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A hybrid fuzzy-based approach for identifying global logistics strategies

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Abstract

This paper presents a hybrid fuzzy-based method that integrates fuzzy-AHP and fuzzy-MADM approaches for identifying global logistics (GL) strategies when corresponding supply and demand environments are complicated and uncertain. Before applying the methodology, six typical types of GL strategic modes were specified with their distinctive channels of physical distribution and information flows. Survey data collected from integrated circuit (IC) manufacturers in Taiwan was used to demonstrate the applicability of the proposed method. The empirical results indicate that the proposed method can be used to identify GL strategies when the factors that influence GL are complex and uncertain.

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1. Introduction

The competitiveness and complexity faced by globalized high-technology firms have led them to recognize the necessity of employing suitable global logistics strategies for survival and to satisfy the growing demands from their international customers. Herein, global logistics (GL) is regarded as the extension of domestic business logistics in the geographic domain, as some of corresponding logistics functions, e.g., physical distribution and inventory, are executed overseas. Similar definition can also be found elsewhere (Bowersox and Closs, 1996; Dornier et al., 1998c), where GL is termed a form of geographically integrated logistics.

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Compared to domestic logistics strategies, global logistics strategies are more complex and difficult to develop for several reasons. In an international scenario, information and cash flows are more difficult to coordinate than in a single-country environment. This can be seen in that global logistics strategies must consider factors including different exchange rates, trade barriers, transfer prices, and labor resources. On the other hand, the globalization of logistical activities makes business operations increasingly complex because of growing sources of uncertainty such as greater shipment distance, longer lead time, and global market complexity, relative to domestic logistics. Clearly, these factors are very difficult to include in mathematical models, such as mixed integer programming models, which are extensively used for the design of domestic supply chains. Another typical illustration is that in the planning of global logistics distribution strategies, the procedures for aggregation of suppliers, customers, and goods are critical to facilitate modeling the distribution channels of global logistics.

Although there has been much research regarding managerial approaches for global logistics design and coordination, most of the related literature is devoted either to specific topics, such as exchange rate fluctuations, global structuring, and strategic alliances (Kogut, 1985; Carter and Vickery, 1989; Ohmae, 1989; Min et al., 1994); or to qualitative analyses in international supply chain scenarios (Goldsborough, 1992; Bartmess and Cerny, 1993; MacCormack et al., 1994). The importance of flexibility in global companies as a response to fluctuations in exchange rates, changes in government policies, and complexities in competitive moves is discussed in Kogut (1985). Further detailed analysis on exchange rate fluctuations can also be found in Carter and Vickery (1989). Strategic alliances, which are regarded as fundamental tools for succeeding in a highly competitive global market, are characterized in Ohmae (1989). For analysis of global logistics, one method is proposed by Goldsborough (1992), which explores basic factors of global information systems. Comparisons between location decision-making based on direct labor costs and that based on the core competencies of the company are conducted in Bartmess and Cerny (1993). Furthermore, a four-phase decision making process is proposed by MacCormack et al. (1994) for international location decisions, together with related key factors, such as adequate infrastructure and managerial issues.

Accordingly, strategic planning of global logistics for high-technology industries warrants further research, particularly in terms of strategic evaluation. Although various global logistics strategies have been tentatively implemented by the globalized high-technology industries in response to the complexity and uncertainty of the global business environment, there remains a lack of approaches suitable for the systematical evaluation of the existing global logistics strategies. Similarly, some researchers have pointed out that there is limited literature in international logistics strategy, and the existing research seems to focus, for the most part, on descriptive aspects (Fawcett, 1992; Venter and Dincer, 1995). In addition, it is noteworthy that in an international scenario, the high-technology industry may predominate over other traditional industries worldwide, not only with its high-priced products, but also with its world-wide markets of demands which deeply influence the stability of the global economy.

To overcome the issue of complexity and uncertainty in GL strategic planning, this study presents a hybrid fuzzy-based approach, which integrates both fuzzy multi-attribute decision-making (fuzzy-MADM) and fuzzy analytical hierarchy process (fuzzy-AHP) techniques to develop logic rules used to identify appropriate GL strategies for global operations of high-technology industries. Here, fuzzy-MADM refers to a method for multi-attribute decision making

(MADM) under uncertainty, where a finite number of decision alternatives are evaluated under a finite number of performance criteria. The purpose of the analysis is to rank the alternatives in a subjective order of preference. The overall performance of these alternatives is herein assessed via proper assignment of numerical grades or scores measured through fuzzy theories to address the issue of vagueness of human preferential judgment. In addition, considering different weights associated with these attributes perceived by different decision makers in the judgment procedure, the fuzzy-AHP is involved in this study.¹ Accordingly, with the aid of fuzzy-AHP basic principles, a hybrid fuzzy-based approach is proposed in which four major procedures are involved: (1) hierarchical structure development of GL operational strategies, (2) generation of pairwise comparison matrices, (3) weights determination, and (4) specification of decision-making logic rules.

The rest of this paper is organized as follows. In Section 2, we review the fundamentals of global logistics strategies, and illustrate six typical operational modes that have been increasingly used in the globalized high-technology industries of Taiwan. In Section 3, we present the architecture of the proposed hybrid fuzzy-based method, and its primary procedures. Section 4 describes numerical examples to demonstrate the applicability of the proposed method. Finally, concluding remarks are summarized in Section 5.

2. Specification of operational modes of global logistics

The core of global logistics management involves two key elements: integration and sharing of transnational resources. This is evidenced in the operations of the diverse global logistics strategies, including original equipment manufacturing (OEM), original designing and manufacturing (ODM), original branding and manufacturing (OBM), original design logistics (ODL), as well as outsourcing.

Based on the philosophy of integration and sharing of transnational resources, many international companies have perceived that the implementation of global logistics strategies can reduce transportation costs and improve the capability to control inventory, and this efficiency is evident in global logistics operations. For example, Hewlett-Packard contracted with Roadway Logistics to manage its inbound raw materials warehousing in Vancouver, Canada. As a result, nearly 140 Roadway employees replaced 250 HP workers, who were transferred to other HP activities (Wheelen and Hunger, 1998). Other striking cases can be found in the personal computer industry, such as the operational strategies of Compaq and Dell in their head-to-head business competition (Dornier et al., 1998a,b).

¹ Previously fuzzy-MADM techniques have been extensively investigated to address the issue of lack of precision in assessing the relative importance of attributes and performance ratings of alternatives with respect to specific attributes (Dubois and Prade, 1980; Zimmermann, 1987; Chen and Hwang, 1992). Nevertheless, there are some issues, e.g., cumbersome computations and complicated computer programming, still remaining in existing fuzzy-MADM approaches (Chen and Klein, 1997), which may limit their applicability for real-world unstructured decision-making problems, such as the GL issues addressed in this study.

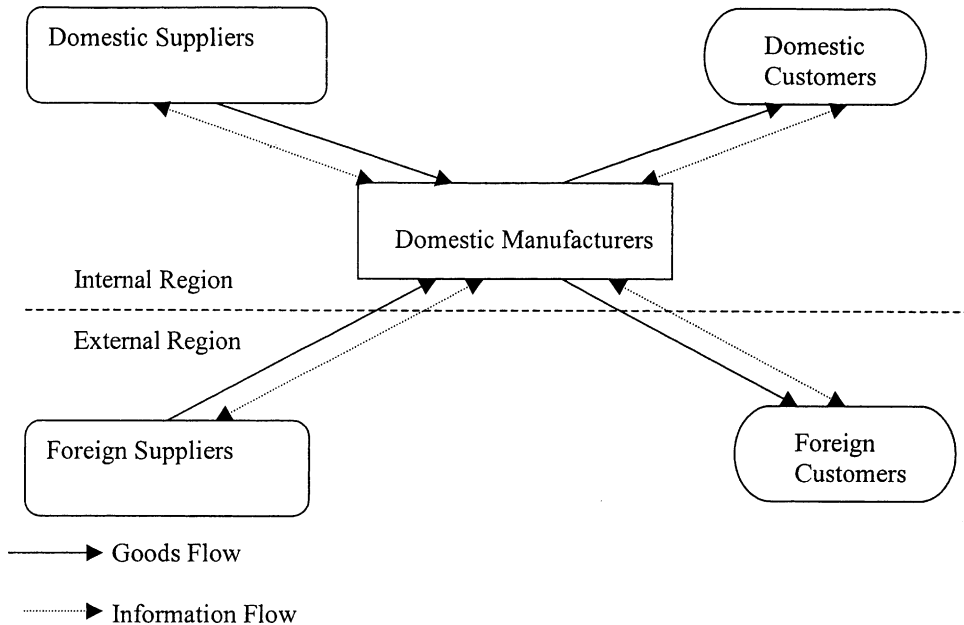


Fig. 1. Global logistics mode *A* (GL-mode *A*).

After elucidating the fundamentals of global logistics management, we illustrate six types of GL operational modes that are typically used by Taiwanese high-technology manufacturing enterprises.² These proposed GL modes are distinguished by their degrees of resource sharing and integration with foreign enterprises. The specified six types of GL operational modes, referred to as modes *A* to *F*, are illustrated in Figs. 1–6, respectively. The distinctive operational features of these modes, together with their specific logistical networks are described below.

GL-mode *A*, shown in Fig. 1, represents a typical mode of internal manufacturing centralization for global logistics operations; it can be widely found in international high-technology manufacturing enterprises, including integrated circuit (IC) and personal computer manufacturers. One distinctive feature of GL-mode *A* is that the entire process of manufacturing, including inventory management is controlled and completed domestically; however, raw materials and potential customers are outsourced abroad.

GL-mode *B*, as depicted in Fig. 2, has almost the same function as GL-mode *A*, except for manufacturing, which is partly outsourced abroad in order to reduce the costs of production. Given either GL-mode *A* or *B*, the activities of inventory and delivery with respect to finished products are controlled primarily by the domestic firm.

Fig. 3 depicts the network of GL-mode *C*, which can be regarded as an extension of GL-mode *A*. GL-mode *C* maintains the same features as GL-mode *A* in terms of internal centralization of

² The six types of GL modes are specified according to our surveys aiming at the Taiwanese IC manufacturers. This survey was conducted previous to this study, and was supported by National Science Council of Taiwan under grant NSC 89-2416-H-327-027. Details of corresponding procedures of surveys are described elsewhere (Sheu and Wu, 2001), and omitted in this paper.

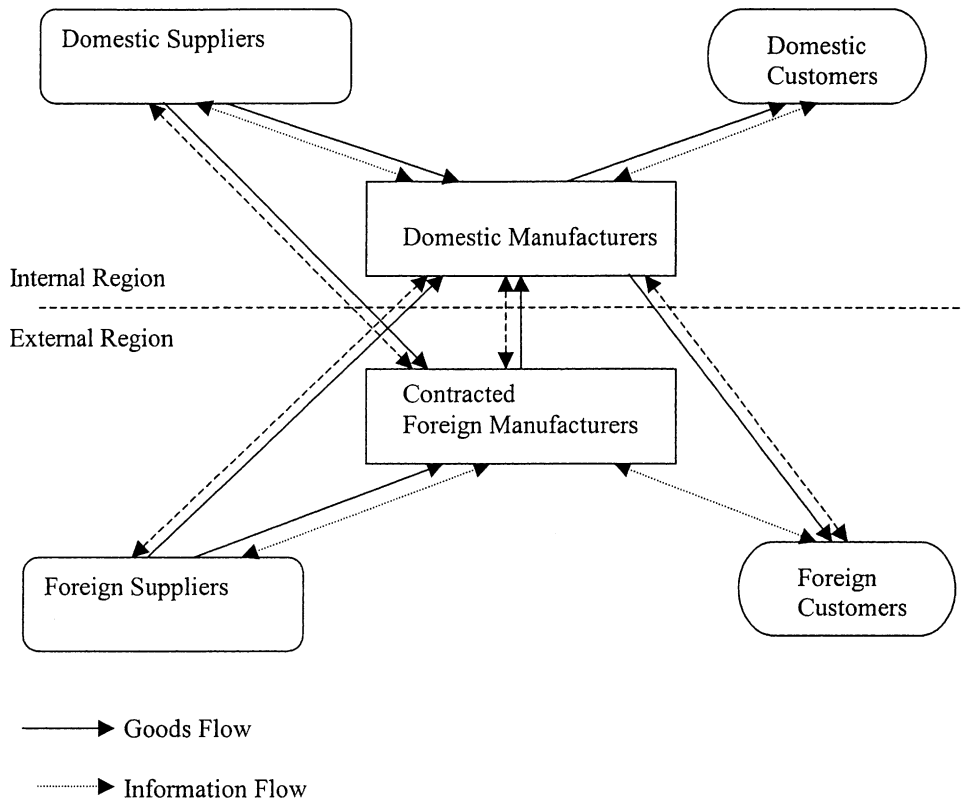


Fig. 2. Global logistics mode *B* (GL-mode *B*).

manufacturing, although their distributions differ. Compared to GL-mode *A*, in which the distribution activity is completely centralized, GL-mode *C* permits external distribution centers to reduce logistics costs for transporting finished products to foreign customers.

As illustrated in Fig. 4, GL-mode *D*, represents a synthesized mode that evolves from both GL-modes *B* and *C*. In addition to the outsourcing to foreign manufacturers, as performed in the operations of GL-mode *B*, GL-mode *D* possesses the same property as GL-mode *C* in terms of utilizing the external distribution resources to enhance the efficiency of overseas distribution channels. Despite the fact that GL-mode *D* relies highly on the competence of foreign contracted logistics partners, in contrast with either GL-mode *B* or *C*, GL-mode *D* may benefit multinational enterprises by its transnational resource integration and sharing in global supply chains.

GL-modes *E* and *F*, in Figs. 5 and 6, represent two sophisticated models of global logistics operations that are increasingly used in high-technology industries. These two modes are greatly advanced in global logistical management, especially in terms of utilizing external sources for both product processing and component assembly. As can be seen, foreign assembly firms with the functions of both product processing and distribution exist in either GL-mode *E* or GL-mode *F*. However, GL-mode *F* differs from GL-mode *E* in outsourcing from contracted foreign manufacturers, and thus has the relative advantage of reducing the logistics costs in serving foreign customers.

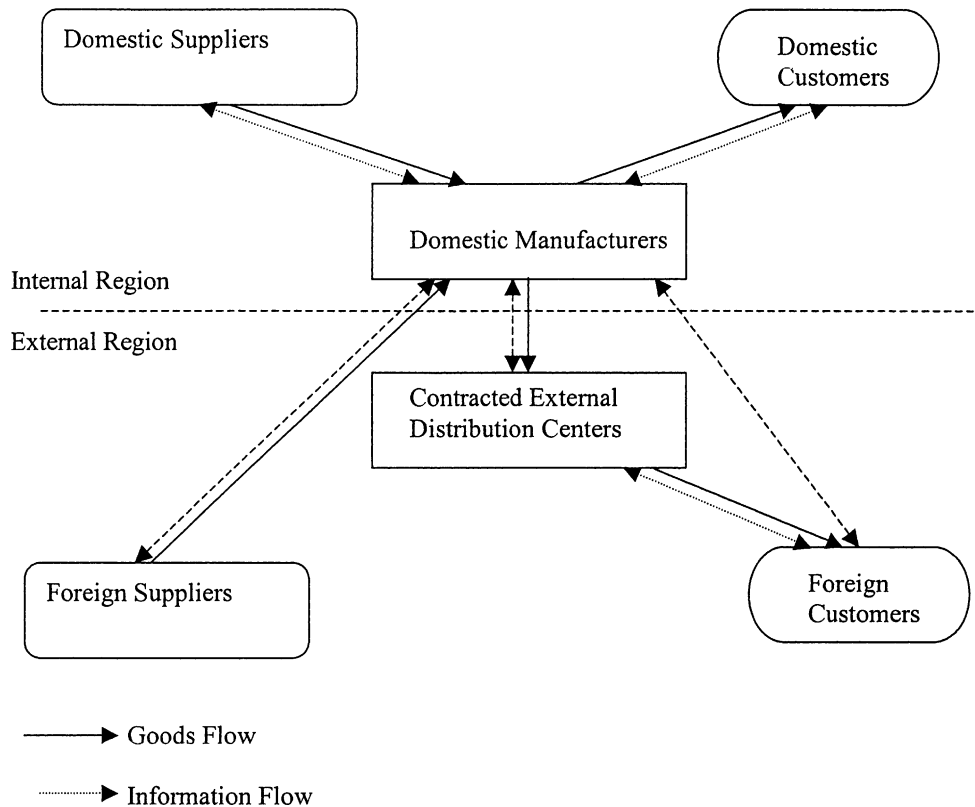


Fig. 3. Global logistics mode C (GL-mode C).

3. Methodology

We formulate the process of assessing GL operational strategies as a multi-criteria decision-making problem using the proposed fuzzy-based method. The proposed approach is based on the techniques of fuzzy-AHP and fuzzy-MADM to restructure the complex domains composed of diverse internal and external factors in the global logistics. The GL decision-making rules generated from the proposed method can identify feasible GL operational strategies for specific high-technology manufacturing enterprises and examine the operational performance of these enterprises in terms of their competencies in implementing GL operational strategies.

Primarily there are three procedures involved in the proposed fuzzy-based method: (1) generation of pairwise significance comparison matrices, (2) specification of fuzzy-weight criteria, and (3) development of decision-making rules. The framework of the proposed fuzzy-based method is presented in Fig. 7, and the details are presented in the following subsections.

3.1. Procedure 1: Generation of pairwise significance comparison matrices

This procedure investigates the relative significance among the attributes of a proposed GL operational strategic framework using fuzzy-AHP. The fuzzy-AHP technique can be viewed as an

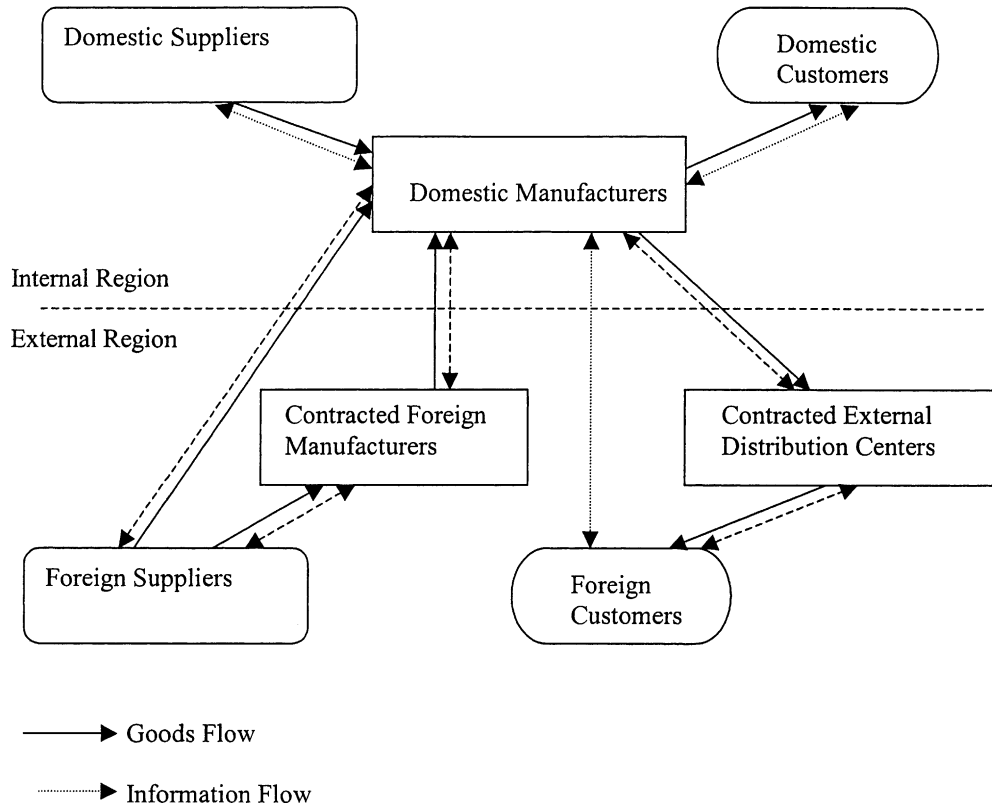


Fig. 4. Global logistics mode *D* (GL-mode *D*).

advanced analytical method improved from Saaty’s analytic hierarchy process (Saaty, 1977; Saaty, 1980), which is a well-known decision-making analytical tool used for modeling unstructured problems in various areas, e.g., social, economic, and management sciences (Khorramshahgol et al., 1988; Wabalickis, 1988; Bard and Sousk, 1990; Triantaphyllou and Mann, 1995). Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers’ judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches (Bouyssou et al., 2000). Therefore, more and more researchers (Laarhoven and Pedrycz, 1983; Buckley, 1985a,b; Boender et al., 1989; Chang, 1996; Ribeiro, 1996; Lootsma, 1997; Yu, 2002) have engaged in the fuzzy extension of Saaty’s theory, referred to as fuzzy-AHP, which has been shown to provide relatively more accurate descriptions of the decision making process in comparison with conventional AHP techniques.

It is also worth noting that other researchers consider the aforementioned imprecise judgments as uncertainty in the stochastic domain, where the pairwise judgment comparison ratio is treated as a random variable (Vargas, 1982; Saaty and Vargas, 1987; Basak and Saaty, 1993; MacKay et al., 1996; Basak, 1997; Rosenbloom, 1997). Such a statistical solution alternative seems comparative to fuzzy-AHP from a theoretical point of view; however it is not considered in this study

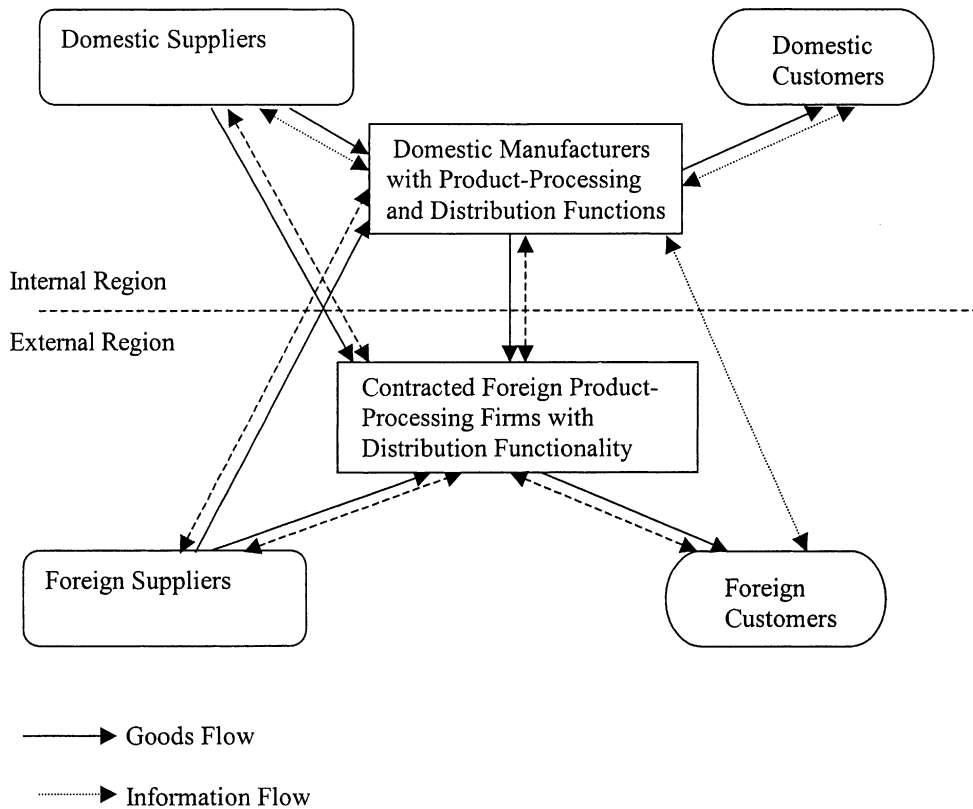


Fig. 5. Global logistics mode E (GL-mode E).

due to our concerns over the rationality of formulating human judgment impreciseness with stochastic processes, and the corresponding cumbersome calibration and validation procedures needed to ensure model's validity.

Here, we utilize the fundamentals of fuzzy-AHP to analyze the aforementioned GL strategy architecture. Employing the principles of fuzzy-AHP, we construct a 3-layer hierarchic framework, as depicted in Fig. 8, which is founded on the basis of three layers: (1) GL operational mode, (2) GL functionality, and (3) key factors influencing GL functionality.

The next step in this procedure is to generate pairwise significance comparison matrices to investigate the relative significance of any two components in the proposed GL hierarchic layers 2 and 3 (i.e., layers of GL functionality and key factors). In the process of generating the elements of a given pairwise significance comparison matrix, the components in the same layer are in linear order, based on the decision maker's judgment of the relative significance of these components, and are associated with specific ordinal numbers. Then, an element e_{ij}^k of the pairwise comparison matrix associated with components i and j of layer k is given by $e_{ij}^k = s_i^k / s_j^k$, where s_i^k and s_j^k represent the aggregated ordinal numbers associated with components i and j of layer k , respectively. Accordingly, any given element e_{ij}^k is also an ordinal number rather than an exact ratio scale which is typically used in classical AHP approaches. Correspondingly, the higher an ordinal

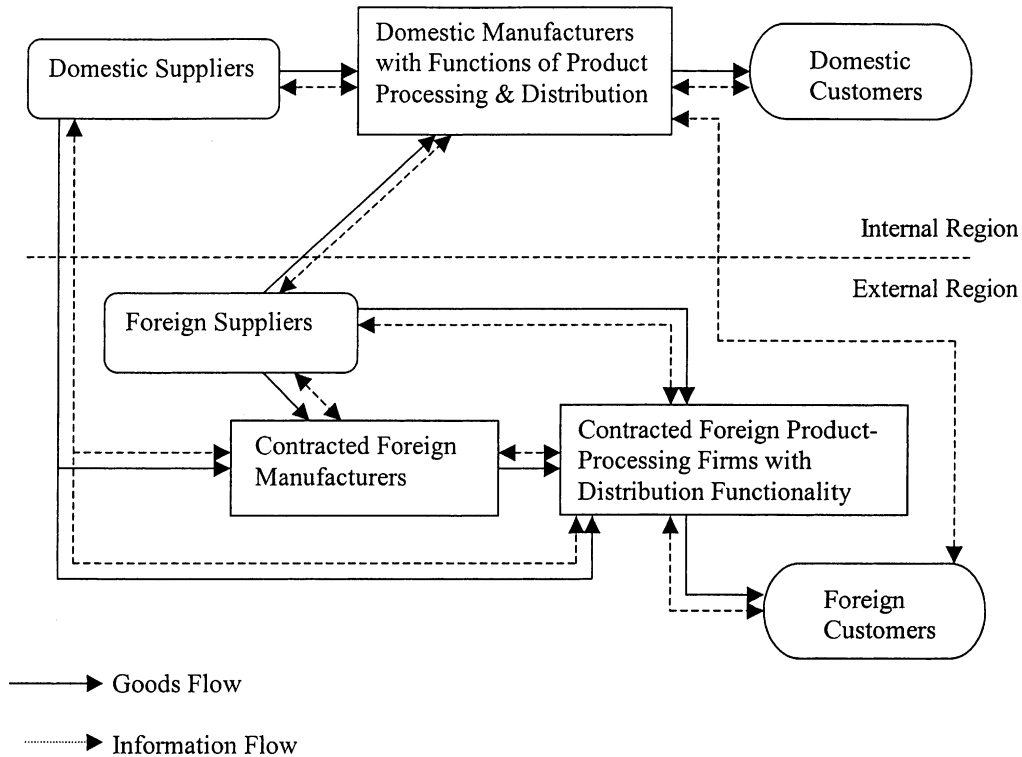


Fig. 6. Global logistics mode F (GL-mode F).

number, the more important the associated component is. Similar concepts can also be found in the early literature of fuzzy-AHP, e.g., Buckley (1984, 1985a,b). As such, utilizing fuzzy-AHP, we have a 5×5 pairwise significance comparison matrix associated with layer 2 (D^2) and a 13×13 significance comparison matrix associated with layer 3 (D^3). Herein, D^2 and D^3 are given by

$$D^2 = \begin{bmatrix} 1 & \varepsilon_{12}^2 & \varepsilon_{13}^2 & \varepsilon_{14}^2 & \varepsilon_{15}^2 \\ \varepsilon_{21}^2 & 1 & \varepsilon_{23}^2 & \varepsilon_{24}^2 & \varepsilon_{25}^2 \\ \varepsilon_{31}^2 & \varepsilon_{32}^2 & 1 & \varepsilon_{34}^2 & \varepsilon_{35}^2 \\ \varepsilon_{41}^2 & \varepsilon_{42}^2 & \varepsilon_{43}^2 & 1 & \varepsilon_{45}^2 \\ \varepsilon_{51}^2 & \varepsilon_{52}^2 & \varepsilon_{53}^2 & \varepsilon_{54}^2 & 1 \end{bmatrix}_{5 \times 5} \quad (1)$$

$$D^3 = \begin{bmatrix} 1 & \varepsilon_{12}^3 & \cdots & \varepsilon_{1,13}^3 \\ \varepsilon_{21}^3 & 1 & \cdots & \varepsilon_{2,13}^3 \\ \vdots & \vdots & \ddots & \vdots \\ \varepsilon_{13,1}^3 & \varepsilon_{13,2}^3 & \cdots & 1 \end{bmatrix}_{13 \times 13} \quad (2)$$

The last step of this procedure is to approximate the fuzzy weights associated with the components in a given layer. Here, we employ the geometric mean technique to facilitate the approximation of the fuzzy weights because this technique is easily extended for computing the

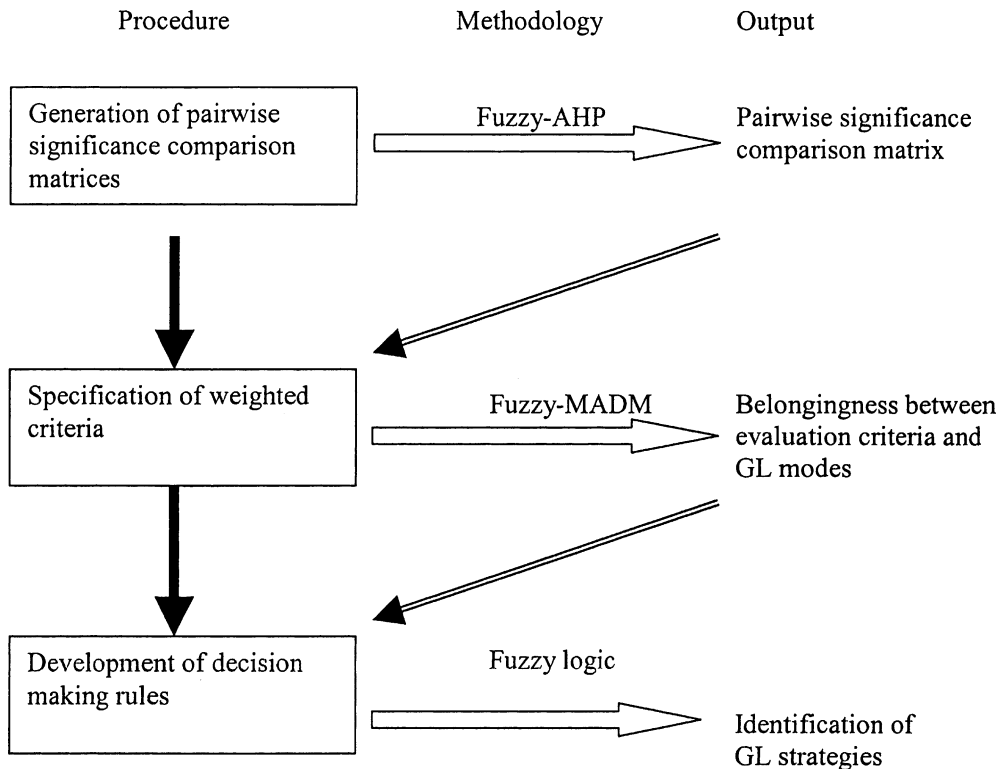


Fig. 7. Framework of the proposed method.

weights of fuzzy positive reciprocal matrices, as explicated in the prior literature (Aczel and Saaty, 1983; Uppuluri, 1983; Buckley, 1985a,b). For instance, given that a fuzzy positive reciprocal matrix is consistent, the geometric mean technique may easily approximate the fuzzy weights the same as those obtained from Saaty's λ -max technique, termed the largest-eigenvalue technique (Saaty, 1980). In addition, the geometric mean technique may also satisfy the condition of the absence of rank reversal, as illustrated in Lootsma (1997). Note that although an increasing number of alternatives have been proposed for the final solutions of true weights (Bryson and Mobolurin, 1997; Ramanathan, 1997; Levary and Wang, 1998; Yu, 2002), it is not our intention to compare these existing alternatives within the scope of this study.

Accordingly, given an $n \times n$ pairwise significance comparison matrix associated with a given layer k (D^k), we have the fuzzy weight associated with component i of layer k (w_i^k):

$$w_i^k = \frac{\sqrt[n]{\left(\prod_{j=1}^n \varepsilon_{ij}^k\right)}}{\sum_{m=1}^n \left[\sqrt[n]{\left(\prod_{j=1}^n \varepsilon_{mj}^k\right)}\right]} \quad (3)$$

where m represents a component index for calculation of the sum with respect to $\sqrt[n]{\prod_j \varepsilon_{ij}^k}$, as shown in the denominator of Eq. (3).

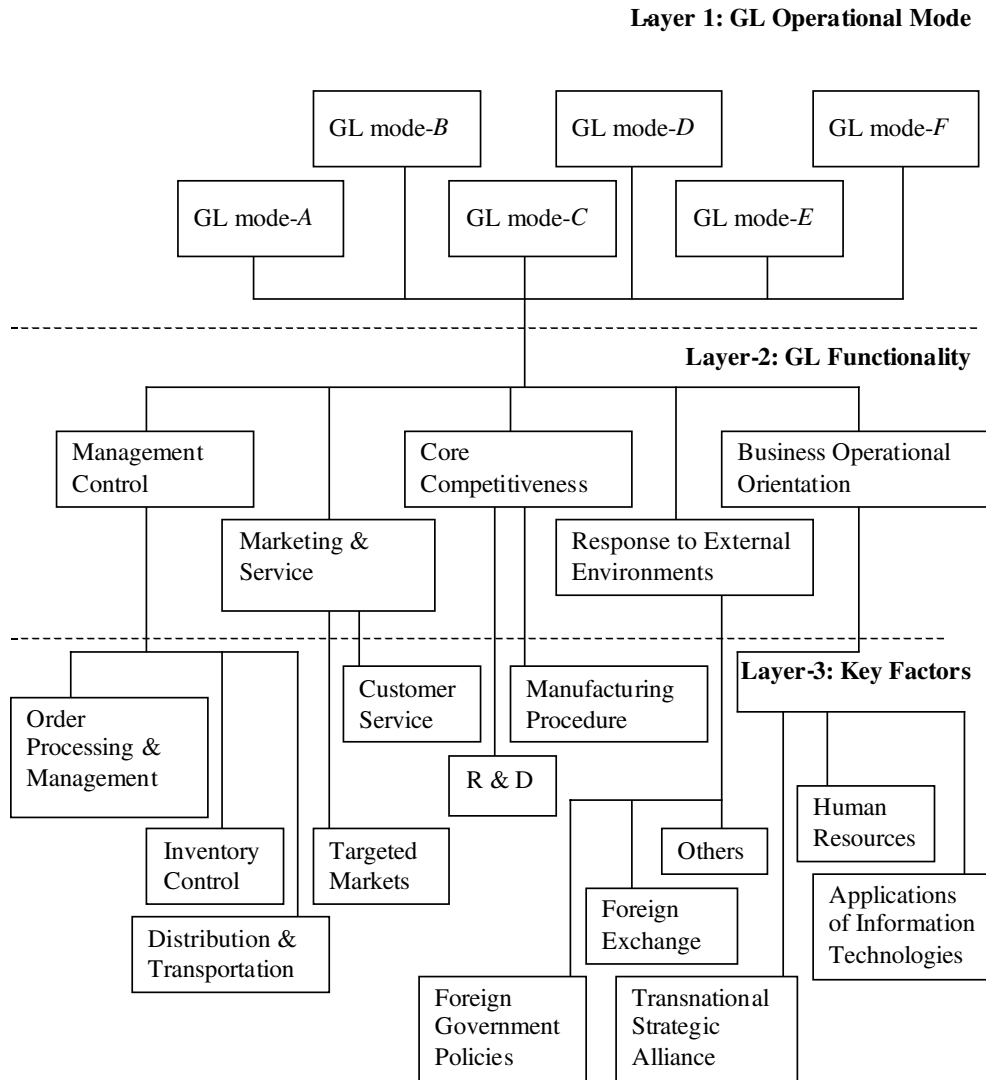


Fig. 8. The hierarchic framework of GL operational strategies.

3.2. Procedure 2: Specification of fuzzy-weight criteria

This procedure generates fuzzy-weight criteria used in the proposed multiple-attribute decision-making rules to identify feasible GL strategic modes. Three scenarios are involved in this sequential procedure, and they are described as follows. First, we specify five linguistic terms, including “very high”, “high”, “medium”, “low”, and “very low”, which represent five qualitative criteria to identify the intensity of the subjective importance associated with each component of a GL hierarchic layer. Second, these qualitative criteria are mapped into specific fuzzy membership functions to obtain raw fuzzy criteria via fuzzy-and-defuzzy transformation. Third,

with the fuzzy weights obtained previously in Procedure 1, the fuzzy-weight criteria associated with the components of GL hierarchic layers are computed.

The scenario of mapping the five specified qualitative criteria into specific fuzzy membership functions is critical in this procedure. According to fuzzy set theory, the concept of fuzziness helps to quantitatively characterize the linguistic terms. Such a feature seems useful for quantifying the pre-specified qualitative criteria. In this procedure, we specified five aggregated fuzzy functions associate the aforementioned five qualitative criteria, respectively, including two trapezoidal and three triangular fuzzy membership functions, as shown in Fig. 9. Note that the parameters of these fuzzy membership functions were approximated on the basis of experts' viewpoints, which we collected prior to the methodology development in a previous study (Sheu and Wu, 2001). Given the lower width (L_*), mean (M_*), and upper width (U_*) of a specified fuzzy membership function $\mu_*(x)$, to integrate the multiple experts' opinions, the following formulas are applied:

$$L_* = \min\{L_*^e\} \quad \forall e = 1, 2, \dots, E \tag{4}$$

$$M_* = \left(\prod_{e=1}^E M_*^e \right)^{\frac{1}{E}} \quad \forall e = 1, 2, \dots, E \tag{5}$$

$$U_* = \max\{U_*^e\} \quad \forall e = 1, 2, \dots, E \tag{6}$$

where L_*^e , M_*^e , and U_*^e respectively represent the lower width, mean, and upper width of the corresponding disaggregated fuzzy membership function $\mu_*^e(x)$ measured by a given expert e . Accordingly, the proposed aggregated fuzzy membership functions are given below.

$$\mu_{\text{VH}}(x) = \begin{cases} 1, & 0.9 < x < 1 \\ 10x - 8, & 0.8 < x < 0.9 \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

$$\mu_{\text{H}}(x) = \begin{cases} (18 - 20x)/3, & 0.75 < x < 0.9 \\ 1, & x = 0.75 \\ (20x - 12)/3, & 0.6 < x < 0.75 \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

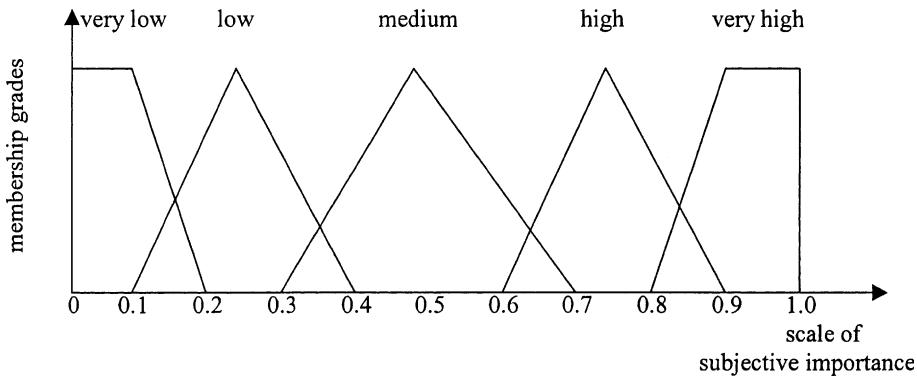


Fig. 9. Fuzzy membership functions for qualitative criteria.

$$\mu_M(x) = \begin{cases} 3.5 - 5x, & 0.5 < x < 0.7 \\ 1, & x = 0.5 \\ 5x - 1.5, & 0.3 < x < 0.5 \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

$$\mu_L(x) = \begin{cases} (8 - 20x)/3, & 0.25 < x < 0.4 \\ 1, & x = 0.75 \\ (20x - 2)/3, & 0.1 < x < 0.25 \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

$$\mu_{VL}(x) = \begin{cases} 2 - 10x, & 0.1 < x < 0.2 \\ 1, & 0 < x < 0.1 \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

where $\mu_{VH}(x)$, $\mu_H(x)$, $\mu_M(x)$, $\mu_L(x)$, and $\mu_{VL}(x)$ represent the fuzzy membership functions associated with the qualitative criteria “very high”, “high”, “medium”, “low”, and “very low”, respectively; and x is the intensity of a given linguistic variable measured on a scale ranging from 0 to 1.

After specifying fuzzy membership functions, the process of defuzzification can then be conducted. Here, we employ the left-and-right scoring method, which has been investigated previously as an efficient approach to accomplish the quantification of linguistic variables with high efficiency (Chen and Hwang, 1992; Chen and Klein, 1997). According to Chen and Hwang (1992), the left-and-right scoring method is a modification of Chen’s approaches (Chen, 1985), aiming to convert fuzzy members to crisp scores (i.e., defuzzy values) by two specific minimizing and maximizing sets, termed the left and right scores. Employing this defuzzifying method, the defuzzy value associated with a given fuzzy membership A ($\mu_T(A)$), can be determined by

$$\mu_T(A) = \frac{[\mu_R(A) + 1 - \mu_L(A)]}{2} \quad (12)$$

where $\mu_R(A)$ and $\mu_L(A)$ represent the right and left score functions, respectively, given by

$$\mu_R(A) = \sup_x [\mu_A(x) \wedge \mu_{\max}(x)] \quad (13)$$

$$\mu_L(A) = \sup_x [\mu_A(x) \wedge \mu_{\min}(x)] \quad (14)$$

In Eqs. (13) and (14), $\mu_{\max}(A)$ and $\mu_{\min}(A)$ are defined as the maximization and minimization with respect to x , both which are given respectively by

$$\mu_{\max}(x) = \begin{cases} x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \quad (15)$$

$$\mu_{\min}(x) = \begin{cases} 1 - x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \quad (16)$$

Using the aforementioned fuzzy-and-defuzzy transformation processes, the fuzzy-weight quantitative criterion, which refers to a specific threshold used to quantitatively assess the significance of a corresponding component of a given GL-strategy mode, can then be determined as follows. Given GL-mode λ , the fuzzy-weight criterion associated with a specific component i of layer k of a given GL-mode λ ($\eta_i^k(\lambda)$) is specified by

$$\eta_i^k(\lambda) = w_i^k \times \left\{ \frac{v_i^k(\lambda)}{\sqrt{\sum_{\lambda=1}^6 [v_i^k(\lambda)]^2}} \right\} \quad (17)$$

where $v_i^k(\lambda)$ is the unweighted criterion associated with the component i of layer k of GL-mode λ , with mathematical form

$$v_i^k(\lambda) = \frac{\sum_{j=1}^5 [\mu_T(A_j)] \times \theta_{A_j|i,k,\lambda}}{S} \quad (18)$$

In Eq. (18), $\mu_T(A_j)$ represents the total score of a given fuzzy membership function associated with a specific qualitative criterion j ; $\theta_{A_j|i,k,\lambda}$ represents the number of the high-technology enterprises that rate the component i of layer k of GL-mode λ with the qualitative criterion j , which can be determined via a questionnaire survey to the high-technology enterprises; and S is the valid sample size of respondents in the survey. For instance, using $\eta_i^k(\lambda)$, the significance of the corresponding component i of layer k of GL-mode λ can be quantitatively identified on the basis of the integrated experts' opinions via the aforementioned fuzz-and-defuzzy procedure, rather than being based merely on individual subjective linguistic opinions, e.g., *important* or *very important*.

3.3. Procedure 3: Development of decision making rules

In Procedure 3, we apply the estimated fuzzy-weight criteria for the generation of decision-making rules that can be used to assist high-technology enterprises to identify effective GL operational strategies. Suppose that in utilizing the pre-specified five linguistic items, the subjective judgment of a high-technology enterprise l on the importance associated with each component of the GL hierarchic framework is known. We then propose the following decision-making logic used for identification of GL strategies suitable for the enterprise l .

Step 0: Input the subjective judgment of the high-technology enterprise l on each component of each given GL layer k .

Step 1: Calculate the corresponding total score of the specific fuzzy membership ($\mu_T(A_{i,j}^{k,l})$) given that the subjective judgment of the high-technology enterprise l on the component i of GL layer k is measured with a given qualitative criterion j .

Step 2: Identify appropriate GL strategies using the following decision-making rules.

- *Rule 1*

$$\text{If } [\omega_i^k \times \mu_T(A_{i,j}^{k,l})] \geq \eta_i^k(\lambda) \quad \text{for all } i \text{ and } k \quad (19)$$

Then Get the GL-mode λ involved in the strategy recommendation list (λ^*); and associate the recommended GL-mode λ with a relative priority index π_λ^l , which is given by

$$\pi_\lambda^l = \frac{\sum_{\forall k} \sum_{\forall i} \{[\omega_i^k \times \mu_T(A_{i,j}^{k,l})] - \eta_i^k(\lambda)\}}{\sum_{\forall \lambda \in \lambda^*} \sum_{\forall k} \sum_{\forall i} \{[\omega_i^k \times \mu_T(A_{i,j}^{k,l})] - \eta_i^k(\lambda)\}} \quad (20)$$

Else GL-mode λ is not regarded as an appropriate GL strategy for further use by the high-technology enterprise l .

- *Rule 2*

If The present GL mode ($\tilde{\lambda}$) executed by the given high-technology enterprise l is consistent with a given GL strategy in the recommendation list, the present GL mode ($\tilde{\lambda}$) is suggested.

Else If the given high-technology enterprise l insists on using the present GL mode ($\tilde{\lambda}$) non-recommended, further improvements in those unsatisfactory GL components (i), i.e., the corresponding value of $[\omega_i^k \times \mu_T(A_{i,j}^{k,l})]$ is less than $\eta_i^k(\lambda)$, are suggested. Otherwise, replacing the current GL mode ($\tilde{\lambda}$) with the one (λ), which has the greatest value of π_λ^l in the recommendation list, is suggested.

Note that from a practical point of view, the fuzzy-weight criteria $\eta_i^k(\lambda)$ shown on the right-hand side of Eq. (19) is determined using the proposed methodology, and the estimate of $\mu_T(A_{i,j}^{k,l})$ shown on the left-hand side of Eq. (19) can be measured using the data collected from the questionnaire survey aimed at any given target enterprise.

4. Numerical examples

To investigate the applicability of the proposed method, a numerical study was conducted during the spring of 2002 using a nation-wide questionnaire mail survey aimed at integrated circuit (IC) manufacturers in Taiwan. Herein, two scenarios are involved: (1) development of decision-making rules using survey data, and (2) demonstration of the model’s capability in terms of identifying appropriate GL strategies.

The survey was distributed to 150 IC manufacturing enterprises, and a total of 33 samples were valid out of the 35 responses received. The data gathered were used as the database to establish the proposed decision-making rules. The contents of the questionnaire were designed on the basis of the proposed GL hierarchical framework, and divided into two sections. In the first section, survey respondents were asked to rank the components of a given layer in the proposed GL hierarchical framework according to the comparative importance of the components. In the second section, they were asked to qualitatively assess these components using the pre-specified five linguistic criteria, i.e., “very high”, “high”, “medium”, “low”, and “very low”. The data collected in the first section were employed to generate the pairwise significance comparison matrices via Procedure 1. The data obtained in the second section served to specify the fuzzy-weight criteria of the decision-making rules quantitatively by means of Procedure 2 of the proposed method.

Note that the condition in terms of the consistency of the estimated pairwise significance comparison matrices associated with given layers must be proved to hold in any AHP-based techniques to ensure the reliability of the numerical results. Accordingly, the data obtained in the first section of the questionnaire were examined utilizing the Cronbach’s α statistic, which is widely used to assess the internal consistency based on the correlation between items, e.g., questions of the questionnaire (Cronbach, 1951). Herein the Cronbach’s α measure is given by

$$\alpha = \frac{\sigma}{\sigma - 1} \left[1 - \frac{\sum_p \varepsilon_p^2}{\varepsilon_T^2} \right] \tag{21}$$

where σ is the total number of the questions in the questionnaire; ε_p is the standard deviation associated with question p ; ε_T represents the aggregated standard deviation of the survey data.

The results of the Cronbach's α tests associated with the components of GL layers 2 and 3 are summarized in Table 1.

The test results shown in Table 1 generally indicated the acceptability of the survey data. As can be seen in Table 1, all the 13 Cronbach's α measurements are greater than 0.35, implying that the survey data associated with the components of layer 3 are acceptable. Similarly, the Cronbach's α statistic associated with the components of GL layer 2 implies high acceptability in terms of the collected data. Note that the criteria 0.35 and 0.75 have been widely used in Cronbach's α tests as loose and demanding thresholds for determining the acceptability of data. Further details regarding the consistency tests can also be found elsewhere (Sheu and Wu, 2001).

The next step is to generate the pairwise significance comparison matrices for GL layers 2 and 3. Here, we calculate the elements of the pairwise significance comparison matrices associated with layers 2 and 3 (i.e., e_{ij}^2 and e_{ij}^3), based on the aggregated data collected in the first section of the questionnaire. These aggregated ordinal numbers associated with the components of GL layers 2 and 3 are summarized in Table 2. The analytical results shown in Table 2 are then used to estimate the pairwise significance comparison matrices associated with GL layers 2 and 3, as shown in Tables 3 and 4.

After inserting the elements of the estimated pairwise significance comparison matrices into Eq. (3), we have the fuzzy weights associated with the components of layers 2 and 3, as summarized in Table 5.

Employing the aggregated data measured from the second section of the questionnaire together with the estimated fuzzy weights, the fuzzy-weight criteria associated with the components of GL

Table 1
Summary of Cronbach's α test results

| Component | Cronbach's α value | Result |
|--------------------------------------|---------------------------|-------------------|
| <i>GL layer 2</i> | | |
| 1. Management control | 0.87 | Highly acceptable |
| 2. Core competitiveness | 0.84 | Highly acceptable |
| 3. Business operational orientation | 0.79 | Highly acceptable |
| 4. Marketing and service | 0.81 | Highly acceptable |
| 5. Response to external environments | 0.77 | Highly acceptable |
| <i>GL layer 3</i> | | |
| 1. Order processing and management | 0.78 | Highly acceptable |
| 2. Inventory control | 0.75 | Highly acceptable |
| 3. Distribution and transportation | 0.76 | Highly acceptable |
| 4. R&D | 0.89 | Highly acceptable |
| 5. Manufacturing procedure | 0.88 | Highly acceptable |
| 6. Transnational strategic alliance | 0.83 | Highly acceptable |
| 7. Human resources | 0.87 | Highly acceptable |
| 8. Applications of IT | 0.80 | Highly acceptable |
| 9. Targeted markets | 0.73 | Acceptable |
| 10. Customer service | 0.66 | Acceptable |
| 11. Foreign government policies | 0.54 | Acceptable |
| 12. Foreign exchange | 0.64 | Acceptable |
| 13. Others | 0.56 | Acceptable |

Table 2
Summary of the aggregated ordinal numbers associated with the components of GL layers 2 and 3

| Component (coded as U_i) | Aggregated ordinal number |
|---|---------------------------|
| <i>Layer 2</i> | |
| U_1 : management control | 4 |
| U_2 : core competitiveness | 5 |
| U_3 : business operational orientation | 3 |
| U_4 : marketing and service | 2 |
| U_5 : Response to external environments | 1 |
| <i>Layer 3</i> | |
| Component (coded as x_i) | |
| x_1 : order processing and management | 9 |
| x_2 : inventory control | 6 |
| x_3 : distribution and transportation | 8 |
| x_4 : R&D | 13 |
| x_5 : manufacturing procedure | 12 |
| x_6 : transnational strategic alliance | 5 |
| x_7 : human resources | 10 |
| x_8 : applications of IT | 11 |
| x_9 : targeted markets | 7 |
| x_{10} : customer service | 4 |
| x_{11} : foreign government policies | 1 |
| x_{12} : foreign exchange | 3 |
| x_{13} : others | 2 |

Table 3
Estimated pair-wise comparison matrix for GL layer 2

| | U_1 | U_2 | U_3 | U_4 | U_5 |
|-------|-------|-------|-------|-------|-------|
| U_1 | 1 | 4/5 | 4/3 | 4/2 | 4/1 |
| U_2 | 5/4 | 1 | 5/3 | 5/2 | 5/1 |
| U_3 | 3/4 | 3/5 | 1 | 3/2 | 3/1 |
| U_4 | 2/4 | 2/5 | 2/3 | 1 | 2/1 |
| U_5 | 1/4 | 1/5 | 1/3 | 1/2 | 1 |

layers 2 and 3 can then be determined via the steps in Procedure 2 above. The estimated fuzzy-weight criteria (i.e., $\eta_i^k(\lambda)$) are summarized in Table 6.

The results generated from the numerical examples generally revealed some important findings with respect to the GL operational situations of the IC manufacturing enterprises in Taiwan. According to Table 5, “core competitiveness” and “management control” have the highest and the second highest priorities in the development of GL system functionality. In addition, “manufacturing procedure” and “R&D” remain the two key factors in determining GL operational strategies of high-technology industries. On the other hand, the IC manufacturing enterprises in Taiwan appear to be rather insensitive to changes in the external environment of global operations, which may indicate that the high-technology manufacturing enterprises of Taiwan may face high risks in the global market.

Table 4
Estimated pair-wise comparison matrix for GL layer 3

| | x_1 | x_2 | x_3 | x_4 | x_5 | x_6 | x_7 | x_8 | x_9 | x_{10} | x_{11} | x_{12} | x_{13} |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|----------|----------|----------|
| x_1 | 1 | 9/6 | 9/8 | 9/13 | 9/12 | 9/5 | 9/10 | 9/11 | 9/7 | 9/4 | 9/1 | 9/3 | 9/2 |
| x_2 | 6/9 | 1 | 6/8 | 6/13 | 6/12 | 6/5 | 6/10 | 6/11 | 6/7 | 6/4 | 6/1 | 6/3 | 6/2 |
| x_3 | 8/9 | 8/6 | 1 | 8/13 | 8/12 | 8/5 | 8/10 | 8/11 | 8/7 | 8/4 | 8/1 | 8/3 | 8/2 |
| x_4 | 13/9 | 13/6 | 13/8 | 1 | 13/12 | 13/5 | 13/10 | 13/11 | 13/7 | 13/4 | 13/1 | 13/3 | 13/2 |
| x_5 | 12/9 | 12/6 | 12/8 | 12/13 | 1 | 12/5 | 12/10 | 12/11 | 12/7 | 12/4 | 12/1 | 12/3 | 12/2 |
| x_6 | 5/9 | 5/6 | 5/8 | 5/13 | 5/12 | 1 | 5/10 | 5/11 | 5/7 | 5/4 | 5/1 | 5/3 | 5/2 |
| x_7 | 10/9 | 10/6 | 10/8 | 10/13 | 10/12 | 10/5 | 1 | 10/11 | 10/7 | 10/4 | 10/1 | 10/3 | 10/2 |
| x_8 | 11/9 | 11/6 | 11/8 | 11/13 | 11/12 | 11/5 | 11/10 | 1 | 11/7 | 11/4 | 11/1 | 11/3 | 11/2 |
| x_9 | 7/9 | 7/6 | 7/8 | 7/13 | 7/12 | 7/5 | 7/10 | 7/11 | 1 | 7/4 | 7/1 | 7/3 | 7/2 |
| x_{10} | 4/9 | 4/6 | 4/8 | 4/13 | 4/12 | 4/5 | 4/10 | 4/11 | 4/7 | 1 | 4/1 | 4/3 | 4/2 |
| x_{11} | 1/9 | 1/6 | 1/8 | 1/13 | 1/12 | 1/5 | 1/10 | 1/11 | 1/7 | 1/4 | 1 | 1/3 | 1/2 |
| x_{12} | 3/9 | 3/6 | 3/8 | 3/13 | 3/12 | 3/5 | 3/10 | 3/11 | 3/7 | 3/4 | 3/1 | 1 | 3/2 |
| x_{13} | 2/9 | 2/6 | 2/8 | 2/13 | 2/12 | 2/5 | 2/10 | 2/11 | 2/7 | 2/4 | 2/1 | 2/3 | 1 |

Table 5
Summary of the estimated fuzzy weights

| Component (coded as U_i) | Fuzzy weight |
|---|--------------|
| <i>Layer 2</i> | |
| U_1 : management control | 0.267 |
| U_2 : core competitiveness | 0.334 |
| U_3 : business operational orientation | 0.200 |
| U_4 : marketing and service | 0.133 |
| U_5 : response to external environments | 0.066 |
| <i>Layer 3</i> | |
| Component (coded as x_i) | |
| x_1 : order processing and management | 0.095 |
| x_2 : inventory control | 0.062 |
| x_3 : distribution and transportation | 0.093 |
| x_4 : R&D | 0.138 |
| x_5 : manufacturing procedure | 0.153 |
| x_6 : transnational strategic alliance | 0.058 |
| x_7 : human resources | 0.105 |
| x_8 : applications of IT | 0.116 |
| x_9 : targeted markets | 0.073 |
| x_{10} : customer service | 0.042 |
| x_{11} : foreign government policies | 0.012 |
| x_{12} : foreign exchange | 0.032 |
| x_{13} : others | 0.021 |

In addition, using the numerical results shown in Table 6, high-technology enterprises can readily recognize appropriate GL strategic modes to follow. For instance, any given high-technology enterprise can be asked to respond to the questionnaire mentioned previously. Then, by following the proposed procedures detailed in the section on methodology, the left-hand-side of

Table 6
Summary of fuzzy-weight criteria for identification of GL strategic modes

| Component (coded as U_i) | Fuzzy-weight criteria | | | | | |
|---|-----------------------|--------|--------|--------|--------|--------|
| | Mode-A | Mode-B | Mode-C | Mode-D | Mode-E | Mode-F |
| <i>Layer 2</i> | | | | | | |
| U_1 : management control | 0.092 | 0.106 | 0.109 | 0.102 | 0.103 | 0.137 |
| U_2 : core competitiveness | 0.151 | 0.126 | 0.143 | 0.116 | 0.116 | 0.160 |
| U_3 : business operational orientation | 0.082 | 0.084 | 0.083 | 0.078 | 0.080 | 0.082 |
| U_4 : marketing and service | 0.058 | 0.055 | 0.048 | 0.059 | 0.064 | 0.037 |
| U_5 : response to external environments | 0.026 | 0.027 | 0.027 | 0.026 | 0.027 | 0.027 |
| <i>Layer 3</i> | | | | | | |
| Component (coded as x_i) | | | | | | |
| x_1 : order processing and management | 0.062 | 0.058 | 0.047 | 0.053 | 0.057 | 0.056 |
| x_2 : inventory control | 0.032 | 0.034 | 0.033 | 0.03 | 0.031 | 0.043 |
| x_3 : distribution and transportation | 0.045 | 0.051 | 0.059 | 0.056 | 0.059 | 0.058 |
| x_4 : R&D | 0.080 | 0.077 | 0.074 | 0.067 | 0.065 | 0.083 |
| x_5 : manufacturing procedure | 0.087 | 0.082 | 0.084 | 0.09 | 0.094 | 0.094 |
| x_6 : transnational strategic alliance | 0.033 | 0.036 | 0.038 | 0.029 | 0.029 | 0.030 |
| x_7 : human resources | 0.060 | 0.059 | 0.072 | 0.066 | 0.065 | 0.048 |
| x_8 : applications of IT | 0.067 | 0.052 | 0.041 | 0.072 | 0.080 | 0.083 |
| x_9 : targeted markets | 0.061 | 0.047 | 0.034 | 0.033 | 0.037 | 0.043 |
| x_{10} : customer service | 0.027 | 0.025 | 0.025 | 0.031 | 0.030 | 0.019 |
| x_{11} : foreign government policies | 0.006 | 0.008 | 0.007 | 0.006 | 0.007 | 0.004 |
| x_{12} : foreign exchange | 0.014 | 0.013 | 0.015 | 0.014 | 0.015 | 0.024 |
| x_{13} : others | 0.011 | 0.010 | 0.012 | 0.013 | 0.013 | 0.012 |

Eq. (19) associated with the enterprise can be calculated, and compared to the estimated value of the fuzzy-weight criteria $\eta_i^k(\lambda)$. If the condition shown in Eq. (19) holds, the GL strategies associated with GL mode- λ are recommended for the given enterprise. Otherwise, further improvement in the performance of the current GL operational strategy is suggested for the target enterprise, particularly aiming at those GL components, which exhibit relatively greater negative values in terms of $[\omega_i^k \times \mu_T(A_{i,j}^{k,l})] - \eta_i^k(\lambda)$.³

To demonstrate the capability of the proposed method in terms of the identification of GL strategies for high-technology enterprises, the developed decision-making rules were tested using interview survey data. Herein, the survey data were collected from other Taiwanese IC manufacturers, which are not involved in the previous valid samples, to ensure the validity of the proposed method. In this scenario, a total of 10 Taiwanese IC manufacturing enterprises (termed E-1 to E-10 for short) are targeted for the interview survey. Out of these 10 target IC enterprises, five enterprises presently conduct GL-mode A, three ones conduct mode C, and the rest follow mode F. In the face-to-face interview survey, the corresponding decision makers of these enterprises were asked to qualitatively assess the potential performance with respect to each GL

³ Given a strategic component i of layer k , a negative value of the measurement of $[\omega_i^k \times \mu_T(A_{i,j}^{k,l})]$ minus the predetermined value of $\eta_i^k(\lambda)$ may indicate that the improvement associated with the strategic component i of layer k is needed in order to efficiently execute the current GL operational mode.

Table 7
Numerical results for GL-mode identification

| Target sample | GL mode (presently used) | GL mode (suggested) | Accepted/rejected (by the enterprise) | GL mode (finalized) |
|---------------|-----------------------------|------------------------|--|------------------------|
| E-1 | A | A | Accepted | A |
| E-2 | A | A | Accepted | A |
| E-3 | A | E | Accepted | E |
| E-4 | A | A | Accepted | A |
| E-5 | A | A | Accepted | A |
| E-6 | C | E | Rejected | C |
| E-7 | C | C | Accepted | C |
| E-8 | C | E | Accepted | E |
| E-9 | F | F | Accepted | F |
| E-10 | F | F | Accepted | F |

component under the present operational condition of the given enterprise, and the possibility of implementing any other ones of the specified six GL modes. The pre-specified five linguistic criteria, e.g., “very high” and “very low” remain used as the evaluation measures in this scenario.

Using the proposed method, the disaggregate value of $\mu_T(A_{i,j}^{k,l})$ associated with each target enterprise was calculated, and then input to the proposed decision-making rules, as mentioned in Procedure 3 of the methodology development. The corresponding numerical results in this scenario are summarized in Table 7.

The numerical results of Table 7 imply the efficiency of the proposed method used as a decision-making support tool for identification of GL strategies. Out of the sampled 10 IC enterprises, seven are identified for using the same GL modes as suggested by the proposed decision-making rules. The remaining three had different GL modes: two of these accepted our suggestion; however, the remaining last one rejected our suggestion due to the limitations of existing operational resources. Overall, nine suggestion cases are accepted out of 10, implying the efficiency of the proposed method for practical uses.

5. Conclusion

This paper has presented a new approach that integrates fuzzy-AHP and fuzzy-MADM approaches for identifying GL strategies, particularly under the condition that corresponding supply and demand environments are complicated and uncertain. The proposed fuzzy-based method involves three major procedures: (1) generation of pairwise significance comparison matrices, (2) specification of fuzzy-weight criteria, and (3) development of decision-making rules. Before applying the methodology, six types of GL strategic modes were characterized with their distinctive channels of physical distribution and information flows.

In addition, a nation-wide questionnaire survey aiming at the Taiwanese IC manufacturing industry was conducted to gather data that were used to demonstrate the applicability of the proposed method. The results from the numerical example revealed that the high-technology industries in Taiwan, including the IC manufacturing enterprises, apparently regard “core competitiveness” and “management control” as two vital elements in the GL system functionality.

Furthermore, “R&D” and “manufacturing procedure” remain as two key factors in determining GL operational strategies of high-technology industries. However, the IC manufacturing enterprises in Taiwan seem rather insensitive to the external environment in the global operational context. This may further reveal that the high-technology manufacturing enterprises in Taiwan may face high risks in their global operations.

Our study differs from previous GL strategic planning research in several aspects. First, we classify high-technology GL operational strategies into six types of operational modes according their distinctive properties in terms of physical distribution channels as well as the patterns of information flows. Such classification helps to clarify the GL system functionality and key factors that influence the system functionality. Second, we characterize the high-technology GL strategic modes on the basis of the proposed GL hierarchic framework established using the fuzzy-AHP approach. Clearly, the utilization of the proposed GL hierarchic framework facilitates the assessment of the comprehensive GL architecture. Third, we propose decision-making rules to make available the quantitative evaluation used for identifying proper GL strategic modes. We hope that the methodology presented in this research would stimulate research in the related fields of global logistics, and may help address issues regarding the uncertainty and complexity of global logistics operations.

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References

- Aczel, J., Saaty, T.L., 1983. Procedures for synthesizing ratio judgments. *Journal of Mathematical Psychology* 27, 93–102.
- Bard, J.F., Sousk, S.F., 1990. A tradeoff analysis for rough terrain cargo handlers using the AHP: an example of group decision making. *IEEE Transactions on Engineering Management* 37 (3), 222–228.
- Bartmess, A., Cerny, K., 1993. Building competitive advantage through a global network of capabilities. *California Management Review* (Winter), 78–103.
- Basak, I., 1997. Rank-based statistical procedures in analytic hierarchy process. *European Journal of Operational Research* 101, 39–50.
- Basak, I., Saaty, T.L., 1993. Group decision making using the analytic hierarchy process. *Mathematical and Computer Modeling* 17, 101–109.
- Boender, C.G.E., de Graan, J.G., Lootsma, F.A., 1989. Multicriteria decision analysis with fuzzy pairwise comparisons. *Fuzzy Sets and Systems* 29, 133–143.
- Bowersox, D.J., Closs, D.J., 1996. Global logistics. In: Bowersox, D.J., Closs, D.J. (Eds.), *Logistical Management: The Integrated Supply Chain Process*. McGraw-Hill, Singapore, pp. 129–135.
- Bouyssou, D., Marchant, T., Pirlot, M., Perny, P., Tsoukias, A., Vincke, P., 2000. *Evaluation Models: a Critical Perspective*. Kluwer, Boston.
- Bryson, N., Mobolurin, A., 1997. Modeling pairwise comparisons on ratio scales. *European Journal of Operational Research* 102, 538–553.

- Buckley, J.J., 1984. The multiple judge, multiple criteria ranking problem: a fuzzy set approach. *Fuzzy Sets and Systems* 13 (1), 25–37.
- Buckley, J.J., 1985a. Ranking alternatives using fuzzy members. *Fuzzy Sets and Systems* 15, 21–31.
- Buckley, J.J., 1985b. Fuzzy hierarchical analysis. *Fuzzy Sets and Systems* 17, 233–247.
- Carter, J.R., Vickery, S.K., 1989. Managing volatile exchange rates in international purchasing. *Journal of Purchasing and Materials Management* (Winter), 13–20.
- Chang, D.-Y., 1996. Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research* 95, 649–655.
- Chen, C.-B., Klein, C.M., 1997. An efficient approach to solving fuzzy MADM problems. *Fuzzy Sets and Systems* 88, 51–67.
- Chen, S.J., Hwang, C.L., 1992. Fuzzy Multiple Attribute Decision Making Methods and Applications. In: *Lecture Notes in Economics and Mathematical Systems*, vol. 375. Springer-Verlag, New York.
- Chen, S.H., 1985. Ranking fuzzy members with maximizing set and minimizing set. *Fuzzy Sets and Systems* 17, 113–129.
- Cronbach, L.J., 1951. Coefficient alpha and the internal structure of tests. *Psychometrika* 16, 297–334.
- Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P., 1998a. Supplier network development. In: Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P. (Eds.), *Global Operations and Logistics: Text and Cases*. Wiley, New York, pp. 146–171.
- Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P., 1998b. Logistics network design for global operations. In: Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P. (Eds.), *Global Operations and Logistics: Text and Cases*. Wiley, New York, pp. 251–305.
- Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P., 1998c. Organizational structure for global logistics excellence. In: Dornier, P.-P., Ernst, R., Fender, M., Kouvelis, P. (Eds.), *Global Operations and Logistics: Text and Cases*. Wiley, New York, pp. 440–441.
- Dubois, D., Prade, H., 1980. *Fuzzy Sets and Systems: Theory and Applications*. Academic Press, New York.
- Fawcett, S.E., 1992. Strategic logistics in coordinated global manufacturing success. *International Journal of Production Research* 30 (4), 1081–1099.
- Goldsborough, W., 1992. Global logistics management: gaining a competitive edge through integrated systems. Report no. 818, Business Intelligence Program, SRI International.
- Khorranshahgol, R., Azani, H., Gousty, Y., 1988. An integrated approach to project evaluation and selection. *IEEE Transactions on Engineering Management* 35 (4), 265–270.
- Kogut, B., 1985. Designing global logistics: profiting from operational flexibility. *Sloan Management Review* (Fall), 27–38.
- Laarhoven, P.J.M., Pedrycz, W., 1983. A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems* 11, 229–241.
- Levary, R.R., Wang, K.A., 1998. A simulation approach for handling uncertainty in the analytic hierarchy process. *European Journal of Operational Research* 106, 116–122.
- Lootsma, F., 1997. *Fuzzy Logic for Planning and Decision-Making*. Kluwer, Dordrecht.
- MacCormack, A.D., Newman III, L.J., Rosenfield, D.B., 1994. The new dynamics of global manufacturing site location. *Sloan Management Review* (Summer), 69–80.
- MacKay, D.B., Bowen, W.M., Sinnes, J.J., 1996. A Thurstonian view of the analytic hierarchy process. *European Journal of Operational Research* 89, 427–444.
- Min, H., LaTour, M., Williams, A., 1994. Positioning against foreign supply sources in an international purchasing environment. *Industrial Marketing Management* 23, 371–382.
- Ohmae, K., 1989. The global logic of strategic alliances. *Harvard Business Review* (March–April), 143–154.
- Ramanathan, R., 1997. A note on the use of goal programming for the multiplicative AHP. *Journal of Multi-Criteria Decision Analysis* 6, 296–307.
- Ribeiro, R.A., 1996. Fuzzy multiple attribute decision making: a review and new preference elicitation techniques. *Fuzzy Sets and Systems* 78, 155–181.
- Rosenbloom, E.S., 1997. A probabilistic interpretation of the final rankings in AHP. *European Journal of Operational Research* 96, 371–378.

- Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* 15, 234–281.
- Saaty, T.L., 1980. *The Analytic Hierarchy Process*. McGraw-Hill, New York.
- Saaty, T.L., Vargas, L.G., 1987. Uncertainty and rank order in the analytic hierarchy process. *European Journal of Operational Research* 32, 107–117.
- Sheu, J.-B., Wu, W.-M., 2001. The application of global logistics to establishment of the optimal decision-making model for the operations of the high-tech industry in Taiwan. Research Report of the National Science Council of Taiwan, NSC 89-2416-H-327-02, Taiwan.
- Triantaphyllou, E., Mann, S.H., 1995. Using the analytic hierarchy process for decision making in engineering applications: some challenges. *International Journal of Industrial Engineering: Applications and Practice* 2 (1), 35–44.
- Uppuluri, V.R.R., 1983. Expert opinion and methods. Oak Ridge National Laboratory, NRC FIN Report no. B044, Oak Ridge, TN, 37830.
- Vargas, L.G., 1982. Reciprocal matrices with random coefficients. *Mathematical Modeling* 3 (1), 69–81.
- Venter, V., Dincer, M.C., 1995. Global manufacturing strategy. In: Drezner, Z. (Ed.), *Facility Location: A Survey of Applications and Methods*. Springer-Verlag, New York, pp. 263–282.
- Wabalickis, R.N., 1988. Justification of FMS with the analytic hierarchy process. *Journal of Manufacturing Systems* 17, 175–182.
- Wheelen, T.L., Hunger, J.D., 1998. Strategy formulation: functional strategy and strategic choice. In: Wheelen, T.L., Hunger, J.D. (Eds.), *Strategic Management and Business Policy: Entering the 21st Century Global Society*. Addison-Wesley, California, pp. 159–181.
- Yu, C.-S., 2002. A GP-AHP method for solving group decision-making fuzzy AHP problems. *Computers and Operations Research* 29, 1969–2001.
- Zimmermann, H.J., 1987. *Fuzzy Sets, Decision Making, and Expert System*. Kluwer Academic Publishers, Dordrecht.