European Journal of Operational Research 200 (2010) 63–73

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

A hybrid fuzzy integral decision-making model for locating manufacturing centers in China: A case study

Cheng-Min Feng [a,*], Pei-Ju Wu [a,1], Kai-Chieh Chia [b,2]

[a] Institute of Traffic and Transportation, National Chiao Tung University, 4F, 118, Sec. 1, Chung Hsiao W. Rd., Taipei 10012, Taiwan, ROC
[b] Department of Business Administration, Soo Chow University, 56, Sec. 1, Kuei-Yang Street, Taipei 10012, Taiwan, ROC

A R T I C L E I N F O

Article history:
Received 24 February 2006
Accepted 6 December 2008
Available online 16 December 2008

Keywords:
Location
Manufacturing center
Hybrid decision model
Fuzzy integral
Multiple criteria

A B S T R A C T

This study presents a hybrid fuzzy integral decision-making model that integrates factor analysis, interpretive structural modeling, Markov chain, fuzzy integral and the simple additive weighted method for selecting locations of high-tech manufacturing centers in China. The analytical results of this case study demonstrate the feasibility of the proposed model for solving fuzzy multiple attribute decision-making problems, especially when criteria are interdependent. Further, the empirical study brings out some properties that are crucial for high-tech manufacturing centers to invest in China.

1. Introduction

Over the past decade, many Taiwanese manufacturing enterprises have modified the processes and activities of their supply chains to enhance competitiveness in an increasingly globalized economy. Global competition has also imposed tremendous pressure on manufacturing enterprises to transform and adjust their supply chain operations. Meanwhile, countries with considerably low worker salaries have attracted enterprises to relocate manufacturing activities (Bock, 2008). Based on this trend, many Taiwanese enterprises have relocated their supply chain activities and have advanced into Mainland China to capture comparative advantages in production costs.

When configuring global supply chains, the manufacturing processes of a product are often distributed across multinational borders. Complicating factors therefore arise, such as duties, trade blocks, exchange rates, transfer prices, taxes and production import/export quotas (Vidal and Goetschalckx, 2001; Goetschalckx et al., 2002; Lakhal et al., 2005; Leung et al., 2007). Moreover, agglomerated economies usually drive the location decisions of enterprises. Figueiredo et al. (2002) indicated that overseas location choices are strongly governed by agglomeration economies and proximity to major urban centers, possibly replicating prior location decisions to economize on search costs. Blonigen et al. (2005) also demonstrated that the location decisions of enterprises are affected by membership in either vertical or horizontal keiretsu. Other important location factors include labor climate, land costs and utilities, proximity to markets and customers, industrial development incentives and quality of life (Sarkis and Sundarraj, 2002; Coyle et al., 2003).

Aside from the above factors, it should be noted that, in China, most logistics activities are administered or controlled by the government (Luk, 1998). Sheu (2003) further pointed out several critical issues of the facility location problem in China such as the diversity of local governmental regulations in logistics, cultural differences, etc.

Additionally, model formulations and solution algorithms for the location problem have been proposed and extensively developed over the past several decades. Herein, some studies synthesize an extensive array of past research concerning the evolution of location literature. For example, ReVelle and Eiselt (2005) reviewed many facets of location analysis by referencing both seminal works and current reviews. Further details can be found elsewhere (Vidal and Goetschalckx, 1997; Min et al., 1998; Owen and Daskin, 1998; Goetschalckx et al., 2002; Díaz-Báñez et al., 2004; Klose and Drexl, 2005; Alumur and Kara, 2008). However, the above methods are hard to deal with some qualitative factors regarding this problem.

In real-world systems, manufacturing center location decisions may involve conflicts between the above factors. However, most criteria are interdependent or interactive, so they cannot be evaluated by conventional additive measures. Further, the values of the qualitative criteria are often imprecisely defined by decision

* Corresponding author. Tel.: +886 2 2349 4956; fax: +886 2 2349 4965.
E-mail address: cmfeng@mail.nctu.edu.tw (C.-M. Feng).
[1] Tel.: +886 2 2349 4956; fax: +886 2 2349 4965.
[2] Tel.: +886 2 2311 1531; fax: +886 2 2371 7990.

0377-2217/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2008.12.004

makers under many situations. Considering many different criteria to evaluate facility location candidates may yield a vast body of data that are often inaccurate or uncertain. Doukas et al. (2007) indicated that using crisp values in the decision-making problem may oversimplify the imprecision and subjectivity of related information. Sheu (2008) also mentioned that most decision-making approaches, *e.g.*, analytic hierarchy process (AHP), appear inadequate for imprecise and vague comparisons of qualitative criteria.

The purpose of this research is therefore to develop a hybrid fuzzy integral decision-making model for locating manufacturing centers in China which combines factor analysis, interpretive structural modeling (ISM), Markov chain, fuzzy integral and the simple additive weighted (SAW) method. Real-world case studies show that the proposed model is a suitable method for solving the location decision problem, particularly when the criteria are not independent. Moreover, the empirical data reveal some properties that are critical for high-tech manufacturing centers investing in China.

The rest of this paper is organized as follows. Section 2 presents the architecture of the proposed hybrid fuzzy integral decision-making model and its primary procedures. Section 3 describes a case study to demonstrate the feasibility of the proposed method and to further analyze the case study findings. Finally, Section 4 summarizes the conclusions of the study.

2. Methodology

Appropriate locations were identified using a hybrid fuzzy integral decision-making method. The proposed approach involves five procedures. Fuzzy set theory is also applied to weight criteria as well as the performance values of alternatives. Fig. 1 presents the framework of the proposed hybrid fuzzy integral decision-making model, and the main details are presented in the following subsections.

2.1. Extracting common factors by factor analysis

Since the decision criteria are not completely independent, factor analysis can be introduced to extract common factors where the factors are mutually independent.

Hence, factor analysis can reveal latent structures (dimensions) of a set of variables and reduce attribute space from a larger number of variables to a smaller number of factors. For example, from Fig. 1 the set of $\{x_1^F, x_2^F\}$ is in the same aspect and the set of $\{x_3^F, x_4^F, x_5^F, x_6^F\}$ is in the other aspect through factor analysis, where superscript F is termed a form of factor analysis.

2.2. Structuring the criteria relationship by ISM

Traditional pairwise comparison matrices assumed that the relationship of the criterion x_i^F affected by the criterion x_j^F is analogous to how criterion x_j^F is affected by the criterion x_i^F. However, the relationship between x_i^F and x_j^F may have different effects. Therefore, ISM technology was used to cope with the above problem.

ISM (Warfield, 1974a,b, 1976; Huang et al., 2005) is a computer-assisted methodology to construct and understand the fundamental of the relationships of the criteria in complicated situations or systems. The theory of ISM is based on discrete mathematics, group decision-making, graph theory, computer assistance, and social sciences (Huang et al., 2005). The ISM procedures were implemented through individual or group mental models to calculate binary matrices, also called relation matrices, to present the relations of the criteria (Huang et al., 2005). A relation matrix can be formed by asking a question (Huang et al., 2005) such as "Does criterion x_i^F affect criterion x_j^F? "If the answer is "Yes" then $\pi_{ij} = 1$; otherwise, $\pi_{ij} = 0$. From Fig. 1, the first aspect of the relation matrix can be presented as follows:

$$R = \begin{array}{c} \\ x_1^F \\ x_2^F \end{array} \begin{array}{c} \begin{array}{cc} x_1^F & x_2^F \end{array} \\ \begin{bmatrix} 0 & \pi_{12} \\ \pi_{21} & 0 \end{bmatrix} \end{array}, \tag{1}$$

where x_1^F is the *1*th criterion, π_{12} denotes the relation between *1*th and *2*th criteria, R is the relation matrix.

After constructing the relation matrix, the reachability matrix can be calculated using the following equations:

$$E = R + I, \tag{2}$$

$$E^* = E^k = E^{k+1}, \quad k > 1, \tag{3}$$

where I is the unit matrix, k denotes the powers, and E^* is the reachability matrix. Thereafter, the original pairwise comparison matrix is transferred to ISM pairwise comparison matrix based on the reachability matrix E^*. Restated, ISM pairwise comparison matrix creates zeros according to the corresponding position in the reach-

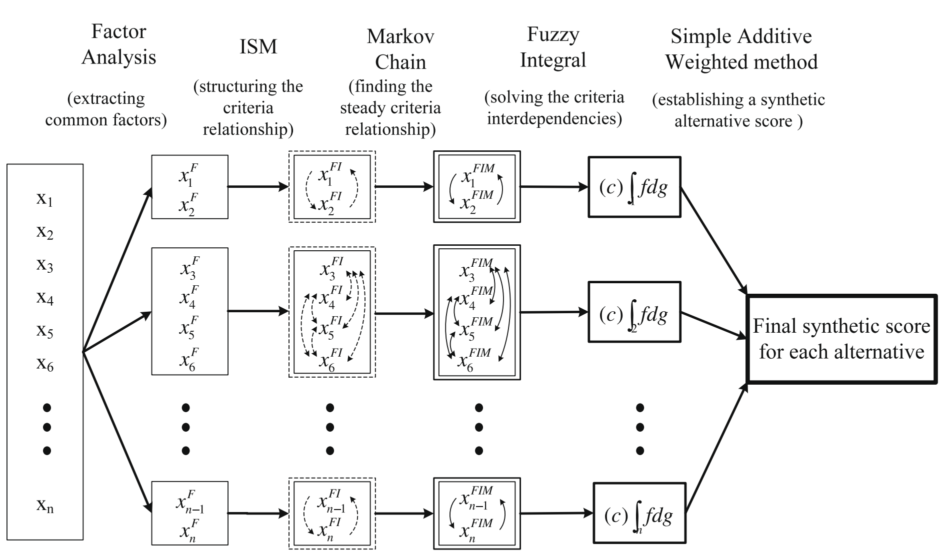

Fig. 1. Framework of the proposed method.