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A model based on 2-tuple fuzzy linguistic representation and Analytic Hierarchy Process for supplier segmentation using qualitative and quantitative criteria

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ABSTRACT

The literature on supply base segmentation has increasingly adopted multi-criteria decision making (MCDM) techniques into recently proposed models. However, most proposals segment the supply base from the standpoint of the purchased item, which prevents them from providing guidelines that are specific to each supplier. Some authors have attempted to overcome these limitations by putting forward portfolio models based on the relationship with suppliers. These approaches use fuzzy variables and MCDM methods that take qualitative judgements by experts as the only input for decision making. However, many companies have databases with historical data about the performance of past transactions with suppliers that should be considered by expert systems that aim to comprehensively evaluate suppliers' performance. This paper seeks to address this gap by proposing a segmentation model based on the relationship with suppliers capable of aggregating quantitative and qualitative criteria. Analytic Hierarchy Process (AHP) was used to determine the relative importance of each criteria. Fuzzy 2-tuple, a prominent computing with word (CWW) approach, was used to evaluate suppliers with a mixture of historical quantitative data and qualitative judgements by purchasing experts. An illustrative application of the proposed model was carried out in the pharmaceutical supply center (PSC) of a teaching hospital. The proposed model can be viewed as a decision support system capable of aggregating the qualitative judgements of experts and quantitative historical performance measures, thus providing guidelines to improve the relationship between suppliers and the buyer firm.

1. Introduction

The participation of suppliers in the cost and value proposition of products has increased over the past few decades (Prajogo, Chowdhury, Yeung, & Cheng, 2012). Hence, supply management needs to be aligned with and contribute to the strategic objectives of the buyer firm (Abdollahi, Arvan, & Razmi, 2015; González-Benito, 2007). This process has to be efficient and well-structured because it consumes the firm's limited resources (Krause, 1997). According to Dyer, Cho, and Chu (1998), the segmentation of the supplier base, which consists in grouping together suppliers according to their similarities, is tantamount to any organization seeking to properly manage its supply process. Researchers and practitioners have emphasized the use of purchasing portfolio models for managing the supplier base due to their simplicity and effectiveness (Drake, Lee, & Hussain, 2013; Dubois & Pedersen, 2002; Gelderman & Weele, 2003).

The first purchasing portfolio model was introduced by Parasuraman (1980), who stablished a rational connection between consumer market and supplier base segmentation. The model, however, did not determine relevant variables for supplier segmentation. Kraljic (1983) addressed this gap by developing a practical purchasing portfolio model based on the purchased item's characteristics. The model has two dimensions that cover aspects that are both internal and external to the buyer firm. The internal criteria refer to the impact of the supplied item over the final product's cost and quality. External criteria are associated with supply risk and address issues as the number of potential suppliers and the bargaining power of suppliers. The combination of low and high levels of these dimensions results in four categories of purchased items: non-critical routine items (low impact and low risk), leverage items (high impact and low risk), bottleneck items (low

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impact and high risk) and strategic items (high impact and high risk). The model introduced by Kraljic (1983) is regarded in the literature as the most influential purchasing portfolio model (Caniels & Gelderman, 2007; Day, Magnan, & Munkgaard, 2010; Luzzini, Caniato, Ronchi, & Spina, 2012; Osiro, Lima-junior, & Carpinetti, 2014; Rezaei & Ortt, 2013a).

Other theoretical models based on internal and external dimensions were put forward by Nellore and Soderquist (2000); Olsen and Ellram (1997) and Pagell, Wu, and Wasserman (2010). In addition, several studies such as Ferreira, Arantes, and Kharlamov (2014), Lee and Drake (2010), Luo, Wu, Rosenberg, and Barnes (2009), Padhi, Wagner, and Aggarwal (2012), and Segura and Maroto (2017) used multi-criteria techniques to evaluate and aggregate the various criteria of these two dimensions and ultimately serve as a tool for supplier base assessment.

The segmentation based solely on the characteristics of the supplied item does not provide guidance on how suppliers of items of the same category, but with different performance levels, should be developed (Dubois & Pedersen, 2002; Rezaei & Ortt, 2012). According to Day et al. (2010), portfolio approaches should involve the analysis of buyer-supplier relationship to more effectively guide supplier development and value creation initiatives. In this sense, approaches that seek to analyse the buyer-supplier relationship, such as Bensaou (1999), Olsen and Ellram (1997) and Rezaei and Ortt (2012) have gained relevance.

Rezaei and Ortt (2012) developed a supplier portfolio model that has been combined with various multi-criteria decision making (MCDM) approaches. In order to focus on the long-term relationship between the buyer and its suppliers, the model has two dimensions: (i) supplier capabilities and (ii) supplier willingness to cooperate. The authors define supplier capabilities as the "*complex bundles of skills and accumulated knowledge, exercised through organizational processes that enable firms to co-ordinate activities and make use of their assets in different business functions that are important for a buyer*", whereas supplier willingness to cooperate refers to the "*confidence, commitment and motivation to engage in a (long-term) relationship with a buyer*".

When implementing a portfolio model, the buyer firm may choose multiple criteria to constitute each dimension. Some of them may be quantitative, thus deriving from numerical data concerning previous transactions between both parties. With the rise of information technologies as big data and the wide adoption of organizational information systems, companies now have databases with historical data concerning past transactions with suppliers. Such data can be compiled into quantitative performance measures that should be combined with qualitative assessment by purchasing experts to more comprehensively support decision making in the supply base management (Segura & Maroto, 2017). However, the approaches that build on Rezaei and Ortt's (2012) portfolio model, based on fuzzy variables and MCDM methods, rely solely on the decision maker's judgement to evaluate all criteria. Historical performance indicators with quantitative data have yet not been added to these approaches.

Supplier selection and evaluation is regarded in the literature as a very complex activity because it involves multiple criteria and often rely on experienced staff (Ho, Xu, & Dey, 2010; Sarkis & Talluri, 2002). Additionally, decisions regarding supplier selection and evaluation need to be made routinely, thus demanding considerable efforts by the purchasing department (Krause, Handfield, & Scannell, 1998). This calls for the development of expert systems, whose purpose is to model the knowledge of human experts and use computerized methods to replicate their decisions (Liao, 2005). Henceforth, the adoption of such decision support systems might improve efficiency of the supplier evaluation and selection processes, making them faster and enabling more complex analyses such as portfolio models to be conducted.

The literature on expert systems for supplier evaluation and selection is very complex, with the proposition of a wide variety of methods. Soft computing and artificial intelligence techniques such as fuzzy logic, neural networks, AHP, ANP (Analitic Network Process), TOPSIS and others MCDM methods have often been integrated in various configurations to propose new methods to evaluate, segment and select suppliers (Chai, Liu, & Ngai, 2013; Govindan, Rajendran, Sarkis, & Murugesan, 2015).

The supplier portfolio models based on supplier capabilities and willingness to cooperate found in the literature require great efforts by experts during the knowledge modelling phase. For example, Rezaei and Ortt (2013a) proposed the use of fuzzy rule-based systems, also known as fuzzy inference systems – FIS, to assess the two dimensions. In the evaluation of each criterion, the decision makers use scores ranging from 1 to 5 for their judgment. The greatest hurdle of this approach is the large number of rules that have to be created. Preference relations-based fuzzy AHP (Analytic Hierarchy Process) is used by Rezaei and Ortt (2013b) to evaluate the criteria. In their application, they used six criteria to evaluate supplier capabilities and another six criteria to evaluate supplier willingness to cooperate. The role of AHP is to determine the weights of the criteria in both dimensions. This lead to a consistent priority-ranking with experts having to make only $(n^2 - n)/2$ pairwise comparisons.

More recently, Rezaei, Wang, and Tavasszy (2015) proposed the application of a new MCDM method known as Best Worst Method to segment suppliers using their portfolio matrix. In their work, the evaluation of criteria aggregated in both dimension is based on judgments of experts. The weights of the criteria are defined after the decision makers conduct pairwise comparisons between the best criterion and the remaining criteria and between the worst criterion and the other criteria.

Osiro et al. (2014) proposed a fuzzy logic approach to supplier evaluation and development that has two matrices. The first classifies the purchased items and the second is used to evaluate the suppliers. The dimensions of the second matrix are delivery performance and potential for partnership, which are analogous to the dimensions used by Rezaei and Ortt (2012). Again, the evaluation of all the criteria derive from experts' judgements. The decision makers use scores ranging from 1 to 10 for their judgments and three linguistic terms are used in the fuzzification process.

It is also worth noting that the aforementioned supplier segmentation approaches did not include performance indicators with quantitative data. These approaches focused only on modeling knowledge and reaching consensus among the actors involved with the supply process. They did so with qualitative judgements made by experts as the only means to evaluate suppliers. The aim of this paper is thus to address this gap by presenting a new model for supplier segmentation that combines experts' judgements and quantitative historical data in the assessment of the supplier base. In this manner, evaluation criteria for both Rezaei and Ortt's (2012) dimensions "supplier capabilities" and "supplier willingness to cooperate" can take advantage of data stored in databases with historical information about the performance of suppliers.

The method proposed in this paper is based on two techniques: AHP and 2-tuple linguistic representation. AHP is used only to determine the relative weights of the criteria in both dimensions of the portfolio matrix. In a traditional AHP application, further pairwise comparisons would have to be carried out to compare all suppliers in each criterion. Even with a small number of suppliers, this would lead to a huge number of pairwise comparisons. Also, if suppliers are added or removed, all pairwise comparisons would need to be updated, which would make the supplier evaluation process rather cumbersome. The use of 2-tuple linguistic representation (Herrera & Martinez, 2000a) allows for a more flexible and efficient supplier evaluation system, because it does not