行政院國家科學委員會專題研究計畫　成果報告

先進反應需求式物流輸配送營運模式之研究

計畫類別：個別型計畫
計畫編號：NSC92-2416-H-009-005-
執行期間：92 年 08 月 01 日至 93 年 07 月 31 日
執行單位：國立交通大學交通運輸研究所

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報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 93 年 8 月 31 日

A Hybrid Fuzzy-based Approach for Identifying Global Logistics Strategies

Transportation Research Part E 40(1), 39-61 (**NSC 92-2416-H-009-005; SCI, SSCI, EI**)

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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.

Keywords: *Global logistics*; *Fuzzy-AHP*; *Fuzzy-MADM*; *Production research*; *Transportation*

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 et al., 1996; Dornier et al., 1998c), where GL is termed a form of geographically integrated logistics.

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 et al., 1989; Ohmae, 1989; Min et al., 1994); or to qualitative analyses in international supply chain scenarios (Goldsborough, 1992; Bartmess et al., 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 et al. (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 et al. (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; Verter et al., 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

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[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 et al., 1980; Zimmermann, 1987; Chen et al., 1992). Nevertheless, there are some issues, e.g., cumbersome computations and complicated computer programming, still remaining in existing Fuzzy-MADM approaches (Chen et al., 1997), which may limit their applicability for real-world unstructured decision-making

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 et al., 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).

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 to 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

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problems, such as the GL issues addressed in this study.

[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 et al., 2001), and omitted in this paper.

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.

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

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

Figure 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 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.

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

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.

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

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

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

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.

Fig. 7. Framework of the proposed method

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 advanced analytical method improved from Saaty's analytic hierarchy process (Saaty, 1977; Saaty, 1980), which is a well-know 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 et al., 1990; Triantaphyllou et al., 1995). Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers' judgments, fuzzyness 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 et al., 1983; Buckley, 1985; 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 et al., 1987; Basak et al., 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 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.

Fig. 8. The hierarchic framework of GL operational strategies

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 ε_{ij}^{k} of the pairwise comparison matrix associated with components *i* and *j* of layer *k* is given by $\varepsilon_{ij}^{k} = s_i^k / s_j^k$, 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 ε_{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 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, 1985). 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

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

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

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 weights of fuzzy positive reciprocal matrices, as explicated in the prior literature (Aczel et al., 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 $\lambda - \max$ 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 et al., 1997; Ramanathan, 1997; Levary et al., 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):

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

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

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, 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:

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

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

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

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.

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

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

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

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

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

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.

Fig. 9. Fuzzy membership functions for qualitative criteria

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

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

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

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

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

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

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

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

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

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

where $\nu_i^k(\lambda)$ is the un-weighted criterion associated with the component *i* of layer *k* of

GL-mode λ, with mathematical form

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

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.

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**

IF $\left[\omega_i^k \times \mu_T(A_{i,j}^{k,l})\right] \geq \eta_i^k(\lambda)$ for all *i* and *k* (19)

THEN Get the GL-mode λ involved in the strategy recommendation list ($\boldsymbol{\lambda}^*$); and associate the recommended GL-mode λ with a relative priority index π_λ^l, which is given by

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

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 $\left[\omega_i^k \times \mu_T(A_{i,j}^{k,l})\right]$ 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.

Table 1. Summary of Cronbach's α test results

The test results shown in Table 1 generally indicated the acceptability of the survey data. As can be seen in Table 1, all the thirteen 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, 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., ε_{ij}^2 and ε_{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.

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

Table 3. Estimated pairwise comparison significance matrix for GL layer 2

Table 4. Estimated pairwise significance comparison matrix for GL layer 3

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.

Table 5. Summary of the estimated fuzzy weights

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 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.

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

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.

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 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 $\left[\omega_i^k \times \mu_T(A_{i,j}^{k,l})\right] - \eta_i^k(\lambda)$[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 ten Taiwanese IC manufacturing enterprises (termed *E*-1 to *E*-10 for short) are targeted for the interview survey. Out of these ten 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

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[3] Given a strategic component *i* of layer *k*, a negative value of the measurement of $\left[\omega_i^k \times \mu_T(A_{i,j}^{k,l})\right]$ minus the predetermined value of $\eta_i^k(\lambda)$ may indicate that the improvement associated with the strategic component *i* of

these enterprises were asked to qualitatively assess the potential performance with respect to each GL 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.

Table 7. Numerical results for GL-mode identification

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 ten 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 ten, 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

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layer k is needed in order to efficiently execute the current GL operational mode.

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.

Acknowledgements

This research was supported by grant NSC 92-2416-H-009-005 from the National Science Council of Taiwan. The author would like to thank the referees for their helpful comments. Also, special thanks to Professor Wayne K. Talley for his valuable suggestions to improve this paper. Any errors or omissions remain the sole responsibility of the author.

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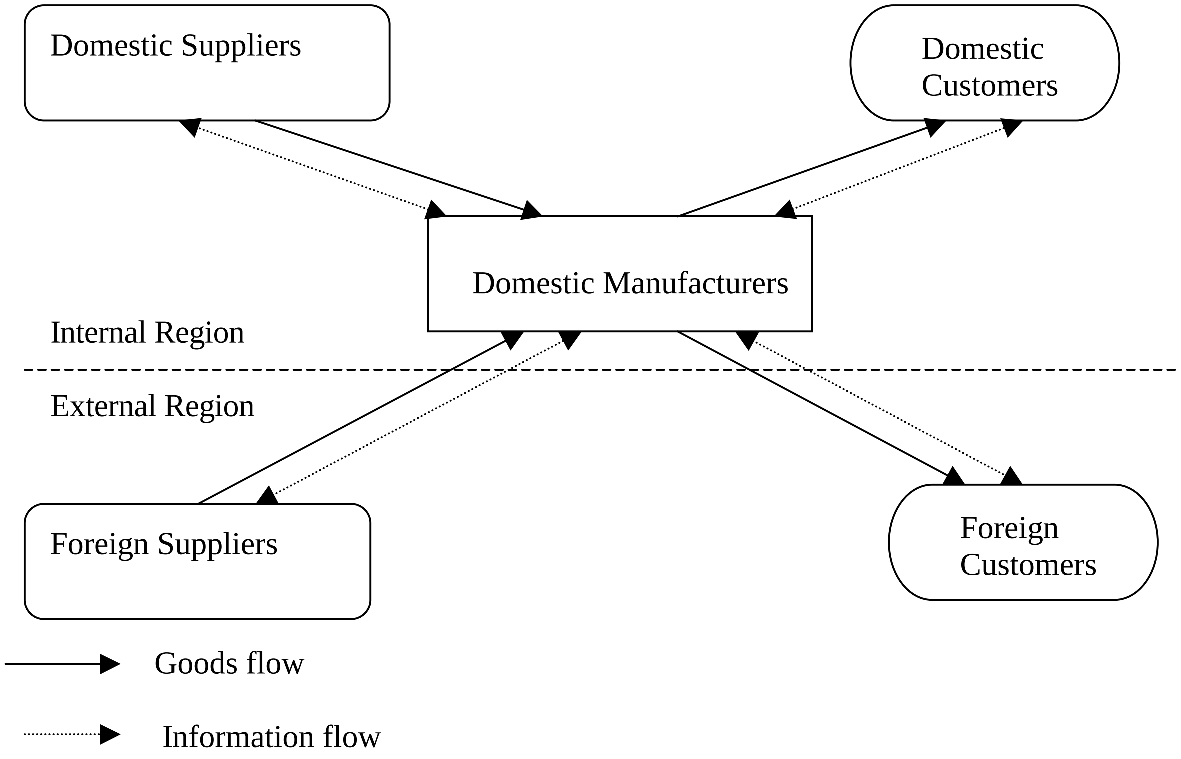

Fig. 1. Global logistics mode *A* (GL-mode *A*)

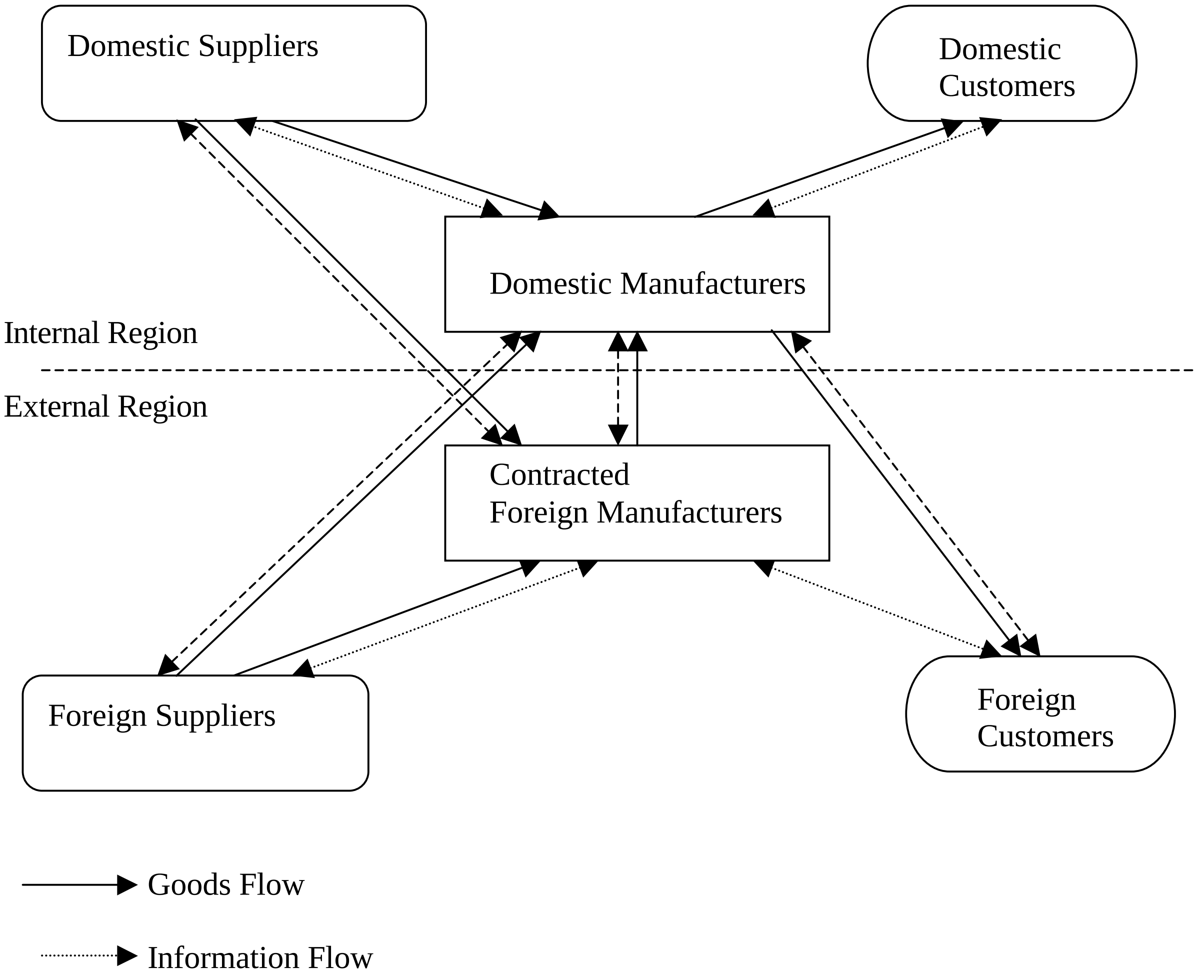

Fig. 2. Global logistics mode *B* (GL-mode *B*)

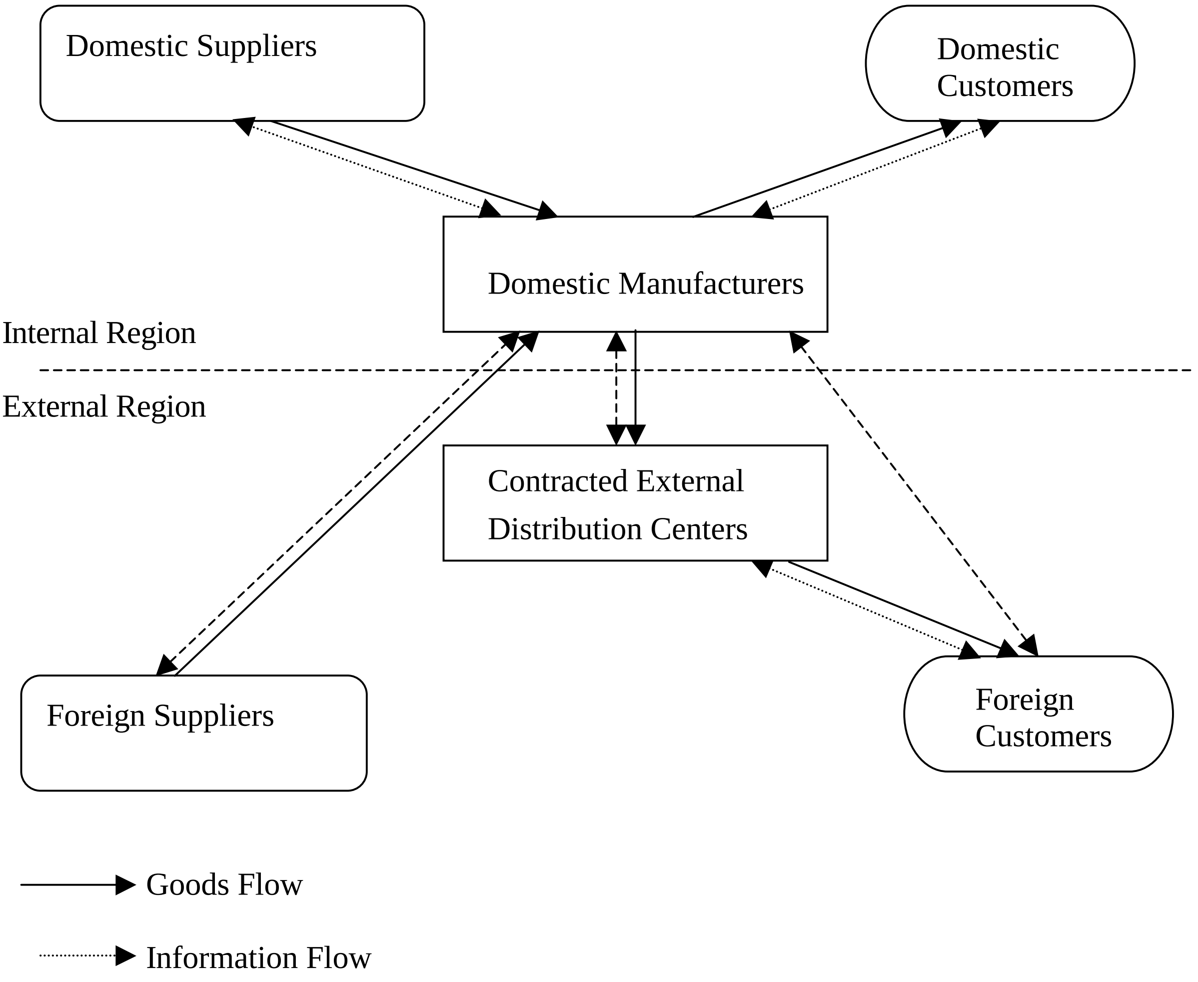

Fig. 3. Global logistics mode *C* (GL-mode *C*)

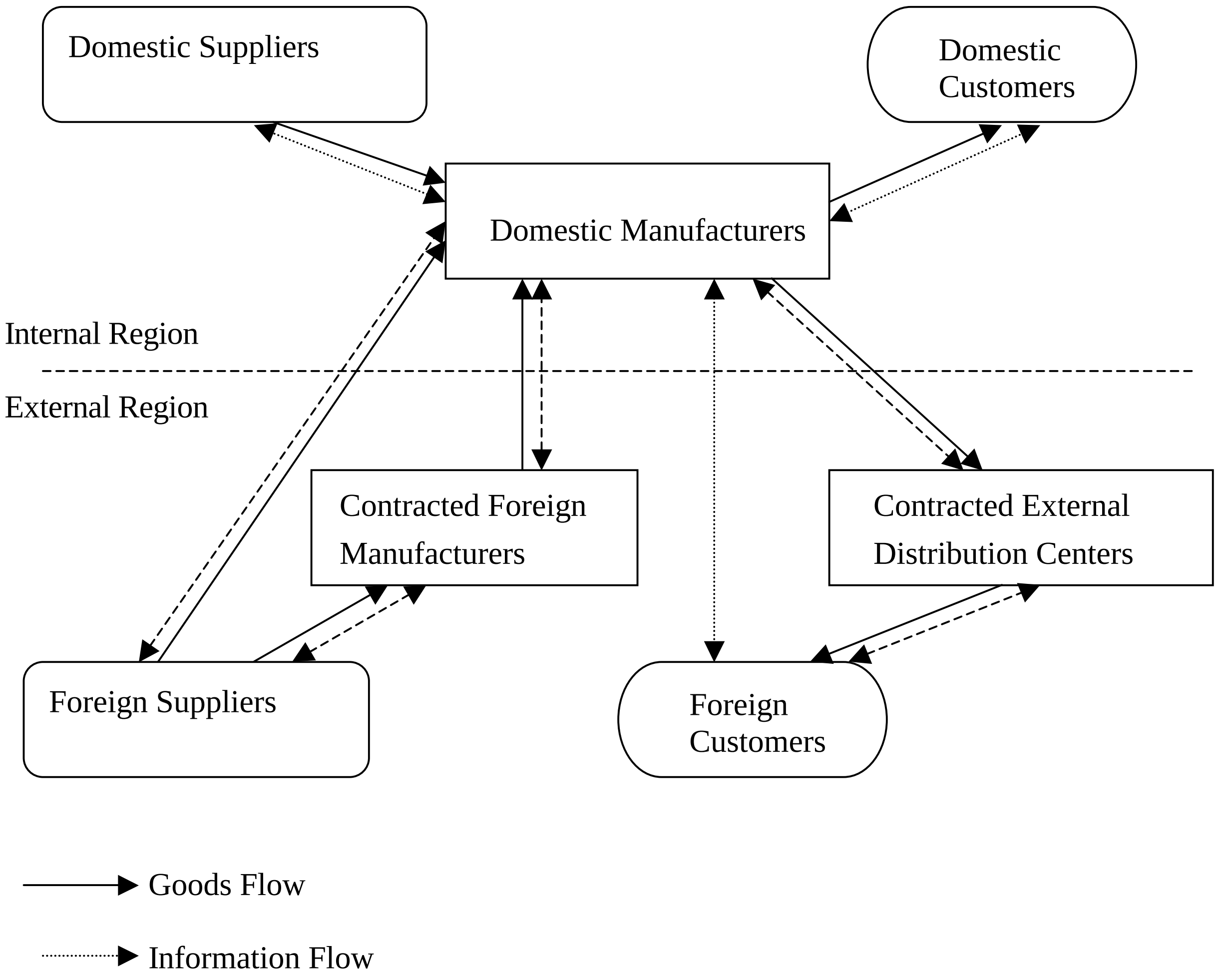

Fig. 4. Global logistics mode *D* (GL-mode *D*)

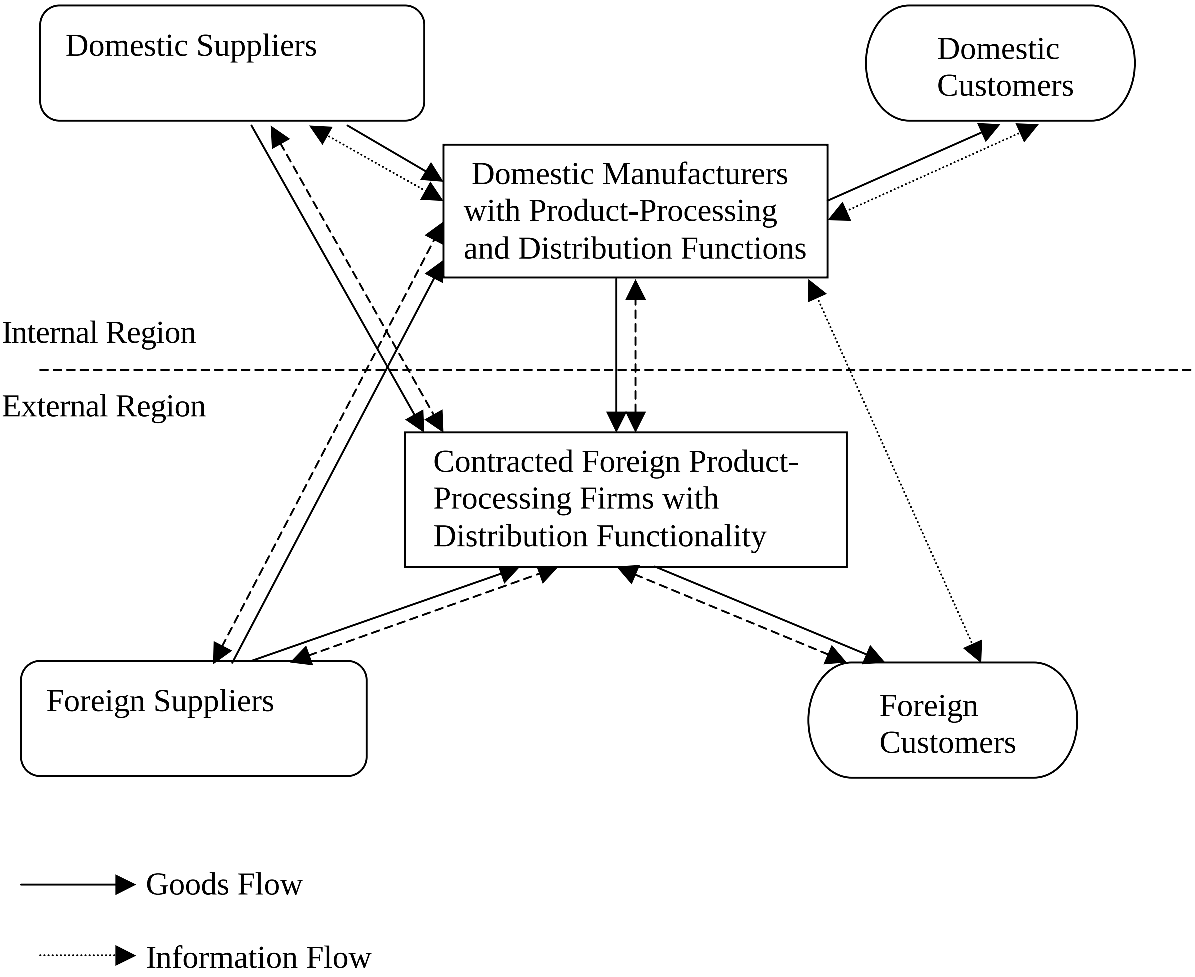

Fig. 5. Global logistics mode *E* (GL-mode *E*)

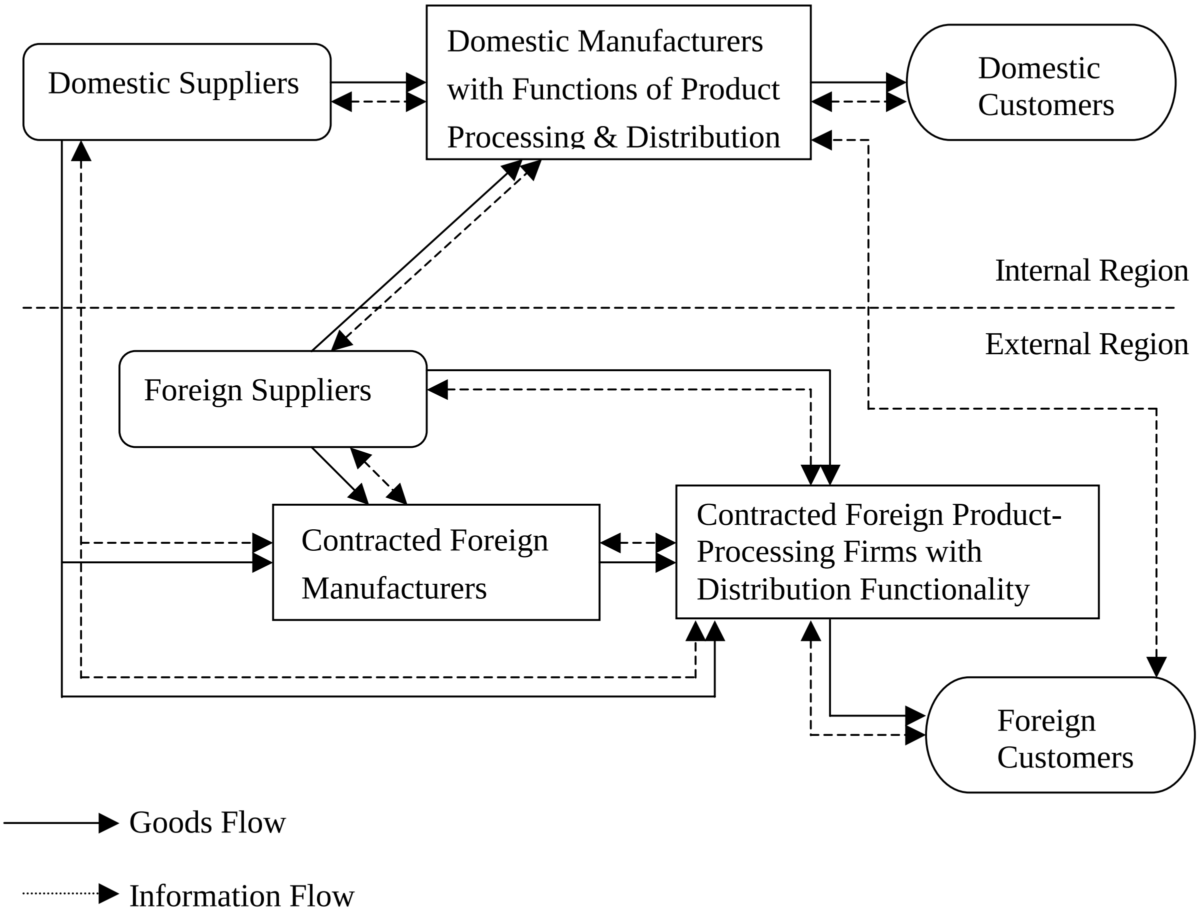

Fig. 6. Global logistics mode *F* (GL-mode *F*)

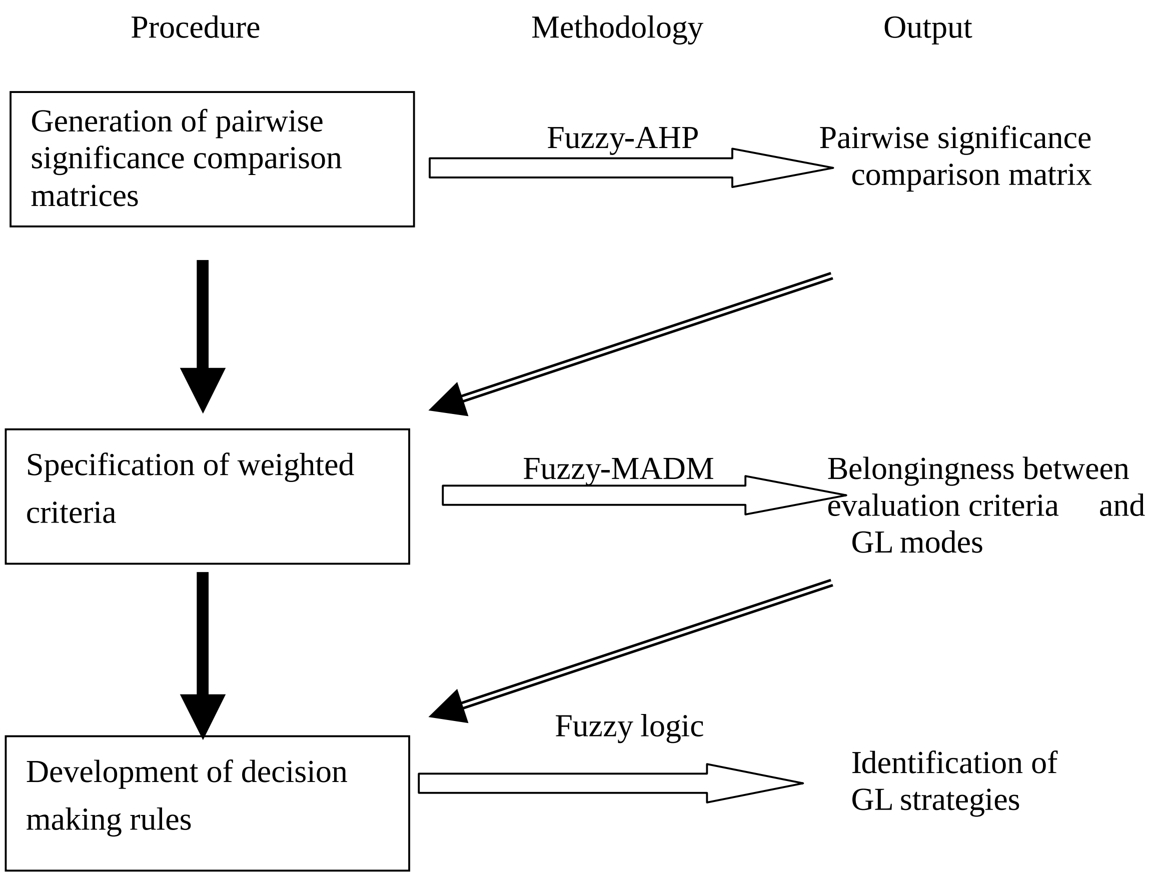

Fig. 7. Framework of the proposed method

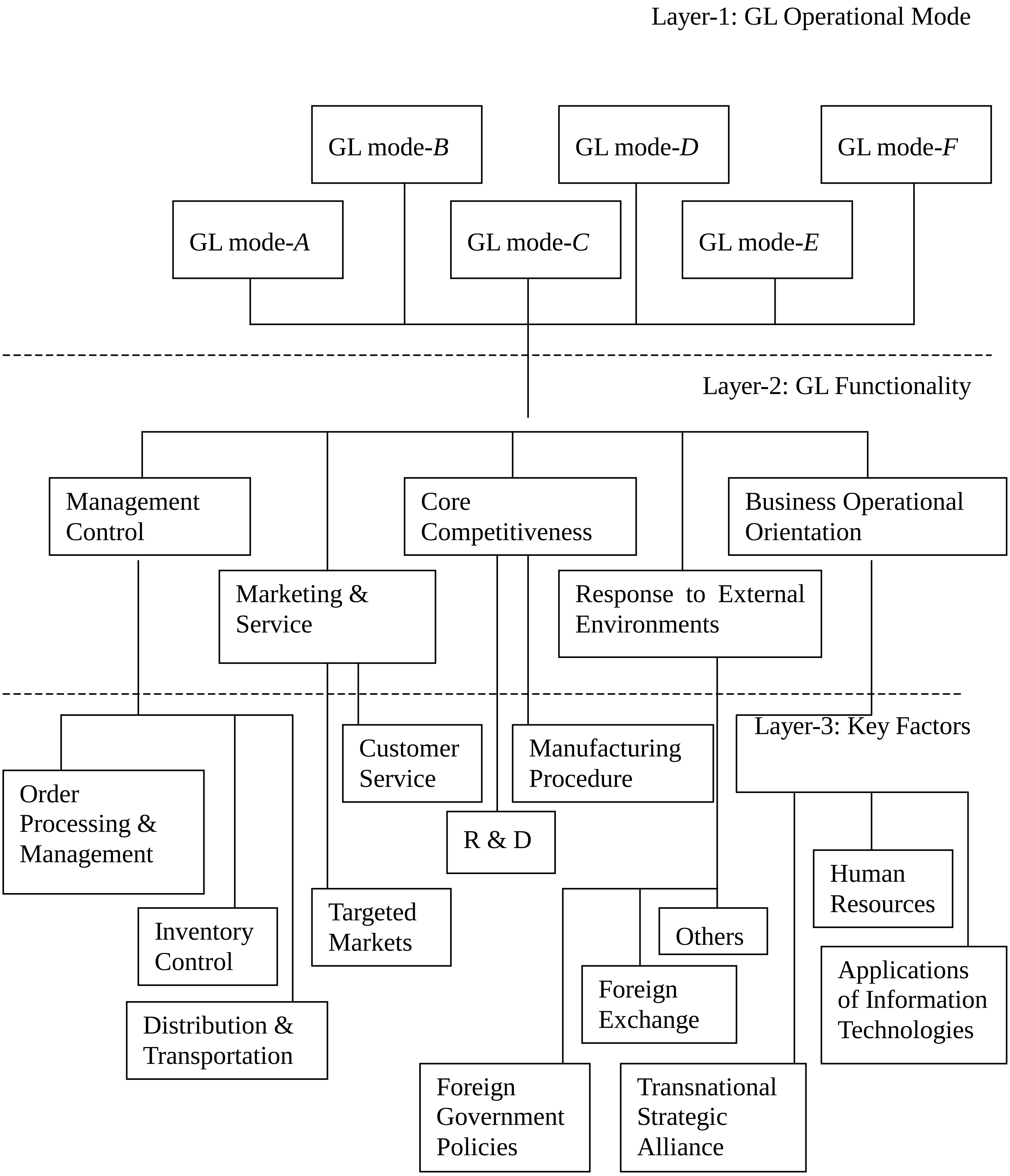

Fig. 8. The hierarchic framework of GL operational strategies

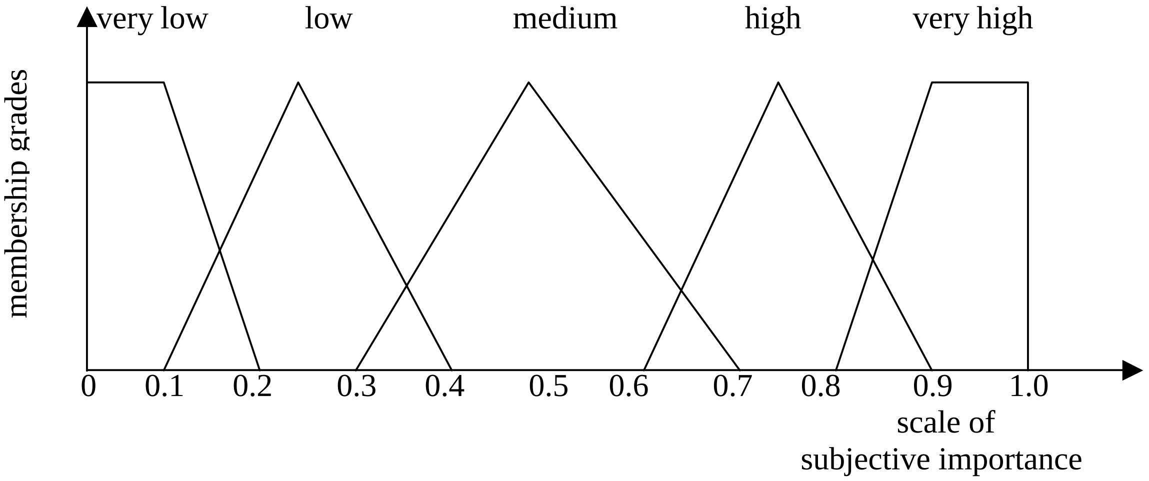

Fig. 9. Fuzzy membership functions for qualitative criteria

Table 1. Summary of Cronbach’s α test results

GL Layer 2		
Component	Cronbach’s α value	Result
1. Management Control	0.87	highly acceptable
2. Core Competitiveness	0.84	highly acceptable
3. Business Operational Orientation	0.79	highly acceptable
4. Marketing & Service	0.81	highly acceptable
5. Response to External Environments	0.77	highly acceptable
GL Layer 3		
Component	Cronbach’s α value	Result
1. Order Processing & Management	0.78	highly acceptable
2. Inventory Control	0.75	highly acceptable
3. Distribution & 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

Layer 2	
Component (coded as U_i)	Aggregated Ordinal Number
U_1: Management Control	4
U_2: Core Competitiveness	5
U_3: Business Operational Orientation	3
U_4: Marketing & Service	2
U_5: Response to External Environments	1
Layer 3	
Component (coded as x_i)	Aggregated Ordinal Number
x_1: Order Processing & Management	9
x_2: Inventory Control	6
x_3: Distribution & 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

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

Layer 2	
Component (coded as U_i)	Fuzzy Weight
U_1: Management Control	0.267
U_2: Core Competitiveness	0.334
U_3: Business Operational Orientation	0.200
U_4: Marketing & Service	0.133
U_5: Response to External Environments	0.066
Layer 3	
Component (coded as x_i)	Fuzzy Weight
x_1: Order Processing & Management	0.095
x_2: Inventory Control	0.062
x_3: Distribution & 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

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

Layer 2						
Component (coded as U_i)	Fuzzy-Weight Criteria					
	mode-*A*	mode-*B*	mode-*C*	mode-*D*	mode-*E*	mode-*F*
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 & 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
Layer 3						
Component (coded as x_i)	Fuzzy-Weight Criteria					
	mode-*A*	mode-*B*	mode-*C*	mode-*D*	mode-*E*	mode-*F*
x_1: Order Processing & 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 & 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

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