct-relation matrix **S**.

The study obtains a generalized direct-relation matrix **S** through the formula (1) in which all principal diagonal elements are between 1 to zero. The generalized direct-relation matrix is shown as Table 6.

Step 6. Set up the total-relation matrix **M**.

The total-relation matrix **M** is acquired using Eq. (3) from the generalized direct-relation matrix. The total-relation matrix is shown as Table 7.

Step 7. Obtain the sum of rows and columns.

The sum of rows and the sum of columns are separately denoted as **D** and **R** within the total-relation matrix **M** as below: Sum of rows = 2.000 1.477 2.074 1.980 1.930 2.892 1.923 2.285 1.975 1.240.

Sum of columns = 2.444 1.754 2.704 2.078 2.067 2.224 1.735 1.947 1.868 1.785.

Table 4
The triangular fuzzy numbers.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
A_1	0	(0.5, 0.75, 1.0)	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0, 0.25)
A_2	(0.5, 0.75, 1.0)	0	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
A_3	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	0	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
A_4	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0	(0.5, 0.75, 1.0)	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
A_5	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	0	(0.75, 1.0, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
A_6	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)
A_7	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
A_8	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0	0	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)
A_9	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0	(0.5, 0.75, 1.0)
A_{10}	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

Table 5
The initial direct-relation matrix **F**.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
A_1	0	0.637	0.747	0.404	0.486	0.555	0.445	0.239	0.431	0.349
A_2	0.829	0	0.418	0.267	0.239	0.143	0.226	0.184	0.473	0.431
A_3	0.802	0.624	0	0.527	0.376	0.5	0.267	0.527	0.418	0.431
A_4	0.404	0.473	0.582	0	0.5	0.445	0.486	0.678	0.349	0.28
A_5	0.367	0.253	0.253	0.637	0	0.816	0.39	0.486	0.418	0.363
A_6	0.871	0.692	0.775	0.747	0.72	0	0.692	0.761	0.527	0.624
A_7	0.322	0.171	0.322	0.404	0.678	0.72	0	0.525	0.445	0.404
A_8	0.5	0.198	0.596	0.733	0.651	0.678	0.582	0	0.486	0.418
A_9	0.486	0.335	0.431	0.431	0.555	0.596	0.363	0.486	0	0.514
A_{10}	0.253	0.28	0.28	0.28	0.225	0.349	0.198	0.253	0.459	0

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

Table 6
The generalized direct-relation matrix **S**.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
A_1	0	0.099	0.117	0.063	0.076	0.087	0.069	0.037	0.067	0.054
A_2	0.129	0	0.065	0.042	0.037	0.022	0.035	0.029	0.074	0.067
A_3	0.125	0.097	0	0.082	0.059	0.078	0.042	0.082	0.065	0.067
A_4	0.063	0.074	0.091	0	0.078	0.069	0.076	0.106	0.054	0.044
A_5	0.057	0.039	0.039	0.099	0	0.127	0.061	0.076	0.065	0.057
A_6	0.136	0.108	0.121	0.117	0.112	0	0.108	0.119	0.082	0.097
A_7	0.05	0.027	0.05	0.063	0.106	0.112	0	0.082	0.069	0.063
A_8	0.078	0.03	0.093	0.114	0.102	0.106	0.091	0	0.076	0.065
A_9	0.076	0.052	0.067	0.067	0.087	0.093	0.056	0.076	0	0.08
A_{10}	0.039	0.044	0.044	0.044	0.035	0.054	0.031	0.039	0.072	0

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

Table 7
Total-relation matrix **M**.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
A_1	0.16	0.216	0.25	0.203	0.213	0.232	0.184	0.172	0.193	0.176
A_2	0.232	0.093	0.169	0.143	0.14	0.136	0.121	0.124	0.164	0.154
A_3	0.277	0.219	0.153	0.225	0.203	0.23	0.166	0.214	0.196	0.191
A_4	0.215	0.189	0.227	0.145	0.216	0.219	0.191	0.232	0.18	0.165
A_5	0.205	0.158	0.181	0.234	0.142	0.266	0.178	0.206	0.187	0.174
A_6	0.347	0.275	0.318	0.314	0.309	0.224	0.272	0.302	0.263	0.267
A_7	0.197	0.144	0.187	0.203	0.238	0.255	0.119	0.21	0.19	0.18
A_8	0.25	0.172	0.251	0.272	0.26	0.276	0.224	0.159	0.218	0.203
A_9	0.224	0.171	0.206	0.207	0.222	0.239	0.174	0.205	0.128	0.197
A_1	0.136	0.118	0.132	0.131	0.123	0.147	0.105	0.122	0.148	0.078

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

Step 8. Set up degrees of central role and relation.

The first calculation obtains amount from MATLAB. Second, in this step, we calculate these direct/indirect matrix **M** values. The results are showed in Table 8.

Step 9. Set up the causal diagram.

The causal diagram was built by the horizontal axis (**D** + **R**) which the degree of central role. The vertical axis (**D** − **R**) which is the degree of relation.

4.3. Analyzing the evaluation criteria of significance

This study integrates seventeen questionnaires from expert interviews to find out the evaluation criteria of significant, and then calculates the average values as shown in Table 9.

Research results show the most important four criteria with importance value greater than or equal to 3.5, namely product quality (A1), service (A4), stable delivery of goods (A6) and reaction to demand change in time (A8). These criteria has higher importance value than product price (A2), technology ability (A3), delivery performance (A5), lead-time (A7), production capability (A9) and financial situation (A10). The ranking of importance value of criteria is product quality (A1), stable delivery of goods (A6), reaction to reaction to demand change in time (A8), service (A4), product price (A2), delivery performance (A5), technology ability (A3), production capability (A9), financial situation (A10) and lead-time (A7).

Table 9
Evaluation criteria of significance.

Evaluation criteria	Average value	Ranking
(A1) Product quality	3.884	1
(A6) Stable delivery of goods	3.764	2
(A8) Reaction to demand change in time	3.705	3
(A4) Service	3.588	4
(A2) Product price	3.470	5
(A5) Delivery performance	3.411	6
(A3) Technology ability	3.235	7
(A9) Production capability	3.000	8
(A10) Financial situation	2.941	9
(A7) Lead-time	2.882	10

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

4.4. Analyzing the degree of central role and relation

This work establishes a threshold value to sift important evaluation criteria from the total-relation matrix **M** from Table 7. The

Table 8
The degree of central role (**D** + **R**).

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
R	2	1.477	2.074	1.98	1.93	2.892	1.923	2.285	1.975	1.24
D	2.244	1.754	2.074	2.078	2.067	2.224	1.735	1.947	1.868	1.785
D + R	4.244	3.231	4.148	4.058	3.997	5.116	3.658	4.232	3.843	3.025
D − R	−0.244	−2.77	0	−0.098	−0.137	0.668	0.188	0.338	0.107	−0.545

Note: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9), financial situation (A10).

degree of central role $(D_x + R_x)$ in DEMATEL represents the strength of influences both dispatched and received. On the other hand, if $(\mathbf{D}_x - \mathbf{R}_x) > 0$, then the evaluation criterion x dispatches the influence to other evaluation criteria more than it receives. If $(\mathbf{D}_x - \mathbf{R}_x) > 0$, the evaluation criterion x receives the influence from other evaluation criteria more than it dispatched. The $(\mathbf{D}_x - \mathbf{R}_x)$ values are reported in Table 8.

4.5. The strategy map and the causal diagram

The strategy map is an organizational strategy showing the relation between the cause and effect model. The study finds evaluation criteria of causal relationships from the fuzzy DEMATEL method to set up a strategy map. Based on the results of the total-relation matrix in Table 7, the causal relationships among SCM supplier selection criterions can be depicted as the strategy map (Fig. 2) and the causal diagram (Fig. 3). In the strategy map, the thick arrow is drawn from criterion x to criterion y when $Z_{xy} \geqslant 0.3$, the thin arrow when $0.3 > Z_{xy} \geqslant 0.25$, and no arrow when $Z_{xy} < 0.25$, respectively. The criterion is circled with the thick line when the importance value of $V_i \geqslant 3$, with the thin line when $3 > V_i \geqslant 2.5$, and with a dotted line when $V_i < 2.5$. The values of $(D_x + R_x)$ and $(D_x - R_x)$ are shown under each criterion.

Each criterion is circled by a thick line if the importance value is greater than or equal to 3.5, and a thin line if the importance value is between 3.0 and 3.5, and a dotted line when importance value is less than 3.0. According to the opinions of experts, the strategy map of Fuzzy DEMATEL points that the important values of "product quality", "technology ability", "delivery performance", "stable delivery of goods", "product price", "service", and "reaction to demand change in time" are higher than 0.25 value. These seven evaluation criteria are more important than other evaluation criteria. In addition, evaluation criterion with several interactive arrows in the strategy map means that each evaluation criteria shows a frequent interactive relation with other evaluation criteria. The "stable delivery of goods" obtained nine interactive arrows as important values.

In the strategy map, the thin line represents criteria which includes product price (A2), technology ability (A3) and delivery performance (A5) with importance value between 3.0 and 3.5. Three criteria—lead-time (A7), production capability (A9) and financial situation (A10) with important value less than 3.0 (dotted line).

The study findings from the causal diagram (Fig. 3) are described as follows. First, "Stable delivery of goods (A6)", "lead-time (A7)", "reaction to demand change in time (A8)", and "production capability (A9)" are influence dispatching evaluation criteria. These criteria influence "product quality (A1)", "product price (A2)", "technology ability (A3)", "service (A4)", "delivery performance (A5)", and "financial situation (A10)". Although experts did not consider "production capability" as a very important evaluation criterion of significance, this criterion frequently interacted with other criteria. Furthermore, experts did not consider "product quality" as a very important and significant evaluation criteria, this criteria still interacted very little with other criteria. Focusing on evaluation criterion of "stable delivery of goods", it could indirectly influence evaluation criterion of "product quality", "product price", "technology ability", "service", "delivery performance", "lead-time", "reaction to demand change in time", "production

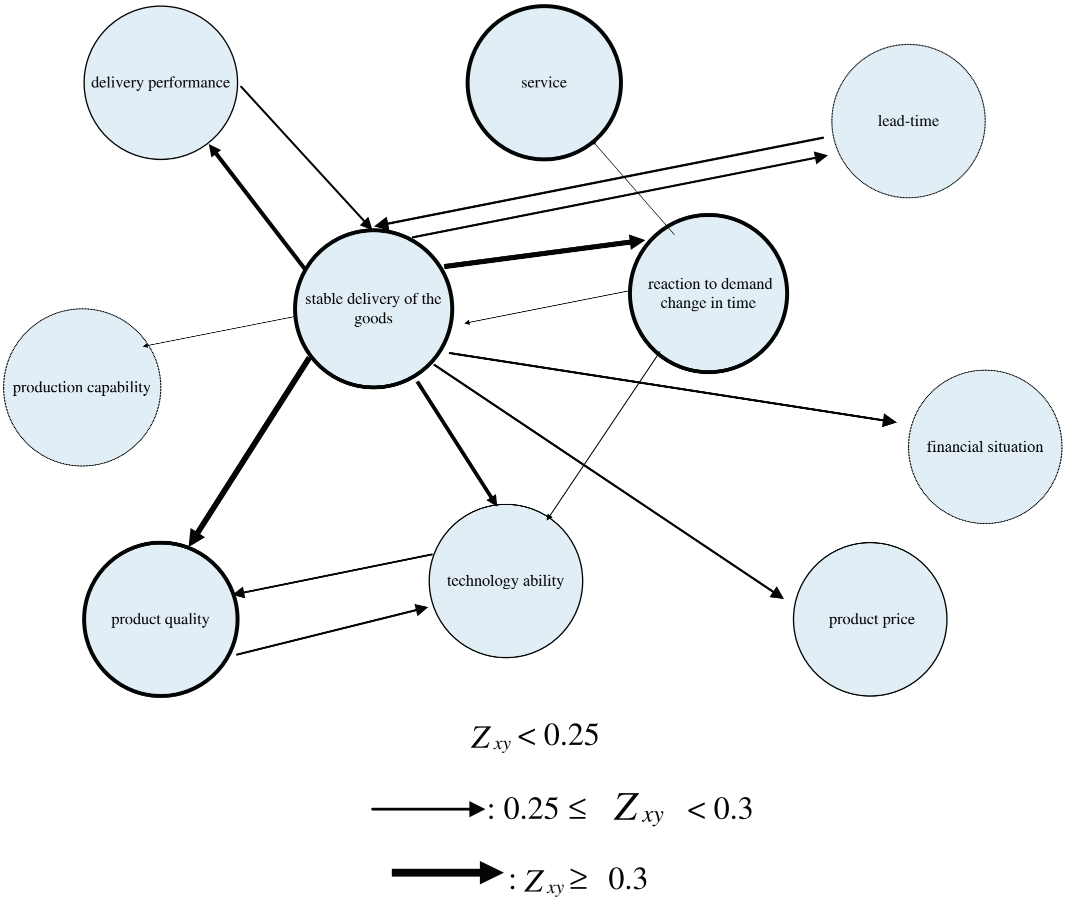

Fig. 2. Strategy map.

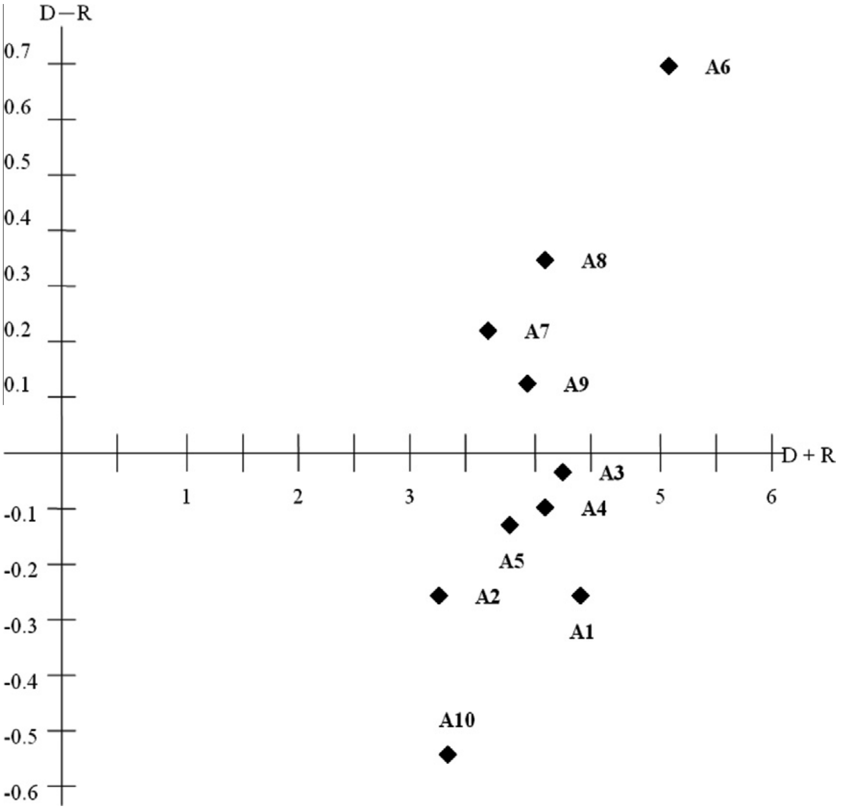

Fig. 3. The causal diagram. Using ♦ as the symbol for evaluation criteria: product quality (A1), product price (A2), technology ability (A3), service (A4), delivery performance (A5), stable delivery of goods (A6), lead-time (A7), reaction to demand change in time (A8), production capability (A9) and financial situation (A10).

capability” and “financial situation”. Focusing on evaluation criterion of “reaction to demand change in time”, it could indirectly influence evaluation criterion of “stable delivery of goods”.

5. Conclusion and future study

This study uses the DEMATEL method to analyze and forecast electronic industry suppliers. The results of this study can hopefully help enterprises precisely forecast which suppliers are suitable by focusing on crucial factors found in this study. Our research results show that stable delivery of goods has the greatest influence among the criteria for selecting suppliers. Although it was not the number one factor with the highest value of evaluation of significance, it can effectively help businesses to choose SCM suppliers. According to analysis results, stable delivery of goods could directly or indirectly influence many other characteristics such as product quality, product price, technology ability, service, delivery performance, lead-time, reaction to demand change in time, production capability and financial situation. This research suggests that businesses wanting to forecast and select suppliers should first observe which suppliers possess characteristic stable delivery of goods, since this evaluation criterion greatly influences other factors. Businesses generally pay close attention to product quality, product price and delivery performance when selecting or evaluating suppliers. This study however finds that stable delivery of goods is the real source that influences other factors, perceived as the most important factors by experts. A supplier with stable delivery of goods may have higher product quality and better delivery performance.

This study finds criteria that influence supplier selection, and constructs the strategy map among these criteria using DEMATEL. The strategy map finds interdependencies among these criteria and their strengths. Businesses typically evaluate select supplier criteria according to product quality, price, services and delivery performance of the supplier. The current study finds that “technology ability”, “stable delivery of goods”, “lead-time”, and “production capability” criteria are more influential than other evaluation criteria. These potential evaluate criteria could help businesses forecast appropriate suppliers. Businesses wanting to forecast suppliers should first observe suppliers according to evaluation criteria of ranking importance including “stable delivery of goods”, “technology ability”, “production capability” and “lead-time”. The results of this study could provide businesses with evaluation criterion to sieve out suitable ones from a large number of suppliers according to this factor. This study suggests that the fuzzy DEMATEL method be extended and applicable to many businesses which must deal with complex criteria problems that need to use group-decision-making in the fuzzy environment.

This research suggests further studies in order to extend the scope of this study. For example: the addition of a green supply chain could be explored in future studies. Such research could boost awareness of environmental protection from green design, green production, green purchasing, green products, green sales and marketing, green consumption to green living. Businesses could better maintain a balanced development within the economy and the environment. International electronic companies have been driven by green necessities for their products, reengineering green design and green products. Therefore, the green supply chain that is already a hot topic could become the new trend of the future.

References

Araz, C., & Ozkarahan, I. (2007). Supplier evaluation and management system for strategic sourcing based on a new multicriteria sorting procedure. *International Journal of Production Economics, 106*(2), 585–606.

Chang, S.-L., Wang, R.-C., & Wang, S.-Y. (2007). Applying a direct multi-granularity linguistic and strategy-oriented aggregation approach on the assessment of supply performance. *European Journal of Operational Research, 177*(2), 1013–1025.

Choi, T. Y., & Krause, D. R. (2006). The supply base and its complexity: Implications for transaction costs, risks, responsiveness, and innovation. *Journal of Operations Management, 24*(5), 637–652.

Cousins, P. D., Lawson, B., & Squire, B. (2006). Supply chain management: Theory and practice – The emergence of an academic discipline? *International Journal of Operations and Production Management, 26*(7), 697–702.

Cousins, P. D., & Menguc, B. (2006). The implications of socialization and integration in supply chain management. *Journal of Operations Management, 24*(5), 604–620.

Dickson, G. W. (1996). An analysis of vendor selection systems and decision. *Journal of Research, 141*, 70–87.

Gencer, C., & Gurpinar, D. (2007). Analytic network process in supplier selection: A case study in an electronic firm. *Applied Mathematical Modelling, 31*(11), 2475–2486.

Hsu, L. C. (2003). Apply the grey prediction model to the global integrated circuit industry. *Technological Forecasting and Social Change, 70*(6), 563–574.

Huang, C. Y., & Tzeng, G. H. (2008). Multiple generation product life cycle predictions using a novel two-stage fuzzy piecewise regression analysis method. *Technological Forecasting and Social Change, 75*(1), 12–31.

Jayaraman, V., Srivastava, R., & Benton, W. C. (1999). Supplier selection and order quantity allocation: A comprehensive model. *The Journal of Supply Chain Management, 35*(2), 50–58.

Krause, D. R., & Ellram, L. M. (1997). Critical elements of supplier development – The buying-firm perspective. *European Journal of Purchasing and Supply Management, 3*, 21–31.

Kreng, V. B., & Wang, I. C. (2005). Supplier management for manufacturer – a case study of flexible PCB. *The International Journal of Advanced Manufacturing Technology, 25*(7), 785–792.

Lee, C. H., & Rhee, B. D. (2007). Channel coordination using product returns for a supply chain with stochastic salvage capacity. *European Journal of Operational Research, 177*(1), 214–238.

Li, R. J. (1999). Fuzzy method in group decision making. *Computers and Mathematics with Applications, 38*(1), 91–101.

Li, X., & Wang, Q. (2007). Coordination mechanisms of supply chain systems. *European Journal of Operational Research, 179*(1), 1–16.

Lin, C. T., & Yang, S. Y. (2003). Forecast of the output value of Taiwan's opto-electronics industry using the Grey forecasting model. *Technological Forecasting and Social Change, 70*(2), 177–186.

Ni, M., Xu, X., & Deng, S. (2007). Extended QFD and data-mining-based methods for supplier selection in mass customization. *International Journal of Computer Integrated Manufacturing, 20*, 280–291.

Noorul, H. A., & Kannan, G. (2006). Fuzzy analytical hierarchy process for evaluating and selecting a vendor in a supply chain model. *The International Journal of Advanced Manufacturing Technology, 29*(7), 826–835.

Pi, W. N., & Low, C. (2006). Supplier evaluation and selection via Taguchi loss functions and an AHP. *The International Journal of Advanced Manufacturing Technology, 27*(5), 625–630.

Prahinski, C., & Benton, W. C. (2004). Supplier evaluations: Communication strategies to improve supplier performance. *Journal of Operations Management, 22*(1), 39–62.

Quayle, M. (2003). A study of supply chain management practice in UK industrial SMEs. *Supply Chain Management: An International Journal, 8*, 79–86.

Saen, R. F. (2007). A new mathematical approach for suppliers selection: Accounting for non-homogeneity is important. *Applied Mathematics and Computation, 185*(1), 84–95.

Sako, M. (2004). Supplier development at Honda, Nissan and Toyota: comparative case studies of organizational capability enhancement. *Industrial and Corporate Change, 13*(2), 281–308.

Sarmah, S. P., Acharya, D., & Goyal, S. K. (2006). Buyer vendor coordination models in supply chain management. *European Journal of Operational Research, 175*(1), 1–15.

Shin, H., Collier, D. A., & Wilson, D. D. (2000). Supply management orientation and supplier/buyer performance. *Journal of Operations Management, 18*, 317–333.

Tessarolo, P. (2007). Is integration enough for fast product development? An empirical investigation of the contextual effects of product vision. *Journal of Product Innovation Management, 24*(1), 69–82.

Wang, S. J., & Hu, H. A. (2005). *Application of rough set on supplier's determination*. Paper presented at the third annual conference on uncertainty.

Weber, C. A., & Current, J. R. (1993). A multiobjective approach to vendor selection. *European Journal of Operational Research, 68*(2), 173–184.

Weber, C. A., Current, J. R., & Benton, W. C. (1991). Vendor selection criteria and methods. *European Journal of Operational Research, 50*(1), 2–18.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338–353.