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A hybrid intelligent fuzzy predictive model with simulation for supplier evaluation and selection

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ABSTRACT

Supplier evaluation and selection constitutes a central issue in supply chain management (SCM). However, the data on which to base the corresponding choices in real life problems are often imprecise or vague, which has led to the introduction of fuzzy approaches. Predictive intelligent-based techniques, such as Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS), have been recently applied in different research fields to model fuzzy multi-criteria decision processes where the understanding and learning of the relationships between the input and output data are the key to select suitable solutions. In this paper, a hybrid ANFIS-ANN model is proposed to assist managers in their supplier evaluation process. After aggregating the data set through the Analytical Hierarchy Process (AHP), the most influential criteria on the suppliers' performance are determined by ANFIS. Then, Multi-Layer Perceptron (MLP) is used to predict and rank the suppliers' performance based on the most effective criteria. A case study is presented to illustrate the main steps of the model and show its accuracy in prediction. A battery of parametric tests and sensitivity analyses has been implemented to evaluate the overall performance of several models based on different effective criteria combinations.

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1. Introduction

In today's competitive world, decision making represents a very complicated process at basically all levels. It is undoubtedly hard for decision makers to select the best alternative based on several attributes/criteria/factors, particularly when the information on which to rely is incomplete or imprecise. Multi-Criteria Decision Making (MCDM) is the main research field dealing with the complexity of both evaluation and selection problems and their possible solution methods.

Several MCDM techniques have been presented to support decision makers through their decision making processes, including the Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP), Data Envelopment Analysis (DEA), Mathematical Programming (MP) and hybrid models combing the previous and other ranking techniques. Each one of these methods has its advantages and limitations. For instance, AHP and ANP are easy to use, but rely heavily on human judgment, especially in determining the weights of criteria (Vahdani, Iranmanesh, Mousavi, & Abdollahzade, 2012). DEA is sensitive to outliers and statistical noise (Azadeh, Saberi, & Anvari, 2011) while MP models are very precise but do not consider qualitative attributes (Golmohammadi, 2011). We will often refer to Golmohammadi (2011) through the current paper. Thus, we will denote this reference by GHD henceforth.

In the last decades, Artificial Intelligence (AI) has been receiving more attention in the decision making literature. The AI approach is usually twofold: prediction, which constitutes the focus of this paper, and optimization. Prediction is carried out by implementing different techniques such as Artificial Neural Network (ANN), Adaptive Neuro Fuzzy Inference System (ANFIS) and Support Vector Machine (SVM), which enable decision makers to take the best possible decision (output) based on past and present information and future predictions (input) (GHD).

Decisions concerning the evaluation and selection of the right suppliers play a fundamental role in all manufacturing activities.

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Two main problems arise when selecting the best possible alternative: determining the proper criteria and assessing the performance of the alternatives on the basis of the selected criteria. Theoretically, there might be many factors affecting the performance of the available alternatives but, in practice, only a few criteria determine the evaluation process. An unnecessary large number of inputs not only weakens the clarity of the underlying model, but also increases its computational complexity (Jang, 1996). At the same time, the existence of conflicting criteria (i.e. cost and quality, responsiveness and flexibility) complicates the identification of the main ones determining the performance of the alternatives. Therefore, a powerful enough method is needed to find the most important criteria (inputs) and use them to identify the best performing alternative (output).

The main objective of the current paper is to illustrate how two ANN approaches such as ANFIS and the ANN architecture known as Multi-Layer Perceptron (MLP) can complement each other in the design of a supplier selection framework with incomplete information. In this regard, the strategic integration of ANFIS within the initial stages of an MLP-based supplier evaluation model constitutes the main contribution of this paper. The capacity of ANN to replicate the behavior of the alternatives becomes particularly important when data on a given alternative are missing. At the same time, ANFIS allows us to identify the most influential combinations of characteristics that can be used to replicate the performance of the potential suppliers and evaluate their behavior. That is, consider a situation where the decision maker has limited information processing capacity or faces a very large set of supplier characteristics. In this case, the decision maker can use ANFIS to select a subset of characteristics that allow him to classify the alternatives via MLP with the same confidence as if he was able to use the entire set of data.

In order to show its applicability to decision making situations, the proposed model has been implemented in a case study involving an automotive industry whose alternatives are the suppliers of the company. Moreover, in order to test its effectiveness, the results derived from our ANFIS-ANN framework have been compared with those obtained using only the ANN model. This comparison shows that the proposed model is more accurate. As a result, it can be applied to a large class of MCDM problems and implemented by managers to rank alternatives without having to continuously update their judgments (data set) or when lacking a subset of observations from a given alternative.

The paper proceeds as follows. Section 2 provides a short review of the related literature on decision making. Section 3 presents the methodology, while Section 4 illustrates the case study discussing the data collection and the results derived from the model. In Section 5, the performance of the model is evaluated using different statistical tests and compared with the results provided by other techniques. Section 6 discusses the applicability of our hybrid model to real-life supplier evaluation problems. Finally, Section 7 concludes.

2. Literature review

2.1. Supply chains and their evolution

The academic research on supply chains has evolved through time while emphasizing the following characteristics of the chain:

- Initially, it mainly focused on the pecuniary incentives motivating the vertical integration and quasi-integration of firms (Blois, 1972; Houssiaux, 1957). In particular, researchers acknowledged the fact that the costs of integrating operations within the chain could be smaller than those of contracting due to the existence of appropriable quasi-rents and the possibility of default by other firms (Aoki, 1988; Klein, Crawford, & Alchian, 1978).
- The literature moved towards emphasizing cooperation in the organization of vertical markets when accounting for the circulation of information and technology across the chain (Colombo & Mariotti, 1998; Esposito & Passaro, 2009). The emergence of trust between firms (Day, Fawcett, Fawcett, & Magnan, 2013; Sako, 1992), and the existence of different knowledge and technology capacities within the chain followed as main research topics (Cannavacciuolo, Iandoli, Ponsiglione, & Zollo, 2015; Esposito & Raffa, 1994).
- The literature has lately emphasized the skill specificity acquired by suppliers through learning and technological investments (Asanuma, 1989; Day, Lichtenstein, & Samouel, 2015) together with the resilience of the chain to disruptions caused by unforeseen events (Heckmann, Comes, & Nickel, 2015; Hohenstein et al., 2015).

Recently, criticisms have been raised regarding the standard approaches focusing on data transmission to measure the interactions across supply chain partners. It has been argued that increasing the cooperation and integration of the different elements composing the chain (Stevens, 1989) requires a complex framework that goes beyond data and information transmission and considers the exchange of opinions, expertise and knowledge (Bessant, Kaplinsky, & Lamming, 2003; Frohlich & Westbrook, 2001; Gressgård & Hansen, 2015; Opengart, 2015). As a result, fuzzy methods have gained incremental attention when applied to manage the sharing of subjective opinions and expertise reports provided by different agents along the chain (Bruno, Esposito, Genovese, & Simpson, 2016; Labib, 2011).

2.2. MCDM and AI methods for supplier selection

MCDM methods have been successfully implemented in different research areas such as the textile industry, the automotive industry, civil engineering, banking and supply chains (Guneri, Ertay, & YüCel, 2011; Guneri, Yucel, & Ayyildiz, 2009; Opricovic & Tzeng, 2004; Wu, 2009; Wu, Yang, & Liang, 2006; GHD; Büyüközkan & Çifçi, 2012a, 2012b).

When considering supplier selection, the literature initially emphasized costs as the main selection criterion but the complexity of the supplier evaluation problem has led to the implementation of MCDM techniques (Bhutta, 2003), whose application has evolved significantly in the latter years (Parthiban, Zubar, & Katakar, 2013). In this regard, AHP has become a standard technique used to determine the relative importance of the selection criteria (Bruno, Esposito, Genovese, & Passaro, 2012). Moreover, AHP can be easily combined with other techniques such as DEA (Weber, Current, & Benton, 1991) and ANN (Ha & Krishnan, 2008) to obtain a final ranking of the alternatives. The use of AI-based methods remains generally limited in relation to other techniques (de Boer, Labro, & Morlacchi, 2001), a tendency that pervades nowadays (Chai, Liu, & Ngai, 2013). However, due to their capacity to replicate the behavior of suppliers, these latter methods become particularly useful when firms face incomplete information environments.

Several papers implementing AI-based methods such as ANN or ANFIS within different decision making environments are recalled below.

Choy, Lee, and Lo (2003) proposed a combined ANN-based model to choose and benchmark potential partners of Honeywell Consumer Products Limited in Hong Kong. Lee and Ou-Yang (2009) introduced an ANN-based predictive decision model for assessing vendors' performance. Guneri et al. (2011) proposed a predictive ANFIS-based model for both criteria selection and perfor-

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