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Combined DEMATEL technique with hybrid MCDM methods for creating the aspired intelligent global manufacturing & logistics systems

Gwo-Hshiung Tzeng · Chi-Yo Huang

Abstract The concept of globalization has been prosperous in the past decades while manufacturing as well as logistics have already become one of the most significant issues in the globalization era. However, while modern globalized firms are leveraging both global manufacturing resources as well as logistics systems for pursuing higher quality, lower cost as well as product differentiation, how to evaluate, selecting an appropriate global manufacturing strategy by considering issues from both aspects of global manufacturing as well as logistics has become one of the most critical and difficult issues. Moreover, how the chosen intertwined global manufacturing as well as logistics system is to be optimized so that the aspired level of the global manufacturing system can be achieved have few been addressed. Thus, this research aims to resolve the above mentioned global manufacturing and logistics strategy selection as well as system reconfiguration issue. A Decision Making Trial and Evaluation Laboratory (DEMATEL) technique based novel multiple criteria decision making (MCDM) method with Analytic Network Process (ANP), Grey Relational Analysis (GRA) as well as VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) will be proposed for selecting and re-configuring the aspired global manufacturing and logistics system. An empirical study based on the global manufacturing and logistics system design of a semiconductor company will be provided for verifying the effectiveness of this proposed methodology.

Keywords Global manufacturing · Logistics · MCDM (Multiple Criteria Decision Making) · DEMATEL (Decision Making Trial and Evaluation Laboratory) · Semiconductor

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1 Introduction

The economic and industrial communities worldwide are confronted with the increasing impact of competitive pressures resulting from the globalization of markets and supply chains for product fulfillment (Pontrandolfo and Okogbaa 1999). Moreover, logistics are playing a daily important role on impacting on the success of global manufacturing (Fawcett 1992). The manufacturing practices being shifted from traditional make-to-stock to make-to-order are driving global manufacturing and logistics (Jiao et al. 2006) to be the mainstream thinking of modern manufacturing management.

The last two decades have been characterized by the growing globalization of economic and social enterprises, especially in the areas of the logistics of production (Pontrandolfo and Okogbaa 1999). According to Jiao et al. (2006), more and more manufacturing enterprises are being driven to pursue a global manufacturing strategy, determining where a company locates manufacturing facilities and how its global supply chain functions (McGrath 2001), which aims to transcend national boundaries to leverage capabilities and resources worldwide. The globalization and regionalization of production offers companies a great potential to optimize their production footprint while the consequential utilization of local advantageous factors will lead to an increased specialization of manufacturing activities (Abele et al. 2006). Logistics' impact on the success of global manufacturing from both aspects of moving and storing of materials throughout the manufacturing process and providing a fundamental mechanism for managing this increased environmental uncertainty and for linking, in a coordinated manner, a firm's diverse global operations (Fawcett 1992).

Albeit important, designing a global manufacturing as well as logistics strategy is not an easy task. According to Warner (1996), there are no straightforward answers addressing how a global manufacturing strategy should be designed to fit any business context. Not to mention how a manufacturing strategy should be designed by considering factors being related to global logistics. Meanwhile, from the aspect of MCDM (multiple criteria decision making), though the global manufacturing and logistics have already become a sound, very few researches addressed the design or reconfiguration of a global manufacturing and logistics system based on modern MCDM approaches. Some researches tried to explore the MCDM nature of global manufacturing and logistics problems by traditional approaches. E.g., Abele et al. (2006) suggests a framework of criteria which are regarded as an adequate set to support the configuration of a production network. Hübner and Günther (2007) evaluated the strategic production site using AHP by assuming the independence of criteria. However, dependences between the criteria, especially the intertwined effects between manufacturing and logistics, are usually neglected. Furthermore, problems inside some TOPSIS based researches which determines the compromise solutions with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Hwang and Yoon 1981; Yoon 1987) while not considering the relative importance of these distances can be prohibited by the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic and Tzeng 2003, 2004, 2007).

Thus, the authors would like to propose a novel multiple criteria decision making (MCDM) framework for selecting an appropriate manufacturing strategy and enhancing the manufacturing and logistics capability of the strategy and achieve the aspired level. The factors for selecting the best manufacturing and logistics strategy are summarized using the Delphi method. Meanwhile, the current level of the manufacturing strategy will be surveyed based on experts' opinions. The current level of the manufacturing strategy of the industry leader of also will be surveyed by the same experts for serving as the aspired level of the manufacturing and logistics strategy. Then, the relationships between the factors for selecting the best manufacturing and logistics strategy will be derived by DEMATEL (Decision

Making Trial and Evaluation Laboratory). The weights of each factor versus the goal of the MCDM problem, selecting the best global manufacturing and logistics strategy, then will be derived based on the structure of the decision problem by using the Analytic Network Process (ANP). Each strategy will be evaluated while the grades will be calculated by introducing the weights. After the factors are derived, the relationships between the factors and the manufacturing strategies being used to enhance the global manufacturing and logistics capability will be derived by Grey Relational Analysis (GRA) based on the weights of each factor being derived by ANP. After the global manufacturing and logistics strategy are introduced, the target firm's global manufacturing and logistics competences will be surveyed again to ensure the improvement.

A case study on a globalized semiconductor integrated device manufacturer (IDM) with multiple front-end DRAM wafer manufacturing fabs belonging to the IDM itself as well as its subsidiary and other semiconductor foundries all over the world, including Taiwan, Japan, Germany, and China, and backend testing facilities belonging to the IDM itself as well as third party DRAM testing houses being located in Japan, Taiwan, Singapore as well as Italy will be given as an example for verifying the effectiveness of this novel MCDM technique.

The remainder of this paper is organized as follows. In Sect. 2, the concepts of global manufacturing and logistics are introduced. In Sect. 3, an MCDM based analytic framework and methods by introducing the DEMATEL technique are proposed for constructing the global manufacturing and logistics strategy. Then, Sect. 4 presents an empirical study of a professional semiconductor IDM's selection of manufacturing strategy and achieving its aspired level of global manufacturing and logistics capability will be provided. Discussions will be presented in Sect. 5. Finally, Sect. 6 will conclude the paper with observations, conclusions and recommendations for further study.

2 Intelligent global manufacturing and logistic system design with MCDM

In the past decades, globalization has already become the mega trend impacting manufacturing and logistics strategies of a majority number of firms all over the world. In the following section, literatures being related to manufacturing strategies, logistics strategies, intertwined effects of manufacturing as well as logistics strategies and impacts of globalization on manufacturing and logistics strategies will be reviewed as a foundation for the development of theoretic framework development.

2.1 Manufacturing strategies

As summarized by Dangayach and Deshmukh (2001), Skinner (1969) was the pioneer in defining manufacturing strategy. According to Skinner's viewpoint, manufacturing strategy refers to exploit certain properties of the manufacturing function as a competitive weapon. Cox et al. (1998) defined manufacturing strategy as a collective pattern of decisions that acts upon the formulation and deployment of manufacturing resources. To be most effective, the manufacturing strategy should act in support of the overall strategic directions of the business and provide for competitive advantages (Dangayach and Deshmukh 2006). According to Brown (1998), manufacturing strategy can be vitally important in two ways. Firstly, it can be reactive but central to implementation of an existing business strategy. Secondly, manufacturing strategy can be proactive whereby manufacturing represents a number of core competencies/capabilities that can be exploited and used to create new opportunities for the firm.

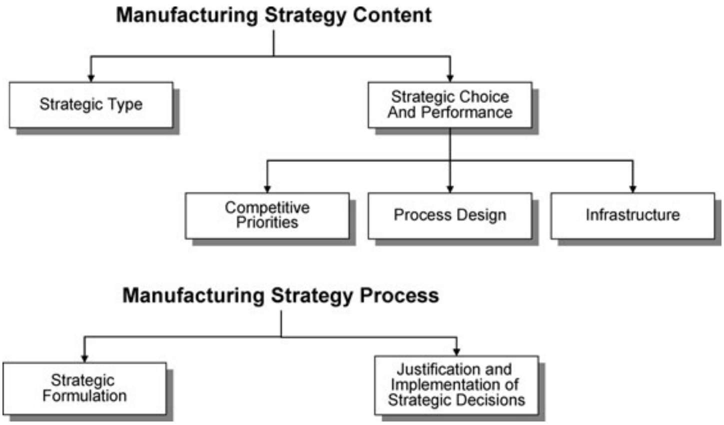

Fig. 1 Manufacturing strategy content vs. process. Source: Swink and Way (1995)

Acur et al. (2003) summarized that manufacturing strategy has been considered from two perspectives: content and process. The content of manufacturing strategy comprises the specific decisions and actions which set the operations' role, objective and activities while the process of manufacturing strategy as the method that is used to make the specific content decisions (Acur et al. 2003; Slack et al. 2001). Swink and Way (1995) describe the distinction between the content and the process of manufacturing strategy in the manner shown in Fig. 1.

Competing in manufacturing requires a long term strategy (Westkämper 2006). Under the influence of the turbulent environment in the world's manufacturing area it is essential to focus research on technologies and methods for global competitiveness by efficiency and adaptability (Westkämper 2006).

2.1.1 *Global manufacturing strategy*

Achieving success in the global market has required fundamental shifts in the way business is conducted and has dramatically affected virtually every aspect of manufacturing strategy (Vastag et al. 1994). To be successful internationally, a company needed to operate manufacturing facilities in the major foreign countries where it sold its products based on following reasons: (1) customers' preferences to a product manufactured locally; (2) prevention of protectionism; (3) facilitation of the understanding of local requirements; (4) provisions of a focal point for customer visits, allowing a company to demonstrate the care and quality that go into production (McGrath 2001).

Finally, based on Dangayach and Deshmukh's review (Dangayach and Deshmukh 2001), the best practices which may be used as manufacturing strategies for enhancing firms' manufacturing capabilities include: (1) manufacturing resource planning, (2) optimized production technology, (3) flexible manufacturing system, (4) group technology, (5) total quality management, (6) just-in-time, (7) lean production and (8) concurrent engineering.

2.1.2 *Critical factors for deciding global manufacturing strategy*

The manufacturing strategy literature has identified a number of manufacturing-related dimensions on which firms may compete (Stock et al. 1998). These competitive dimensions, which have been labeled "competitive priorities" in the literature, can include cost, quality, flexibility, and delivery performance among others (Corbett and Van Wassenhove 1993; Minor et al. 1994; Vickery 1991) where these competitive priorities can be viewed as the objectives of the firm's manufacturing strategy from a strategy perspective (Stock et al. 1998).

2.2 Logistics strategies

As stated by Chow et al. (2005), since 1990s, the Japanese philosophy of distributed manufacturing and lean manufacturing has become the key technique which is widely adopted around the world which changed the traditional viewpoints recognizing logistics as a distinct function in the past. Consequently, the logistics operation is forced to change in order to fit such new Japanese manufacturing strategy and has become an extremely complicated process in which expert knowledge is required (Chow et al. 2005).

The logistics practices of leading edge companies were inclined to provide more commitment to achieving customer satisfaction (Bowersox et al. 1990). With the greater strategic value attached to the logistics function, more and more companies in the manufacturing, retail, wholesale and service industries are establishing formal logistics strategies (Hill 1994). As summarized by Fabbe-Costes and Colin (2007), general logistics strategies include (1) cost reduction, (2) service quality enhancement, (3) support for innovation, (4) source/motor for alliance, (5) support for new profession integration, (6) support for extension as well as (7) use of logistics synergies.

2.2.1 Global logistics strategies

As businesses continue to globalize, attention has increasingly turned to logistics (Cooper 1993). With increasing product and process complexity and with advancing globalization, cross-company assessment and standardized optimization of procurement, production and sales processes are becoming increasingly important (Graf 2006). Thus, in this rapidly changing world, not only internal manufacturing processes but also its external logistical infrastructure needs to be changed (Vastag et al. 1994).

Manufacturing companies require new supporting infrastructures to compete successfully in quickly changing global markets demanding flexibility and timely delivery (Vastag et al. 1994). Since globalization has created a new set of competitive imperatives, and because firms are turning to global operations with greater frequency, logistics' ability to assist firms in their quest to build a sustainable competitive advantage must by re-evaluated (Fawcett 1992).

Much of the impetus for the development of coordinated global manufacturing strategies has come historically from the desire to reduce production costs to compete with lower-cost foreign competitors (Fawcett 1992). Most firms that have adopted these global strategies have sought to improve their competitive position by utilizing the 'best' mix of available worldwide resources in their value adding systems (Fawcett 1992; Porter 1985). This added incentive of gaining access to global markets is now a pervasive argument in the decision to establish global manufacturing operations. Regardless of the reason for implementing a global manufacturing strategy, the key to achieving success rests on the firm's ability to effectively co-ordinate its worldwide operations (Fawcett 1992). That is, through co-ordination the overall global manufacturing network is able to perform as a cohesive, value-adding conversion system. Logistics competence can potentially provide this essential coordinating mechanism (Fawcett 1992).

2.3 Coordinated global manufacturing

Economic globalization of the past decades has had two principal impacts on manufacturing firms: (1) intensification of competitive pressure in most manufacturing industries; (2) economic globalization has initiated a move toward the creation of global markets (Fawcett 1992). To better meet the challenges and take advantage of the opportunities presented by economic globalization, more firms are looking to coordinated global manufacturing strategies (Fawcett 1992).

McGrath and Hoole (1992) contend that operational integration is required for successful global performance. Manufacturing and distribution networks must be tightly coordinated, without redundant processes. They highlight five basic processes from which change must begin: (1) product development; (2) purchasing; (3) production; (4) demand management; and (5) order fulfillment.

Simply stated, a coordinated global manufacturing strategy shifts the productive activities of an organization to the various regions of the world where they will add the most value to the product (Fawcett 1992). These activities are then integrated within a cohesive manufacturing system (Fawcett 1992).

2.3.1 Design of a coordinated global manufacturing system

The decisions as important as the design of the global manufacturing network should be made only after considering the interrelationships and tradeoffs among the principal system elements (Fawcett 1992). The primary objective of co-ordinated global manufacturing is to modify the conversion process through the rationalization of productive resources so that it adds the most value to the firm's product as possible (Fawcett 1992). Therefore, the appropriate system to analyze is the conversion system, which consists principally of the logistics and production functions (Fawcett 1992; Porter 1985) (see Fig. 2).

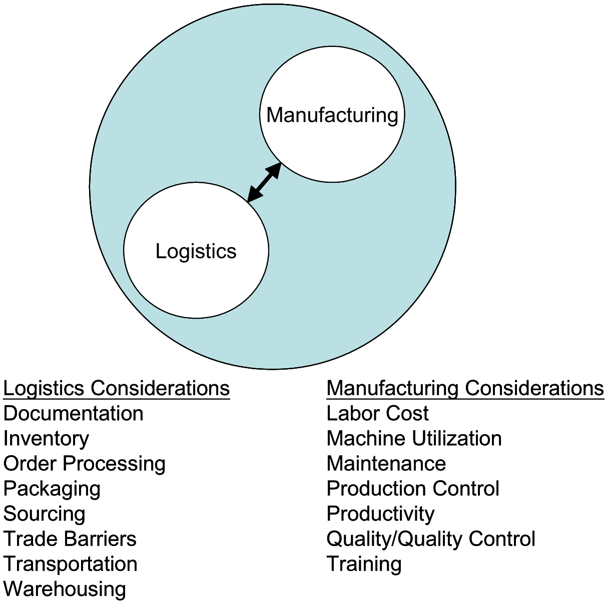

Fig. 2 Coordinated global manufacturing system. Source: Fawcett (1992)

Albeit important, very few article addressed how the above mentioned coordinated global manufacturing and logistics system can be designed. In the following section, a novel MCDM framework combining DEMATEL technique will be proposed for designing the aspired global manufacturing and logistics systems.

3 A novel MCDM methods with the DEMATEL technique

The analytical process for defining innovation strategies is initiated by collecting the determinants needed to develop an SOC design service company's determinant using the Delphi method. Since any determinants to be derived by the Delphi may impact each other, the structure of the MCDM problem will be derived using the DEMATEL. The priorities of every determinant are based on the structure derived by using the ANP. The VIKOR technique will be leveraged for calculating compromise ranking of the alternatives. Finally, the GRA will be applied to get the correlation between the determinants and the global manufacturing and logistics strategies. Based on the gray grades to be derived by the GRA, the global manufacturing and logistics strategies will be derived. In summary, this evaluation framework consists of five main phases: (1) establishing determinants using the Delphi method; (2) building the structure of network relation map (NRM) among determinants by using the DEMATEL; (3) calculating the priorities of every determinant by the ANP based on the structure of NRM derived by using the DEMATEL in (2); (4) ranking the priorities of global manufacturing and logistics systems with the VIKOR; and finally (5) deciding the global manufacturing and logistics strategies and achieving the aspired levels by using GRA (see Fig. 3).

3.1 Delphic oracle's skills of interpretation and foresight

The Delphi method originated in a series of studies conducted by the RAND Corporation in the 1950s (Jones and Hunter 1995). The objective was to develop a technique to obtain the most reliable consensus from a group of experts (Dalkey and Helmer 1963). While

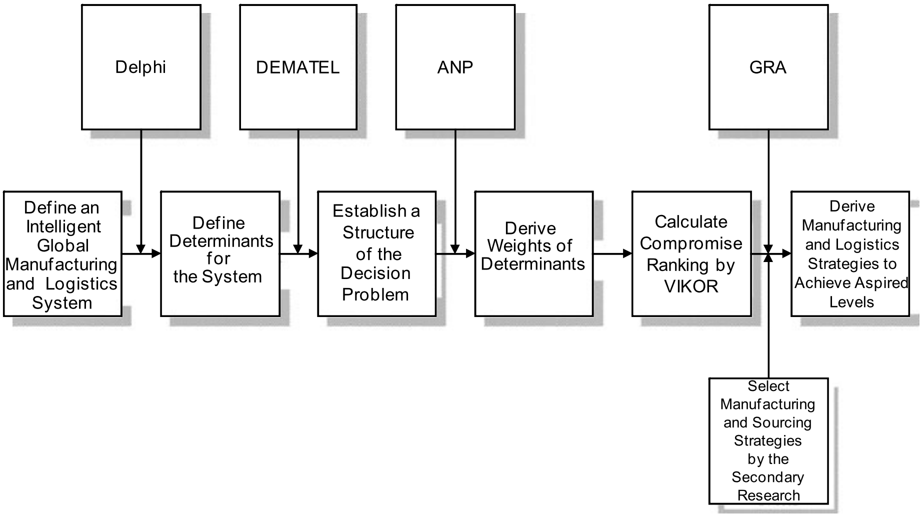

Fig. 3 An analytical framework for aspired global manufacturing and logistics systems definition

researchers have developed variations of the method since its introduction, Linstone and Turoff (1975) captured its common characteristics in the following description: Delphi may be characterized as a method for structuring a group communication process; so the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. To accomplish this 'structured communication', certain aspects should be provided: some feedback of individual contributions of information and knowledge; some assessment of the group judgment or viewpoint; some opportunity for individuals to revise their views; and some degree of anonymity for individual responses (Linstone and Turoff 1975). The Delphi technique enables a large group of experts to be surveyed cheaply, usually by mail using a self-administered questionnaire (although computer communications also have been used), with few geographical limitations on the sample. Specific situations have included a round in which the participants meet to discuss the process and resolve any uncertainties or ambiguities in the wording of the questionnaire (Jones and Hunter 1995). The Delphi method proceeds in a series of communication rounds, as follows:

Round 1: Either the relevant individuals are invited to provide opinions on a specific matter, based upon their knowledge and experience, or the team undertaking the Delphi expresses opinions on a specific matter and selects suitable experts to participate in subsequent questionnaire rounds; these opinions are grouped together under a limited number of headings, and statements are drafted for circulation to all participants through a questionnaire (Jones and Hunter 1995).

Round 2: Participants rank their agreement with each statement in the questionnaire; the rankings then are summarized and included in a repeat version of the questionnaire (Jones and Hunter 1995).

Round 3: Participants re-rank their agreement with each statement in the questionnaire, and have the opportunity to change their score, in view of the group's response; the re-rankings are summarized and assessed for their degree of consensus: if an acceptable degree of consensus is obtained, the process may cease, with the final results then fed back to the participants; if not, this third round is repeated (Jones and Hunter 1995).

3.2 DEMATEL method

The DEMATEL method was developed by the Battelle Geneva Institute (1) to analyze complex 'world problems' dealing mainly with interactive man-model techniques; and (2) to evaluate qualitative and factor-linked aspects of societal problems (Gabus and Fontela 1972). The applicability of the method is widespread, ranging from industrial planning and decision-making to urban planning and design, regional environmental assessment, analysis of world problems, and so forth. It has also been successfully applied in many situations, such as marketing strategies, control systems, safety problems, developing the competencies of global managers and group decision-making (Huang et al. 2007; Liou et al. 2007; Chiu et al. 2006; Wu and Lee 2007; Lin and Wu 2008). Furthermore, a hybrid model combining the two methods has been widely used in various fields, for example, e-learning evaluation (Tzeng et al. 2007), airline safety measurement (Liou et al. 2007), and innovation policy portfolios for Taiwan's SIP Mall (Huang et al. 2007). Therefore, in this paper we use DEMATEL not only to detect complex relationships and build a NRM of the criteria, but also to obtain the influence levels of each element over others; we then adopt these influence level values as the basis of the normalization supermatrix for determining ANP weights to obtain the relative importance. To apply the DEMATEL method smoothly, the

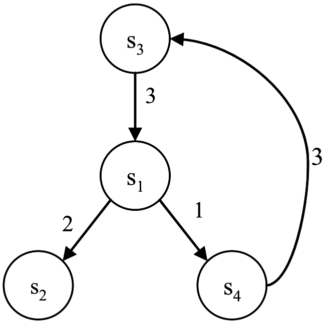

Fig. 4 An example of the directed graph

authors refined the definitions based on above authors, and produced the essential definitions indicated below. The DEMATEL method is based upon graph theory, enabling us to plan and solve problems visually, so that we may divide multiple criteria into a relationship of cause and effect group, in order to better understand causal relationships. Directed graphs (also called digraphs) are more useful than directionless graphs, because digraphs will demonstrate the directed relationships of sub-systems. A digraph typically represents a communication network, or a domination relationship between individuals, etc. Suppose a system contains a set of elements, $S = \{s_1, s_2, \dots, s_n\}$, and particular pair-wise relationships are determined for modeling, with respect to a mathematical relationship, MR. Next, portray the relationship MR as a direct-relation matrix that is indexed equally in both dimensions by elements from the set S. Then, extract the case for which the number 0 appears in the cell (i, j), if the entry is a positive integral that has the meaning of: the ordered pair (s_i, s_j) is in the relationship MR; it has the kind of relationship regarding that element such that s_i causes element s_j. The digraph portrays a contextual relationship between the elements of the system, in which a numeral represents the strength of influence (Fig. 4). The elements s_1, s_2, s_3 and s_4 represent the factors that have relationships in Fig. 2. The number between factors is influence or influenced degree. For example, an arrow from s_1 to s_2 represents the fact that s_1 influences s_2 and its influenced degree is two. The DEMATEL method can convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Chiu et al. 2006).

Definition 1 The pair-wise comparison scale may be designated as eleven levels, where the scores $0, 1, 2, \dots, 10$ represent the range from 'no influence' to 'very high influence'.

Definition 2 The initial direct relation/influence matrix $\boldsymbol{A}$ is an $n \times n$ matrix obtained by pair-wise comparisons, in terms of influences and directions between the determinants, in which a_{ij} is denoted as the degree to which the ith determinant affects the jth determinant.

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

Definition 3 The normalized direct relation/influence matrix $\boldsymbol{N}$ can be obtained through (1) and (2), in which all principal diagonal elements are equal to zero.

$$\boldsymbol{N} = z\boldsymbol{A}, \tag{1}$$

where

$$z = \min\left\{1/\max_i \sum_{j=1}^{n} a_{ij},\ 1/\max_j \sum_{i=1}^{n} a_{ij}\right\}, \quad i, j \in \{1, 2, \dots, n\}. \tag{2}$$

In this case, $\boldsymbol{N}$ is called the normalized matrix. Since $\lim_{\varepsilon\to\infty} \boldsymbol{N}^{\varepsilon} = [0]$.

Definition 4 Then, the total relationship matrix $\boldsymbol{T}$ can be obtained using (3), where $\boldsymbol{I}$ stands for the identity matrix. $\boldsymbol{T} = \boldsymbol{N} + \boldsymbol{N}^2 + \cdots + \boldsymbol{N}^{\varepsilon} = \boldsymbol{N}(\boldsymbol{I} - \boldsymbol{N})^{-1}$, (3) where $\varepsilon \to \infty$ and $\boldsymbol{T}$ is a total influence-related matrix; $\boldsymbol{N}$ is a direct influence matrix and $\boldsymbol{N} = [x_{ij}]_{n\times n}$; $\lim_{\varepsilon\to\infty}(\boldsymbol{N}^2 + \cdots + \boldsymbol{N}^{\varepsilon})$ stands for a indirect influence matrix;
[Explanation]

$$\begin{aligned}
\boldsymbol{T} &= \boldsymbol{N} + \boldsymbol{N}^2 + \boldsymbol{N}^3 + \cdots + \boldsymbol{N}^{\varepsilon} \\
&= \boldsymbol{N}(\boldsymbol{I} + \boldsymbol{N} + \boldsymbol{N}^2 + \cdots + \boldsymbol{N}^{\varepsilon-1})(\boldsymbol{I} - \boldsymbol{N})(\boldsymbol{I} - \boldsymbol{N})^{-1} \\
&= \boldsymbol{N}(\boldsymbol{I} - \boldsymbol{N}^{\varepsilon})(\boldsymbol{I} - \boldsymbol{N})^{-1} \\
&= \boldsymbol{N}(\boldsymbol{I} - \boldsymbol{N})^{-1}, \quad \text{when } \varepsilon \to \infty, \quad \boldsymbol{N}^{\varepsilon} = [0]_{n\times n}
\end{aligned} \tag{3}$$

where $0 \le x_{ij} < 1$, $0 < \sum_{j=1}^{n} x_{ij} \le 1$ and $0 < \sum_{i=1}^{n} x_{ij} \le 1$, at least one row or column of summation is equal to 1, but not all , then $\lim_{\varepsilon\to\infty} \boldsymbol{N}^{\varepsilon} = [0]_{n\times n}$.

The (i, j) element t_{ij} of matrix $\boldsymbol{T}$ denotes the direct and indirect influences of factor i on factor j.

Definition 5 The row and column sums are separately denoted as $\boldsymbol{r}$ and $\boldsymbol{c}$ within the total-relation matrix $\boldsymbol{T}$ through (4), (5), and (6).

$$\boldsymbol{T} = [t_{ij}], \quad i, j \in \{1, 2, \dots, n\} \tag{4}$$

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1} \tag{5}$$

$$\boldsymbol{c} = [c_j]_{n\times 1} = \left(\sum_{i=1}^{n} t_{ij}\right)'_{1\times n} \tag{6}$$

where the $\boldsymbol{r}$ and $\boldsymbol{c}$ vectors denote the sums of the rows and columns, respectively.

Definition 6 Suppose r_i denotes the row sum of the ith row of matrix $\boldsymbol{T}$. Then, r_i is the sum of the influences dispatching from factor i to the other factors, both directly and indirectly. Suppose that c_j denotes the column sum of the jth column of matrix $\boldsymbol{T}$. Then, c_j is the sum of the influences that factor i is receiving from the other factors. Furthermore, when $i = j$ (i.e., the sum of the row sum and the column sum $(r_i + c_i)$ represents the index representing the strength of the influence, both dispatching and receiving), $(r_i + c_i)$ is the degree of the central role that factor i plays in the problem. If $(r_i - c_i)$ is positive, then factor i primarily is dispatching influence upon the strength of other factors; and if $(r_i - c_i)$ is negative, then factor i primarily is receiving influence from other factors (Huang et al. 2007; Liou et al. 2007; Tamura et al. 2002).

3.3 The ANP method

The ANP method, a multi criteria theory of measurement developed by Saaty (1996), provides a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower level elements and about the independence of the elements within a level as in a hierarchy. Compared with traditional AHP (Analytic Hierarchy Process) (Saaty 2005) based applications (e.g. Li and Ma 2008; Ahmad and Laplante 2009) which usually assume the independence between criteria, ANP, a new theory that extends AHP to deal with dependence in feedback and utilizes the supermatrix approach (Saaty 1996), is a more reasonable tool for dealing with complex MCDM problems in the real world (e.g., the selection of technology acquisition mode Lee et al. 2009, locating undesirable facilities Tuzkaya et al. 2008, the selection of logistics service provider Jharkharia and Shankar 2007, etc.). In this section, concepts of the ANP are summarized based on Saaty's earlier works (Saaty 1996, 1999, 2005).

The ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria (Saaty 2003, 2004). A control hierarchy is a hierarchy of criteria and subcriteria for which priorities are derived in the usual way with respect to the goal of the system being considered.

The criteria are used to compare the components of a system, and the subcriteria are used to compare the elements. The criteria with respect to which influence is presented in individual supermatrices are called control criteria. Because all such influences obtained from the limits of the several supermatrices will be combined in order to obtain a measure of the priority of overall influences, the control criteria should be grouped in a structure to be used to derive priorities for them. These priorities will be used to weight the corresponding individual supermatrix limits and add. Analysis of priorities in a system can be thought of in terms of a control hierarchy with dependence among its bottom-level alternatives arranged as a network as shown in Fig. 5. Dependence can occur within the components and between them.

A control hierarchy at the top may be replaced by a control network with dependence among its components, which are collections of elements whose functions derive from the synergy of their interaction and hence has a higher-order function not found in any single element. The criteria in the control hierarchy that are used for comparing the components are usually the major parent criteria whose subcriteria are used to compare the elements need to be more general than those of the elements because of the greater complexity of the components.

A network connects the components of a decision system. According to size, there will be a system that is made up of subsystems, with each subsystem made up of components, and each component made up of elements. The elements in each component interact or have an influence on some or all of the elements of another component with respect to a property governing the interactions of the entire system, such as energy, capital, or political influence. Fig. 4 demonstrates a typical network. Those components which no arrow enters are known as source components such as $\boldsymbol{C}_1$ and $\boldsymbol{C}_2$. Those from which no arrow leaves are known as sink component such as $\boldsymbol{C}_5$. Those components which arrows both enter and exit leave are known as transient components such as $\boldsymbol{C}_3$ and $\boldsymbol{C}_4$. In addition, $\boldsymbol{C}_3$ and $\boldsymbol{C}_4$ form a cycle of two components because they feed back and forth into each other. $\boldsymbol{C}_2$ and $\boldsymbol{C}_4$ have loops

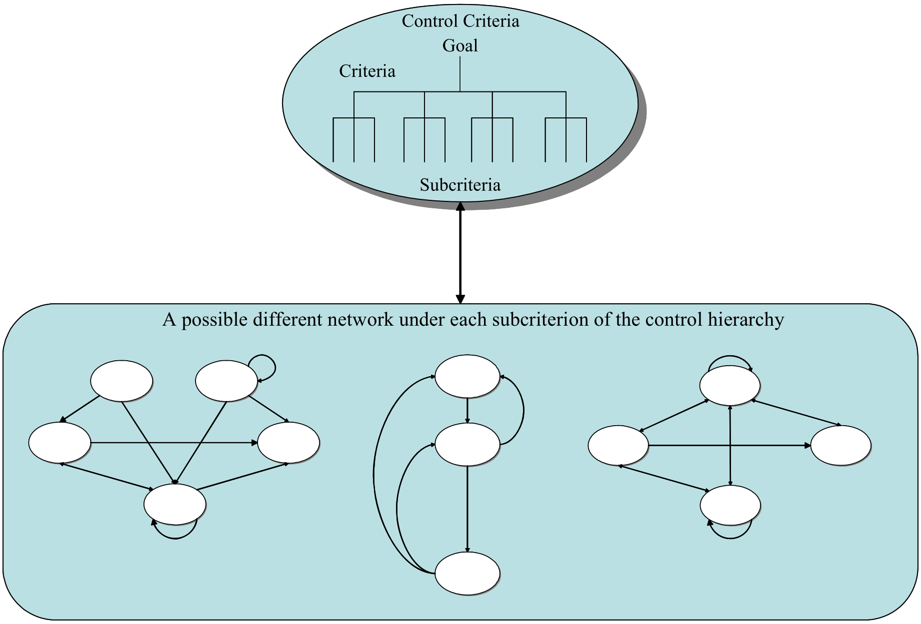

Fig. 5 The control hierarchy. Source: Saaty (1996)

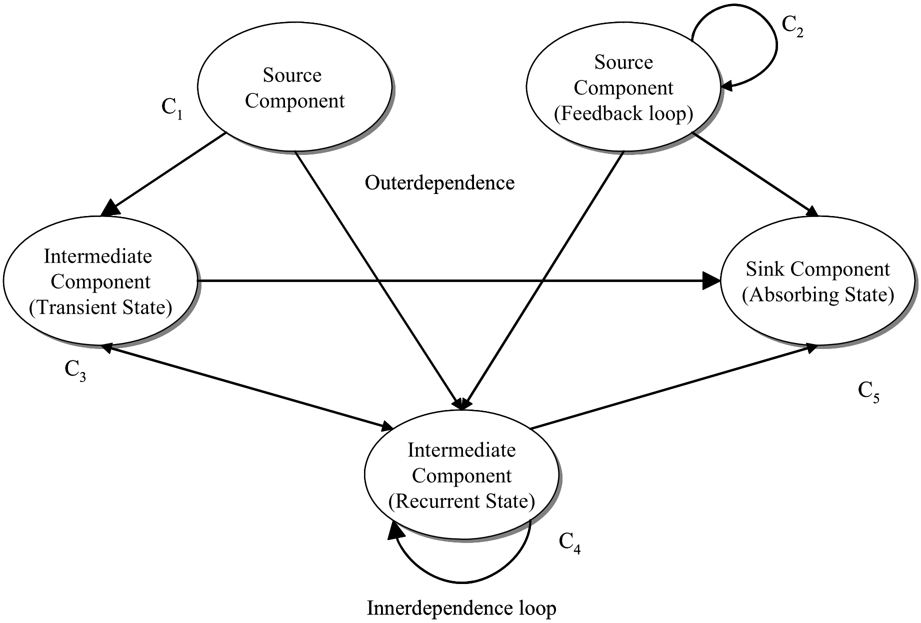

Fig. 6 Connections in a network. Source: Saaty (1996)

that connect them to themselves and are inner dependent. All other connections represent dependence between components which are thus known to be outer dependent (Fig. 6).

A component of a decision network which was derived by the DEMATEL method in Sect. 3.2 will be denoted by $\boldsymbol{C}_h$, $h = 1, \dots, m$, and assume that it has n_h elements (determinants), which we denote by $e_{h1}, e_{h2}, \dots, e_{hm}$. The influences of a given set of elements (determinants) in a component on any element in the decision system are represented by a ratio scale priority vector derived from paired comparisons of the comparative importance of one criterion and another criterion with respect to the interests or preferences of the decision makers. This relative importance value can be determined using a scale of 1–9 to represent equal importance to extreme importance (Saaty 1996). The influence of elements (determinants) in the network on other elements (determinants) in that network can be represented in the following supermatrix:

$$
\boldsymbol{W} = \begin{array}{ccc}
 & & \begin{array}{cccc} \boldsymbol{C}_1 & \boldsymbol{C}_2 & \cdots & \boldsymbol{C}_m \end{array} \\
 & & \begin{array}{cccccccccc} e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{m1} & \cdots & e_{mn_m} \end{array} \\
\begin{array}{c} \\ \\ \boldsymbol{C}_1 \\ \\ \\ \\ \boldsymbol{C}_2 \\ \\ \vdots \\ \\ \\ \boldsymbol{C}_m \\ \\ \end{array} &
\begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \\ e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \\ \vdots \\ e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} &
\left[\begin{array}{cccc}
\boldsymbol{W}_{11} & \boldsymbol{W}_{12} & \cdots & \boldsymbol{W}_{1m} \\
\boldsymbol{W}_{21} & \boldsymbol{W}_{22} & \cdots & \boldsymbol{W}_{2m} \\
 & & \ddots & \\
\vdots & \vdots & & \vdots \\
\boldsymbol{W}_{m1} & \boldsymbol{W}_{m2} & \cdots & \boldsymbol{W}_{mm}
\end{array}\right]
\end{array}
$$

A typical entry $\boldsymbol{W}_{ij}$ in the supermatrix, is called a block of the supermatrix in the following form where each column of $\boldsymbol{W}_{ij}$ is a principal eigenvector of the influence of the elements (determinants) in the ith component of the network on an element (determinants) in the jth component. Some of its entries may be zero corresponding to those elements (determinants) that have no influence.

$$
\boldsymbol{W}_{ij} = \begin{bmatrix}
w_{i_1 j_1} & w_{i_1 j_2} & \cdots & w_{i_1 j_{n_j}} \\
w_{i_2 j_2} & w_{i_2 j_2} & \cdots & w_{i_2 j_{n_j}} \\
\vdots & \vdots & \ddots & \vdots \\
w_{i_{n_i} j_1} & w_{i_{n_i} j_2} & \cdots & w_{i_{n_i} j_{n_j}}
\end{bmatrix}
$$

After forming the supermatrix, the weighted supermatrix is derived by transforming all columns sum to unity exactly. This step is very much similar to the concept of the Markov chain in terms of ensuring that the sum of these probabilities of all states equals 1. Next, the weighted supermatrix is raised to limiting powers, such as (7) to get the global priority vector or called weights (Huang et al. 2005).

$$\lim_{\theta \to \infty} \boldsymbol{W}^{\theta}. \tag{7}$$

In addition, if the supermatrix has the effect of cyclicity, the limiting supermatrix is not the only one. There are two or more limiting supermatrices in this situation, and the Cesaro sum would need to be calculated to get the priority. The Cesaro sum is formulated as follows.

$$\boldsymbol{w} = \lim_{\psi \to \infty} \left(\frac{1}{\nu}\right) \sum_{j=1}^{\nu} \boldsymbol{W}_j^{\psi} \tag{8}$$

to calculate the average effect of the limiting supermatrix (i.e. the average priority weights can be shown by the vector $\boldsymbol{w}$) where $\boldsymbol{W}_j$ denotes the jth limiting supermatrix. Otherwise, the supermatrix would be raised to large powers to get the priority weights (Huang et al. 2005). The weights of the kth determinants derived by using the above ANP processes, namely ω_k, $k \in \{1, 2, \dots, n\}$, will be used as inputs for summing up the grey coefficients of the kth determinant in (12) in the following GRA analysis.

3.4 VIKOR

While solving a complex decision making problem by using an MCDM framework, the alternatives can be ranked and the best one can be selected based on the concept of compromise solution which was developed by Yu (1973) and Zeleny (1982). The compromise solution is a feasible solution, which is the closest to the ideal, and a compromise means an agreement established by mutual concessions (Opricovic and Tzeng 2003). A compromise solution for a problem with conflicting criteria can help the decision makers to reach a final decision (Opricovic and Tzeng 2003). The VIKOR method was introduced as one applicable technique to implement within MCDM (Opricovic 1998). In comparison to one of the most well known traditional compromise ranking method, TOPSIS, which determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Hwang and Yoon 1981; Yoon 1987), the VIKOR can the prohibit the problem of not considering the relative importance of these distances. Following, based on Opricovic and Tzeng (2003), the procedures for VIKOR are introduced as a basis for this hybrid MCDM framework. The VIKOR is applied here to derive the optimal alternative (strategy) with the shortest distance from the ideal solution.

Assume the alternatives can be denoted as $A_1, A_2, \dots, A_l, \dots, A_m$. The rating (performance score) of the jth criterion is denoted by f_{lj} for alternative A_l, w_j is the weight of the jth criterion, expressing the relative importance of the criteria, where $j = 1, 2, \dots, n$, and n is the number of criteria. The VIKOR method began with the following form of L_p*-metric*:

$$L_l^p = \left\{ \sum_{j=1}^{n} \left[w_j \left(|f_j^* - f_{lj}| \right) / \left(|f_j^* - f_j^-| \right) \right]^p \right\}^{1/p}$$

where $1 \le p \le \infty$; $l = 1, 2, \dots, m$; weight w_j is derived using the ANP according to the NRM based on the DEMATEL method. The VIKOR method also uses $L_l^{p=1}$ (as S_l) and

$L_l^{p=\infty}$ (as Q_l) to formulate the ranking measure (Opricovic 1998, Tzeng et al. 2002a, 2002b; Opricovic and Tzeng 2002, 2004, 2007; Tzeng et al. 2005; Ou Yang et al. 2009; Ho et al. 2011).

$$S_l = L_l^{p=1} = \sum_{j=1}^{n} \left[w_j \left(|f_j^* - f_{lj}| \right) / \left(|f_j^* - f_j^-| \right) \right],$$

$$Q_l = L_l^{p=\infty} = \max_j \left\{ w_j \left(|f_j^* - f_{lj}| \right) / \left(|f_j^* - f_j^-| \right) | j = 1, 2, \ldots, n \right\}.$$

The compromise solution $\min_l L_l^p$ will be chosen because its value is closest to the ideal/aspired level. In addition, when p is small, the group utility is emphasized (such as $p = 1$) and as p increases to $p = \infty$, the individual maximal regrets/gaps receive more importance, as shown by Yu (Yu 1973; Freimer and Yu 1976). Therefore, $\min_l S_l$ emphasizes the maximum group utility, whereas $\min_l Q_l$ emphasizes selecting the minimum of the maximum individual regrets.

Based on the above concepts, the compromise ranking algorithm VIKOR has the following steps.

Step 8: Normalize the original rating matrix. In this step, we determine the best f_j^* and the worst f_j^- values of all criterion functions, $j = 1, 2, \ldots, n$. Assuming the jth function represents a benefit: $f_j^* = \max_l f_{lj}$ (or setting an aspired level) and $f_j^- = \min_l f_{lj}$ (or setting a tolerable level). Alternatively, assuming the jth function represents a cost: $f_j^* = \min_l f_{lj}$ (or setting an aspired level) and $f_j^- = \max_l f_{lj}$ (or setting a tolerable level). Moreover, an original rating matrix is transformed into a normalized weight-rating matrix with the following formula:

$$r_{lj} = \left(|f_j^* - f_{lj}| \right) / \left(|f_j^* - f_j^-| \right).$$

Step 9: Compute the values S_l and $Q_l, l = 1, 2, \ldots, m$, using the relations $S_l = \sum_{j=1}^{n} w_j r_{lj}$ and $Q_l = \max_j \{ r_{lj} | j = 1, 2, \ldots, n \}$, where S_l and Q_l show the mean of group utility and maximal regret respectively. In the traditional VIKOR method, Q_l is represented as $\max_j \{ w_j r_{lj} | j = 1, 2, \ldots, n \}$, which implies group utility is more important than maximal regret. Since Q_l is only a part of S_l, S_l is unquestionably more than Q_l. Therefore, S_l is emphasized more than Q_l in the traditional VIKOR method. However, the maximal regret is also very important in practice and is usually taken into account in order to improve it. Therefore, in order to balance S_l and Q_l, $Q_l = \max_j \{ r_{lj} | j = 1, 2, \ldots, n \}$ is used instead of the traditional VIKOR Q_l.

Step 10: Compute the index values $R_l, l = 1, 2, \ldots, m$, using the relation $R_l = v(S_l - S^*)/(S^- - S^*) + (1 - v)(Q_l - Q^*)/(Q^- - Q^*)$, where $S^* = \min_l S_l$, $S^- = \max_l S_l$, $Q^* = \min_l Q_l$, $Q^- = \max_l Q_l$ (here, we can also set the best value to 0 and the worst value to 1) and $0 \le v \le 1$, where v is introduced as a weight for the strategy of maximum group utility, whereas $1 - v$ is the weight of the individual regret.

Step 11: Rank the alternatives, sorting by the value of S_l, Q_l and R_l, for $l = 1, 2, \ldots, m$, in decreasing order. Propose as a compromise the alternative ($A^{(1)}$) which is ranked first by the measure $\min\{R_l | l = 1, 2, \ldots, m\}$ if the following two conditions are satisfied: C1. Acceptable advantage: $R(A^{(2)}) - R(A^{(1)}) \ge 1/(m - 1)$, where $A^{(2)}$ is the alternative with second position in the ranking list by R; m is the number of alternatives. C2. Acceptable stability in decision making: Alternative $A^{(1)}$ must also be the best ranked by S_l or/and

Q_l, $l = 1, 2, \ldots, m$. A set of compromise solutions is proposed if one of the conditions is not satisfied. The set of compromise solutions consists of: (1) Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition C2 is not satisfied, (2) Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if condition C1 is not satisfied. $A^{(M)}$ is determined by the relation $R(A^{(M)}) - R(A^{(1)}) < 1/(m-1)$ for maximum M (the positions of these alternatives are close).

The compromise-ranking method (VIKOR method) determines the compromise solution; the obtained compromise solution is acceptable to the decision-makers because it provides a maximum group utility of the majority (represented by $\min S$), and a minimum individual maximal regret of the opponent (represented by $\min Q$).

3.5 Grey relational analysis

Since Deng (1982) proposed Grey theory, related models have been developed and applied to MCDM problems. Similar to fuzzy set theory, Grey theory is a feasible mathematical means that can be used to deal with systems analysis characterized by inadequate information. Fields covered by the Grey theory include systems analysis, data processing, modeling, prediction, decision-making, and control engineering (Deng 1985, 1988, 1989; Tzeng and Tasur 1994). Furthermore, for multiple criteria decision-making (MCDM) problems, GRA has advantages over traditional statistical correlation analysis. During the past decade, researches like the vendor selection problem by Haq and Kannan (2006), the innovation policy definition problem by Huang et al. (2007) have already demonstrated the feasibility of GRA in real world applications. In this research, the GRA will be introduced for deriving the strategies with the highest relationship (or closest relevancy) to the problems being faced by the global manufacturing and logistics system.

Following, we briefly review some relevant definitions and the calculation process for the Grey Relation Model. This research modified the definitions by Chiou and Tzeng (2001) and produced the definitions indicated below. GRA is used to determine the relationship between two sequences of stochastic data in a Grey system. The procedure bears some similarity to pattern recognition technology. One sequence of data is called the 'reference pattern' or 'reference sequence,' and the correlation between the other sequence and the reference sequence is to be identified (Tzeng and Tasur 1994; Deng 1986; Mon et al. 1995; Wu et al. 1996).

Definition 7 The relationship scale also may be designated into eleven levels, where the scores $0, 1, 2, \ldots, 10$ represent the range from 'no relationship' to 'very high relationship' between the specified determinant and the logistics/manufacturing strategy.

Definition 8 The initial relationship matrix $\boldsymbol{G}$ is an $m \times n$ matrix, where there are m strategies and n determinants, obtained by surveying the relationships, where g_{lk} is denoted as the relationship between the lth strategy and the kth determinant.

$$\boldsymbol{G} = \begin{bmatrix} g_{11} & \cdots & g_{1k} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ g_{l1} & \cdots & g_{lk} & \cdots & g_{ln} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mk} & \cdots & g_{mn} \end{bmatrix}$$

Definition 9 The normalized relationship matrix $\boldsymbol{X}$ can be obtained through (9) and (10).

$$p_k = 1/\max_{1\le l\le m} g_{lk},$$

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & \cdots & x_{1k} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{l1} & \cdots & x_{lk} & \cdots & x_{ln} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mk} & \cdots & x_{mn} \end{bmatrix} \tag{9}$$

$$\boldsymbol{X}_k = p_k \boldsymbol{G}_k. \tag{10}$$

Definition 10 Let $\boldsymbol{x}_0$ be the reference pattern with n entries (i.e. dependent variable): $\boldsymbol{x}_0 = (x_0(1), x_0(2), \dots, x_0(n))$ and $\boldsymbol{x}_l$, the matrix containing the normalized mapping information of each strategy to the determinant, be one of the m patterns with n entries to be compared with the $\boldsymbol{x}_0$ where $\boldsymbol{x}_l$ is written as: when $x_l = x_l(k)$, $k = 1, 2, \dots, n$ in (9) and (10), then $\boldsymbol{x}_l = (x_l(1), x_l(2), \dots, x_l(n))$, $1 \le l \le m$. The sequence $\boldsymbol{x}_l$ generally expresses the influencing factor of $\boldsymbol{x}_0$.

Definition 11 Let $\boldsymbol{X}$ be a normalized factor set of grey relations, $\boldsymbol{x}_0 \in \boldsymbol{X}$ the referential sequence, and $\boldsymbol{x}_l \in \boldsymbol{X}$ the comparative sequence; with $x_0(k)$ and $x_l(k)$ representing the numerals at point l for $\boldsymbol{x}_0$ and $\boldsymbol{x}_l$, respectively. If $\gamma(x_0(k), x_l(k))$ and $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l)$ are real numbers, and satisfy the grey axioms being defined in Deng (1986), then call $\gamma(x_0(k), x_l(k))$ the grey relation coefficient, and the grade of the grey relation $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l)$ is the average value of $\gamma(x_0(k), x_l(k))$. Deng also proposed a mathematical equation for the grey relation coefficient, as follows:

$$\gamma(x_0(k), x_l(k)) = \frac{\{\min_{\forall l}\min_{\forall k}|(x_0(k) - x_l(k))| + \zeta \max_{\forall l}\max_{\forall k}|(x_0(k) - x_l(k))|\}}{\{|(x_0(k) - x_l(k))| + \zeta \max_{\forall l}\max_{\forall k}|(x_0(k) - x_l(k))|)\}} \tag{11}$$

where ζ is the distinguished coefficient ($\zeta \in [0, 1]$). Generally, we pick $\zeta = 0.5$.

Definition 12 If $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l)$ satisfies the four grey relation axioms, then γ is called the Grey Relational Map.

Definition 13 If Γ is the entirety of the grey relational map, $\gamma \in \Gamma$ satisfies the four axioms of the grey relation, and X is the factor set of the grey relation, then $(\boldsymbol{X}, \Gamma)$ will be called the grey relational space, while γ is the specific map for I'.

Definition 14 Let $(\boldsymbol{X}, \Gamma)$ be the grey relational space, and if $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_j)$, $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_p), \dots,$ $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_q)$ satisfy $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_j) > \gamma(\boldsymbol{x}_0, \boldsymbol{x}_p) > \cdots > \gamma(\boldsymbol{x}_0, \boldsymbol{x}_q)$ then we have the grey relational order: $\boldsymbol{x}_j \succ \boldsymbol{x}_p \succ \cdots \succ \boldsymbol{x}_q$. When the grey relational coefficient is conducted with respect to innovation policies, we then can derive the grade of the grey relation $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l)$ between the reference alternative

$$\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l) = \sum_{k=1}^{n} \omega_k \times \gamma(x_0(k), x_l(k)), \tag{12}$$

where k is the number of determinants, ω_k expresses the weight of the kth determinants, and $\gamma(\boldsymbol{x}_0, \boldsymbol{x}_l)$ represents the grade of grey relation in x_l (the lth manufacturing or logistics strategy) correspondence to x_0. In this study, we make the order of the strategies following the grade of grey relation.

The model uses the DEMATEL and ANP procedures in Sects. 3.2 and 3.3 to obtain the weights of criteria with dependence and feedback and uses the VIKOR method being introduced in Sect. 3.4 to obtain the compromise solution. Finally, the GRA being introduced in Sect. 3.5 is introduced to find the most suitable strategies with the highest correlation to the gap existing between the current status and the aspired level of each criterion.

4 A case study of an aspired global semiconductor manufacturing and logistics system definition

For several decades, the semiconductor industry has been making significant adjustments to adapt to globalization, providing an instructive example for other industries contemplating full-scale globalization (Velosa 2005). Although semiconductor design activities are concentrated in specific regions of the United States (including such areas as Silicon Valley, CA; Austin, Texas and northwest Oregon), as well as in Taiwan, semiconductor manufacturing is more widely dispersed (Macher et al. 2002).

In this section, an example being modified from a real case will be presented for demonstrating effectiveness of the proposed novel MCDM framework with DEMATEL technique. One empirical study example will be based on an example being modified from a leading semiconductor IDM vendor with manufacturing fabs or foundry partners being located in Taiwan (Fab T), U.S. (Fab U), Singapore (Fab S), Japan (Fab J) as well as China (Fab C). Furthermore, testing houses being located in Taiwan (Testing House T), Singapore (Testing House Sg), China (Testing House SZ) as well as Italy (Testing House I) are providing integrated circuit back end testing services to this IDM. While the semiconductor IDM vendor is going to fulfill customers all over the world, decisions regarding to which manufacturing fab for the front end wafer processing can be selected under considerations of manufacturing capabilities of some specified fab should be made. Afterward, which third party testing house can be leveraged for providing the backend testing services with the highest quality and the lowest cost should also be selected. Finally, how to select a fab and testing house combination so that the logistics system can fulfill customers' needs should also be considered.

In this case study, three combinations, Fab J and Testing House Sg (named as global manufacturing and logistics system 1, GMLS1), Fab T and Testing House T (named as GMLS2) as well as Fab C and Testing House S (named as GMLS3) will be considered for providing some specified integrated circuits (ICs) for fulfilling a U.S. based telecommunication company's needs. The U.S. based telecommunication company's plant is located in Mexico.

Based on the analytical frame for expanding them, determinants first were selected by using the Delphi. Then, the structure of the global manufacturing as well as logistics strategy definition problem was established by DEMATEL. After that, the weights of each determinant for the decision structure will be decided by using the ANP. The determinants for selecting an appropriate strategy were introduced based on literature review results. The criteria were confirmed as suitable for serving as determinants for a global manufacturing and logistics system by using the second round Delphi. Meanwhile, the relationships between the determinants of the global manufacturing and logistics system and the ANP derivations of the weights of each determinant of the global manufacturing and logistics system also will be derived for the case study. The determinants for the global manufacturing and logistics system were surveyed based on the opinions of experts who are working/have worked in the semiconductor industry. The experts are familiar with the semiconductor IDMs in all aspects, including engineering, marketing, sales, design service capabilities as well as their competitive situation. Meanwhile, the determinants of the world's best global manufacturing and logistics system will be surveyed based on the experts' opinions as the benchmark.

With the understanding of the determinants of the global manufacturing and logistics system, appropriate global manufacturing and logistics strategies will also be proposed by the experts to shorten the gap between the current level of the selected global manufacturing and logistics system and the hoped-for levels of the determinants. Meanwhile, the proposed global manufacturing and logistics strategies will assist the semiconductor IDM to surpass the industry leaders.

After the introduction of appropriate global manufacturing and logistics strategies, the new determinants of the specified semiconductor IDM will be evaluated again by the experts. The global manufacturing and logistics system's total manufacturing and logistics capabilities before the introductions of the suggested manufacturing and logistics strategies hen will be calculated and benchmarked by using the evaluation results and the weights of each determinant. Detailed procedures and results are illustrated below.

4.1 Decision structure derivations by delphi

Production refers to activities involved in creating a product. Logistics refers to the procurement and physical transmission of material through the supply chain, from suppliers to customers. The objective for establishing of an aspired intelligent global manufacturing and logistics systems is to lower the costs of value creation and add value by better serving customer needs (Hill 2008). Based on literature review results, fifteen determinants that are needed for selecting an intelligent global manufacturing and logistics system are reviewed based on the concepts of Porter (1985) and the framework by Fawcett (1992). Furthermore, literatures mainly being published during the past decade were selected for clarifying the definitions as well as importance of the criteria being mentioned in the framework by Fawcett. Three senior experts (including an engineering vice president of a design service company, a sales vice president from a design service company, and an engineering manager from a semiconductor foundry) with more than fifteen years of work experiences from the Taiwanese semiconductor industry as well as two management professors being familiar with the semiconductor industry are invited for reviewing the criteria based on the Delphi process being introduced in Sect. 3.1. Based on the experts' opinions, They are: (1) Documentation management and control; (2) inventory management and control; (3) order processing; (4) packaging; (5) sourcing; (6) trade barriers; (7) transportation; (8) warehousing; (9) labor cost; (10) machine utilization; (11) maintenance; (12) production control; (13) productivity; (14) quality/quality control and (15) training. Following, the determinants are introduced further as a basis of this case study.

(1) Documentation management and control: Documentation management and control is the discipline of creating and managing the documents used in a project. The primary objective of this discipline is to ensure that documents are created, stored, changed,

used, and disposed of systematically and scientifically (Leon 2005). While selecting a semiconductor foundry, its documentation management and control capability is essential for quality assurance.

(2) Inventory management: The need for efficient management of available resources in any business organization requires no emphasis as every industrial undertaking is expected to be run efficiently (Bose 2006).

(3) Order processing: Order processing is strictly related to information flows in the logistics system and includes a number and includes a number of operations (Ghiani et al. 2004).

(4) Packaging: Logistical or industrial packaging is a critical element in the physical distribution of the product, which influences the efficiency of the logistical system (Scople 2007).

(5) Sourcing: Sourcing is the process of identifying the suppliers for the items required by an organization (Gupta and Valarmathi 2009). Global sourcing and supply is probably both the biggest economic trend of the last 20 years and a key ingredient for corporate survival; it takes advantage of low-cost and available labour, cheap international logistics (Waters 2007). From a logistics point of view, strategic sourcing strategies have significant impact on logistics functions (Goldsby and Martichenko 2003).

(6) Trade barriers: According to Bowersox and Closs (1996), while many forces facilitate borderless operations, some significant barriers continue to impede global logistics. Three barriers are significant: markets and competition, financial barriers, and distribution channels. Global logistics management must balance the cost of overcoming these barriers with the potential benefits of international trade to achieve the actual benefits of successful international operations (Bowersox and Closs 1996).

(7) Transportation: Transportation is a necessary activity within logistics which is fundamental to allow us to make product in one place and consume it in another, closing the distance of geographic separation (Goldsby and Martichenko 2003).

(8) Warehousing: Like transportation, warehousing has played a central part in the development of commerce and trade among distant locations (Goldsby and Martichenko 2003).

(9) Labor cost: Direct labor cost contains operator cost directly related to manufacturing a component or product (Lembersky and Lembersky 2005). Riveros (1988) has compared labor cost levels and international labor cost differentials, thus concluding that even after standardizing by productivity, there are important cost differentials between industrial and developing countries which would possibly be associated to the observed trends in less developed countries' manufactured exports (Riveros 1989). Companies attempted to reduce their costs by outsourcing to lower cost (frequently overseas) suppliers much of their internal production, particularly items with high direct labor content which the cost accounting system reported as expensive to produce internally (Brinker 1994).

(10) Machine utilization: Machine utilization is a measurement of how effective a machine is operated or used (Pang 2004). Machine utilization and labor cost are traditional efficiency measures (Brinker 1994) which can be used to evaluate the efficiency of the manufacturing systems.

(11) Maintenance: Maintenance of equipment is required to keep the equipment in a full operational mode. Proactive preventive maintenance not only uses maintenance resources more efficiently, but also improves manufacturing efficiency by avoiding unanticipated shutdowns (Clark 2008).

(12) Production control: Any production process is an input-output system. There are sets of resources such as raw materials, personnel, and machines which are called inputs. These resources are transformed through a series of operations into outputs. The outputs are such things as labor from the personnel, work from the machines, and finished products from the materials. The management of these transformation processes is called production management (Voris 1966).

(13) Productivity: Productivity is the relationship between the output generated by a production or service system and the input provided to create this output (Prokopenko 1987).

(14) Quality/Quality Control: Manufacturing quality control involves monitoring the quality measures of products. When anomalous values are observed, process engineers analyze the data, identify the cause of the anomaly and modify the production process to eradicate it (Maki and Teranishi 2001).

(15) Training: Training has the role of assisting employees to develop a skill set which would allow them to exercise their acquired knowledge in the application of this topic (DIANE Publishing Company 2004).

4.2 Decision problem network relation map structuring by DEMATEL

Since the inter-relationships between the fifteen determinants being summarized through above Delphi process seem too complicated to be analyzed, the decision problem structure will be deducted with the DEMATEL method introduced in Sect. 3.2 (Fig. 7). At first, the direct relation/influence matrix ***A*** is introduced. After that, the direct relation/influence matrix ***A*** is normalized based on (1). Finally, the total relationship matrix ***T*** is deducted based on (3). Here, the major relationships were deducted by setting the threshold value as 0.0879 from both the statistical and natural language aspects so as to derive the most important linkages between determinants (or criteria). The total relationships being derived will serve as references for calculating weights between determinants in the following ANP processes. Please see the next Section for further discussion on the rationality for threshold value defi-

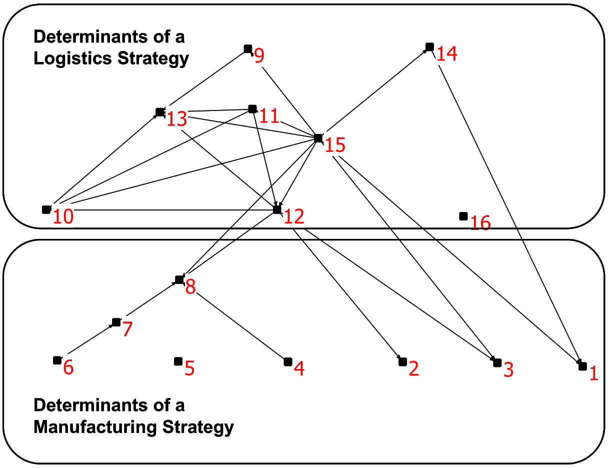

Fig. 7 The causal diagram of total relationship. Remark: 1. Threshold = 0.0879. 2. The number represents the determinant with the same index number being introduced in Sect. 4.1

nitions based on statistics

$$
\boldsymbol{A}=\begin{bmatrix}
0.000 & 1.000 & 5.000 & 1.000 & 6.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 5.000 & 4.000\\
1.000 & 0.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 5.000 & 1.000 & 1.000 & 1.000 & 5.000 & 2.000 & 1.000 & 1.000\\
5.000 & 5.000 & 0.000 & 1.000 & 1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000\\
1.000 & 1.000 & 1.000 & 0.000 & 1.000 & 1.000 & 6.000 & 9.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000\\
1.000 & 1.000 & 2.000 & 1.000 & 0.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 4.000 & 1.000\\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.000 & 8.000 & 2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000\\
1.000 & 5.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.000 & 8.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000\\
1.000 & 5.000 & 1.000 & 1.000 & 1.000 & 1.000 & 5.000 & 0.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 3.000\\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 5.000 & 1.000 & 1.000 & 0.000 & 1.000 & 5.000 & 1.000 & 9.000 & 1.000 & 5.000\\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.000 & 3.000 & 3.000 & 9.000 & 1.000 & 2.000\\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 10.000 & 0.000 & 10.000 & 10.000 & 5.000 & 2.000\\
1.000 & 8.000 & 9.000 & 1.000 & 1.000 & 1.000 & 1.000 & 9.000 & 1.000 & 10.000 & 3.000 & 0.000 & 10.000 & 1.000 & 1.000\\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.000 & 1.000 & 1.000\\
10.000 & 1.000 & 5.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.000 & 1.000\\
10.000 & 1.000 & 10.000 & 1.000 & 1.000 & 1.000 & 1.000 & 10.000 & 10.000 & 10.000 & 10.000 & 10.000 & 10.000 & 10.000 & 0.000
\end{bmatrix}
$$

$$
\boldsymbol{T}=\begin{bmatrix}
0.019 & 0.025 & 0.070 & 0.017 & 0.069 & 0.017 & 0.020 & 0.029 & 0.021 & 0.027 & 0.023 & 0.036 & 0.032 & 0.067 & 0.050\\
0.020 & 0.014 & 0.024 & 0.015 & 0.016 & 0.016 & 0.020 & 0.068 & 0.017 & 0.025 & 0.019 & 0.063 & 0.038 & 0.019 & 0.018\\
0.061 & 0.062 & 0.011 & 0.015 & 0.018 & 0.016 & 0.018 & 0.034 & 0.017 & 0.021 & 0.018 & 0.023 & 0.025 & 0.021 & 0.019\\
0.020 & 0.027 & 0.021 & 0.005 & 0.017 & 0.016 & 0.073 & 0.110 & 0.017 & 0.021 & 0.019 & 0.023 & 0.025 & 0.020 & 0.020\\
0.022 & 0.020 & 0.030 & 0.014 & 0.005 & 0.015 & 0.017 & 0.022 & 0.016 & 0.019 & 0.017 & 0.020 & 0.043 & 0.048 & 0.017\\
0.019 & 0.023 & 0.020 & 0.015 & 0.016 & 0.005 & 0.090 & 0.037 & 0.016 & 0.020 & 0.018 & 0.020 & 0.024 & 0.018 & 0.017\\
0.020 & 0.065 & 0.021 & 0.015 & 0.016 & 0.016 & 0.010 & 0.097 & 0.017 & 0.021 & 0.019 & 0.024 & 0.025 & 0.019 & 0.019\\
0.023 & 0.066 & 0.025 & 0.016 & 0.017 & 0.017 & 0.060 & 0.022 & 0.019 & 0.026 & 0.022 & 0.046 & 0.030 & 0.022 & 0.039\\
0.027 & 0.025 & 0.028 & 0.017 & 0.019 & 0.059 & 0.024 & 0.032 & 0.012 & 0.032 & 0.066 & 0.032 & 0.119 & 0.027 & 0.062\\
0.022 & 0.044 & 0.025 & 0.016 & 0.017 & 0.017 & 0.019 & 0.028 & 0.019 & 0.016 & 0.042 & 0.046 & 0.114 & 0.022 & 0.029\\
0.031 & 0.058 & 0.038 & 0.020 & 0.021 & 0.021 & 0.025 & 0.061 & 0.023 & 0.129 & 0.018 & 0.124 & 0.143 & 0.067 & 0.034\\
0.030 & 0.109 & 0.111 & 0.020 & 0.022 & 0.021 & 0.028 & 0.119 & 0.023 & 0.123 & 0.048 & 0.026 & 0.136 & 0.027 & 0.026\\
0.017 & 0.018 & 0.018 & 0.014 & 0.014 & 0.014 & 0.016 & 0.020 & 0.015 & 0.018 & 0.016 & 0.018 & 0.011 & 0.017 & 0.015\\
0.115 & 0.023 & 0.067 & 0.016 & 0.022 & 0.016 & 0.019 & 0.024 & 0.018 & 0.022 & 0.019 & 0.022 & 0.025 & 0.013 & 0.021\\
0.142 & 0.058 & 0.147 & 0.027 & 0.035 & 0.033 & 0.037 & 0.147 & 0.123 & 0.150 & 0.135 & 0.146 & 0.173 & 0.136 & 0.032
\end{bmatrix}
$$

4.3 Calculating the weights of determinants by ANP

By setting an appropriate global manufacturing and logistics system as the goal, pair wise comparisons of the determinants were executed based on experts' opinions. The interrelationships between the Goal, the determinants of a global manufacturing strategy component, and the determinants of a global logistics strategy component are illustrated in Fig. 8 where the directions of arrows mean the directions of influences. Finally, the pair wise comparison results and the decision problem structure serve as inputs for the ANP. With the aid of the Super Decisions (Creative Decisions Foundation, 2006), a software which is used for decision-making with dependence and feedback by implementing the ANP, the limit super matrix $\boldsymbol{W}$ is calculated as below. Weights corresponding to each determinant (Table 1) are

Table 1 Weights of the determinants being derived by ANP

Determinant	1	2	3	4	5	6	7	
Weights	2.06%	2.06%	2.88%	2.83%	3.69%	8.46%	4.35%	
Determinant	8	9	10	11	12	13	14	15
Weights	3.69%	4.16%	4.16%	10.92%	10.13%	3.45%	4.53%	32.66%

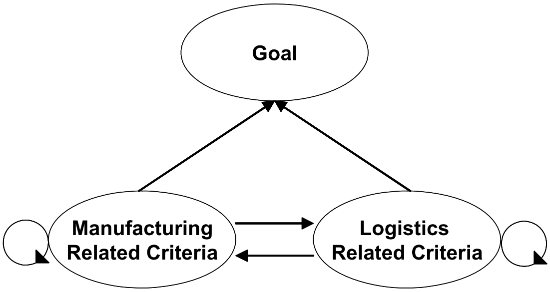

Fig. 8 The analytic network based on the casual diagram of total relationships

derived accordingly which will be used for calculations of weighted averages and VIKOR scores

$$\boldsymbol{W}=\begin{bmatrix}
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.123&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&1.000&0.173&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.173&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.097&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.097&0.000&0.000\\
0.000&0.208&0.154&0.000&0.000&0.000&0.000&0.082&0.000&0.281&0.000&0.345&0.199&0.000&0.000\\
0.000&0.396&0.292&0.000&0.000&0.000&0.000&0.155&0.000&0.184&0.000&0.000&0.131&0.000&0.000\\
0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.345&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000&0.000\\
0.655&0.396&0.555&0.000&0.000&0.000&0.000&0.295&1.000&0.535&1.000&0.655&0.476&1.000&0.000
\end{bmatrix}$$

4.4 Compromise ranking by VIKOR

The three combinations of fabs and testing houses were evaluated based on the 15 determinants (See Table 2). The VIKOR technique being introduced for compromise ranking was applied after determinants' weight calculations by ANP in Sect. 4.3. Meanwhile, weighted averages as well as the compromise ranking by TOPSIS of the three global manufacturing and logistics systems are calculated also as comparisons. Calculation results (Table 3) demonstrated that both VIKOR and ANP reached same conclusions, GMLS 1 $\succ$ GMLS 2 $\succ$ GMLS 3, which implies that the global manufacturing and logistics system consisting of the Fab J and Testing House Sg (or GMLS1) is better than the other two systems either consisting of Fab T and Testing House T or Fab C and Testing House S. This VIKOR based selection of an alternative can be adopted by the IDM as its globalization strategy. Furthermore, the results being ranked by TOPSIS show that GMLS2 $\succ$ GMLS1 $\succ$ GMLS3, which demonstrate that the ranking being derived by VIKOR is really different to the one being derived by TOPSIS.

4.5 Strategies definitions for achieving aspired levels by GRA

The most appropriate global manufacturing and logistics system, GMLS1, was selected in Sect. 4.4. Albeit it was selected based on the hybrid MCDM framework with DEMATEL

Table 2 Evaluation of the three alternatives based on fifteen determinants

Determinants	GMLS1	GMLS2	GMLS3	Weights
1	8	8	7	2.06%
2	8	7	6	2.06%
3	7	7	8	2.88%
4	9	9	6	2.83%
5	8	8	9	3.69%
6	6	6	10	8.46%
7	6	6	10	4.35%
8	10	10	6	3.69%
9	5	5	9	4.16%
10	10	10	7	4.16%
11	10	10	6	10.92%
12	10	10	3	10.13%
13	9	9	5	3.45%
14	10	10	4	4.53%
15	10	10	3	32.66%

Table 3 VIKOR versus weighted average results

Determinants	1	2	3	4	5	6	7	8	9
GMLS1	0.16	0.16	0.20	0.25	0.29	0.76	0.39	0.37	0.21
GMLS2	0.16	0.14	0.20	0.25	0.29	0.76	0.39	0.37	0.21
GMLS3	0.14	0.12	0.23	0.17	0.33	0.85	0.44	0.22	0.37

Determinants	10	11	12	13	14	15	Avg.	VIKOR	TOPSIS
GMLS1	0.42	1.09	1.01	0.31	0.45	3.27	9.36	1.00	0.358
GMLS2	0.42	1.09	1.01	0.31	0.45	3.27	9.34	0.99	0.361
GMLS3	0.29	0.66	0.30	0.17	0.18	0.98	5.46	0.00	0.342

technique, possible manufacturing and logistics strategies should still be considered to check whether the current global manufacturing and logistics system can be enhanced. The system should be enhanced further to achieve the aspired level and avoid the ‘rotten apple to rotten apple’ comparisons, which was usually seen in some MCDM-based researches.

The manufacturing strategies being reviewed in Sect. 2.1 including (1) manufacturing resource planning, (2) optimized production technology, (3) flexible manufacturing system, (4) group technology, (5) total quality management, (6) just-in-time, (7) lean production and (8) concurrent engineering as well as logistics strategies being reviewed in Sect. 2.2 including general logistics strategies include (1) cost reduction, (2) service quality enhancement, (3) support for innovation, (4) source/motor for alliance, (5) support for new profession integration, (6) support for extension as well as (7) use of logistics synergies will be introduced to enhance the selected manufacturing strategy.

The GRA was used so as to derive the relationships between determinants and manufacturing strategies as well as determinants and logistics strategies, respectively. Based on the

GRA definitions being introduced in Sect. 3.5, the initial relationship matrix for deriving logistics strategy, $\boldsymbol{G}_1$, is a 7×15 matrix, where there are 7 strategies and 15 determinants, obtained by surveying the relationships, The normalized relationship matrix $\boldsymbol{X}_1$ can be obtained through (9) and (10). The grey relation coefficients can be calculated by using (11) as well as the weights versus each determinant being derived by ANP (Table 1). Finally, the grades of the grey relation versus each logistics strategy can be derived based on (12) and are demonstrated in the left hand side of Table 4. The grades versus each manufacturing strategy can also be calculated following the same process while the initial relationship matrix for deriving logistics strategy, $\boldsymbol{G}_2$, the normalized relationship matrix $\boldsymbol{X}_2$ are demonstrated below and the grades of the grey relation versus each manufacturing are demonstrated in the right hand side of Table 4.

$$\boldsymbol{G}_1 = \begin{bmatrix}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 10.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 10.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 10.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 5.000 & 5.000 & 5.000 & 5.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 10.000 & 1.000 & 8.000 & 1.000 & 1.000 & 5.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 8.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 5.000 & 1.000 & 1.000 & 5.000 & 1.000 & 10.000 & 10.000 & 1.000 & 1.000 & 1.000 & 5.000 & 5.000 & 1.000 & 1.000
\end{bmatrix}$$

$$\boldsymbol{X}_1 = \begin{bmatrix}
1.000 & 0.200 & 0.100 & 1.000 & 0.100 & 1.000 & 0.100 & 0.100 & 1.000 & 0.125 & 0.200 & 0.200 & 0.200 & 0.100 & 1.000 \\
1.000 & 0.200 & 1.000 & 1.000 & 0.100 & 1.000 & 0.100 & 0.100 & 0.100 & 0.125 & 0.200 & 0.200 & 0.200 & 1.000 & 1.000 \\
1.000 & 0.200 & 0.100 & 1.000 & 0.100 & 1.000 & 0.100 & 0.100 & 0.100 & 0.625 & 1.000 & 1.000 & 1.000 & 0.100 & 1.000 \\
1.000 & 0.200 & 0.100 & 1.000 & 1.000 & 1.000 & 0.800 & 0.100 & 0.100 & 0.625 & 0.200 & 0.200 & 0.200 & 0.100 & 1.000 \\
1.000 & 0.200 & 0.100 & 1.000 & 0.100 & 1.000 & 0.100 & 0.100 & 0.100 & 0.125 & 0.200 & 0.200 & 0.200 & 0.100 & 1.000 \\
1.000 & 0.200 & 0.100 & 1.000 & 0.100 & 1.000 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.200 & 0.200 & 0.100 & 1.000 \\
1.000 & 1.000 & 0.100 & 1.000 & 0.500 & 1.000 & 1.000 & 1.000 & 0.100 & 0.125 & 0.200 & 1.000 & 1.000 & 0.100 & 1.000
\end{bmatrix}$$

$$\boldsymbol{G}_2 = \begin{bmatrix}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 5.000 & 10.000 & 1.000 & 10.000 & 10.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 8.000 & 10.000 & 1.000 & 1.000 & 10.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 8.000 & 1.000 & 1.000 & 8.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
10.000 & 3.000 & 5.000 & 10.000 & 3.000 & 1.000 & 1.000 & 5.000 & 5.000 & 1.000 & 5.000 & 1.000 & 1.000 & 10.000 & 1.000 \\
1.000 & 10.000 & 10.000 & 1.000 & 10.000 & 1.000 & 5.000 & 10.000 & 8.000 & 10.000 & 1.000 & 10.000 & 5.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000
\end{bmatrix}$$

Table 4 Manufacturing and logistics strategies for achieving aspired levels by using GRA

Rank	Logistics strategy	Grey grade	Rank	Manufacturing strategy	Grey grade
5	Cost reduction	0.675	3	Manufacturing resource planning	0.739
3	Service quality enhancement	0.697	4	Optimized production technology	0.690
1	Support for innovation	0.813	5	Flexible manufacturing system	0.639
4	Source/motor for alliance	0.696	6	Group technology	0.612
7	Support for new profession integration	0.647	2	Total quality management	0.765
6	Support for extension	0.675	1	Just-in-time	0.849
2	Use of logistics synergies	0.806	6	Lean production	0.612
			6	Concurrent engineering	0.612

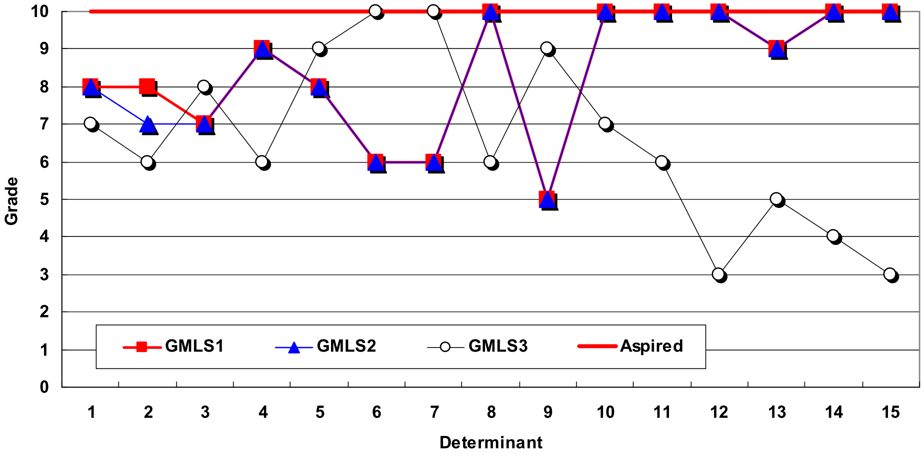

Fig. 9 Evaluation of determinants before/after introducing appropriate strategies

$$X_2 = \begin{bmatrix} 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 0.625 & 1.000 & 0.200 & 1.000 & 1.000 & 0.100 & 1.000 \\ 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 1.000 & 1.000 & 0.200 & 0.100 & 1.000 & 0.100 & 1.000 \\ 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 0.125 & 0.800 & 0.200 & 0.100 & 0.800 & 0.100 & 1.000 \\ 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 0.125 & 0.100 & 0.200 & 0.100 & 0.100 & 0.100 & 1.000 \\ 1.000 & 0.300 & 0.500 & 1.000 & 0.300 & 1.000 & 0.200 & 0.500 & 0.625 & 0.100 & 1.000 & 0.100 & 0.100 & 1.000 & 1.000 \\ 0.100 & 1.000 & 1.000 & 0.100 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.200 & 1.000 & 0.500 & 0.100 & 1.000 \\ 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 0.125 & 0.100 & 0.200 & 0.100 & 0.100 & 0.100 & 1.000 \\ 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 1.000 & 0.200 & 0.100 & 0.125 & 0.100 & 0.200 & 0.100 & 0.100 & 0.100 & 1.000 \end{bmatrix}$$

Based on GRA results, support for innovation as well as use of logistics synergies will be the best strategies for achieving the aspired levels of determinants while just-in time, total quality management and manufacturing resource planning will be the best manufacturing strategies which are most suitable for enhancing the current global manufacturing and logistics system and achieve the aspired levels of determinants.

The experts surveyed again for confirming whether the global manufacturing and logistics system. The experts agreed that the manufacturing and logistics capabilities will achieve the aspired level (Fig. 9) after introducing the above derived strategies.

5 Discussions

Designing a global manufacturing as well as logistics strategy is not an easy task. Meanwhile, there are no straightforward answers addressing how a global manufacturing strategy should be designed to fit any business context (Warner 1996). Not to mention how a manufacturing strategy should be designed by considering factors being related to global logistics. Meanwhile, from the aspect of MCDM (multiple criteria decision making), very few researches addressed this global manufacturing and logistics system design issue. In this research, a novel MCDM framework combing the Delphi, DEMATEL technique, ANP, GRA as well as VIKOR was proposed to address the above mentioned problems and reached satisfactory results.

The novel MCDM model consisting of Delphi, DEMATEL, ANP, VIKOR and GRA was designed to overcome (1) the global manufacturing and logistics strategy definition issue, (2) traditional MCDM approaches for resolving the global manufacturing and logistics

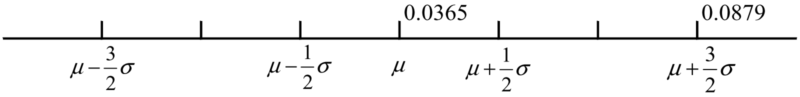

Fig. 10 Definition of the threshold value

strategy definition problem based on the wrong assumptions on the independences between the determinants, (3) the vague correlations between determinants and manufacturing as well as logistics strategies, and (4) the lack of priorities of the manufacturing as well as logistics strategies. Meanwhile, (5) the concept of VIKOR which can be used to derive the optimal strategy which is closest to the ideals solution; and (6) the concept of GRA can be used to derive the solution with the highest relevancy to overcoming the gap between the current state and the aspired level of the manufacturing system. Furthermore, through the case study, we found the hybrid MCDM model to be applicable. In comparison to existing MCDM methods (e.g. Stummer et al. 2009; Koksalan and Tuncer 2009; Peng et al. 2008), this hybrid MCDM method based approach provides another feasible and rationale way of dealing with MCDM problems.

The DEMATEL was introduced in this paper so as to structuring the decision problem. As mentioned in Sect. 4.1, the threshold value was set at 0.087, which is just below the average value (μ, 0.0365) of all the items in the total relationship matrix $\boldsymbol{T}$, 0.0365, plus $3/2$ times of the standard deviation (σ, 0.0343), or 0.0879. Also, from the aspect of natural language, if the opinions of human beings' can be divided into five intervals, very important, important, fair, un-important, not important at all, their corresponding values can be interpreted by the statistics, $\mu+\frac{3}{2}\sigma$, $\mu+\frac{1}{2}\sigma$, μ, $\mu-\frac{1}{2}\sigma$, $\mu-\frac{3}{2}\sigma$ (Please refer to Fig. 10).

Compared with to the traditional Analytic Hierarchy Process (AHP) which has the limitation of a linear hierarchic structure that assumes the independence on of upper levels from lower levels, ANP provides a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower level elements and about the independence of the elements within a level as in a typical hierarchy (Saaty 2005). Thus, for the global manufacturing and logistics system and strategies definition case illustrated in the paper, ANP is apparently a more reasonable tool for analyzing the network structure with feedbacks. Meanwhile, by leveraging the ANP, the most important criteria can be selected. Furthermore, in comparison with most ANP based researches without an appropriate approach for the decision problem structure definition, the DEMATEL based approach provides a reasonable and better alternative for structuring the decision problem structure based on experts' opinions,

The VIKOR method uses an aggregating function Q, representing "closeness to the ideal". In comparison with the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), which determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Chen and Hwang 1992; Tzeng et al. 1994), VIKOR can select the real "closest to idea" solution. On the other hand, a solution by TOPSIS is not always the closest to the ideal. A detailed comparison of TOPSIS and VIKOR has already been presented in the article by Opricovic and Tzeng (Opricovic and Tzeng 2002, 2004, 2007; Tzeng et al. 2005). Meanwhile, based on the empirical study results, the compromise ranking by VIKOR differs from the ranking being derived by TOPSIS. This difference implies that introducing VIKOR in this Hybrid MCDM framework really makes sense.

For problems to be solved by MCDM problems models, the GRA has advantages over traditional statistical correlation analysis in that GRA is not constrained by the sample numbers while the total number of samples should be over thirty for traditional statistical relational analysis. Meanwhile, the weights for criteria can be introduced during the process when calculating the grade in the GRA. Finally, the GRA derives the grade of grey relation between criteria (determinants) and alternatives (global manufacturing and logistics strategies) while statistical relational analysis derives the pairwise correlational coefficients only. In GRA, the minimum and maximum concepts are introduced and the reference point can be set for calculating the grades, namely the distances between the variable and the reference point, while statistical correlational analysis calculates the sum of the products of two standardized values ($z_i = (x_{ij} - \bar{x}_i)/s_i; i = 1, 2, \ldots, p$) summations of the of two variables only. Apparently, the GRA serves as an effective tool for analyzing the correlation between global manufacturing and logistics strategies and determinants, especially particularly when the available experts in some specific fields of emerging technologies and business models are limited. Thus, this procedure which provides a solution for addressing the need for defining the strategies with clear steps is more appropriate for the real-world strategy definition problems.

By summarizing the rationality of the MCDM methods being introduced in the research, apparently, the Delphi, DEMATEL, ANP, VIKOR and GRA based hybrid MCDM method can overcome following problems of a single traditional MCDM method or a combination of some methods being included: (1) the assumption of decision problem structure for the ANP without significant supports; (2) the assumption of independences between criteria; (3) a lack of an appropriate method for correlating multiple criteria with multiple strategies as a portfolio; (4) the compromise solution by TOPSIS which is not the always closest to the ideal one.

For traditional MCDM researches, alternatives being proposed in the researches could be inappropriate at all. However, a terrible alternative was usually selected and proposed. Such “rotten apple versus rotten apple” situation was also resolved by introducing GRA for selecting strategies for achieving the aspired levels.

6 Concluding remarks

This paper mainly advanced the field of global manufacturing and logistics system design perspectives. First, a novel MCDM framework has been proposed for defining a global manufacturing and logistics system which has been verified as effective through verification by an industry expert. Second, the traditional hard-to-define manufacturing strategy problem was resolved based on the novel MCDM approach being proposed. Third, the traditional MCDM approach which may stuck in selecting “rotten apple(s)” was also resolved based on the conceptual advance for achieving aspired level of criteria. Finally, the proposed analytic framework can be leveraged for resolving global logistics and manufacturing problems as well as other MCDM-nature problems.

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