Applied Soft Computing 38 (2016) 213–231

Contents lists available at ScienceDirect

Applied Soft Computing

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

Supplier selection using a clustering method based on a new distance for interval type-2 fuzzy sets: A case study

Armaghan Heidarzade [a,*], Iraj Mahdavi [a], Nezam Mahdavi-Amiri [b]

[a] Department of Industrial Engineering, College of Technology, Mazandaran University of Science & Technology, P.O. Box 734, Babol, Iran
[b] Faculty of Mathematical Sciences, Sharif University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 2 July 2014
Received in revised form 29 June 2015
Accepted 18 September 2015
Available online 30 September 2015

Keywords:
Interval type-2 fuzzy sets
Distance measure
Supplier selection
Hierarchical clustering

ABSTRACT

Supplier selection is a decision-making process to identify and evaluate suppliers for making contracts. Here, we use interval type-2 fuzzy values to show the decision makers' preferences and also introduce a new formula to compute the distance between two interval type-2 fuzzy sets. The performance of the proposed distance formula in comparison with the normalized Hamming, normalized Hamming based on the Hausdorff metric, normalized Euclidean and the signed distances is evaluated. The results show that the signed distance has the same trend as our method, but the other three methods are not appropriate for interval type-2 fuzzy sets. Using this approach, we propose a hierarchical clustering-based method to solve a supplier selection problem and find the proximity of the suppliers. To illustrate the applicability of the proposed method, first a case study of supplier selection problem with 8 criteria and 8 suppliers are illustrated and next, an example taken from the literature is worked through. Then, to test the hierarchical clustering-based method and compare with the obtained results by two other methods, a comparative study using experimental analysis is designed. The results show that while the proposed hierarchical clustering algorithm provides acceptable results, it is also conveniently appropriate for using interval type-2 fuzzy sets and obtaining proximity of suppliers.

1. Introduction

Supplier selection processes have gained due attention recently, since the costs of raw materials and component parts constitute the main cost of a product and most firms need to spend a considerable amount of their revenues on purchasing. Supplier selection is one of the most important decision making problems including both qualitative and quantitative factors to identify suppliers with the highest potential for meeting the needs consistently with acceptable costs. To meet customer's demand and to lessen internal cost and risk, companies select appropriate suppliers to offer more competitive products and distribute the products to customers in order to meet a variety of demands. Nonetheless, for a supply chain with a large number of suppliers, each supplier has its own product strategy with a corresponding level of competitiveness for the varying customer demands and preferences. If customer demand is not considered, then the produced products may be incompliant with customer expectations incurring great losses in the supply chain system [1].

The term "supply chain management" defines management of a network of interconnected businesses involved with the provision of product and service packages required by the end customers in a supply chain [2]. Supply chain management spans all the movement and storage of raw materials, work-in-process inventory, and finished goods from the point of origin to the point of consumption. To select suppliers, researchers have proposed various methods such as data envelopment analysis (DEA) [3], analytical hierarchy process (AHP) [4], fuzzy analytical hierarchy process (FAHP) [5,6], analytic network process (ANP) [7], technique for order performance by similarity to ideal solution (TOPSIS) [8], game theory [9], potential support vector machine (P-SVM) [10], preference programming (PP), fuzzy logic [11], fuzzy case-based reasoning (CBR) [12], simulated annealing [1], etc. Aissaoui et al. [13] gave a comprehensive literature review of the supplier selection and order lot-sizing modeling. The review covers the entire purchasing process, considers both parts and services outsourcing activities, and covers internet-based procurement environments. The review also classifies the published work. The literature is rich with quantitative models using mathematical programming to address the supplier selection problem with order allocation; e.g., linear programming [4], mixed integer programming [14] and mixed integer nonlinear programming [15]. Thanaraksakul and Phruksaphanrat

* Corresponding author. Tel.: +98 2144301184.
E-mail address: a.heidarzade@ustmb.ac.ir (A. Heidarzade).

http://dx.doi.org/10.1016/j.asoc.2015.09.029
1568-4946/

[16] surveyed 76 papers on supplier selection in the purchasing literature and found that price, quality and delivery were the most commonly listed supplier evaluation dimensions. Che [17] stated that the selection of quality suppliers from a large pool of potential suppliers was a very important factor in supply chain decision-making. He proposed an optimization mathematical model and a heuristic method to evaluate suppliers in a multi-echelon supply chain system using cost, time, quality and environmental criteria. Khorasani and Khakzar [18] proposed a supplier selection model to select the best supplier of maize starch in a pharmacy company in Iran. To evaluate the suppliers, criteria such as price, quality, service, and technical issues were used. Punniyamoorthy et al. [19] made an attempt to develop a composite model for supplier selection using structural equation modeling and FAHP. The suppliers were evaluated based on criteria such as management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationship, safety, environment concern and cost. Haq and Kannan [20] compared two supplier selection models of AHP and FAHP in a case study. In their study, quality, delivery, production capability, service, engineering/technical capability, business structure, and price were taken as decision criteria to propose the model for a rubber tube industry in India. Liao and Rittscher [21] used three evaluation criteria of cost, quality and delivery time for supplier selection. [22] proposed a multi-objective mixed-integer programming model for the selection of quality suppliers with respect to price, quality and time.

Cluster analysis (CA) is a statistical method using a categorization algorithm to group a collection of datasets into clusters for easy manipulations. A cluster is therefore a collection of objects which are "similar" to one another and are "dissimilar" to the objects belonging to other clusters. Two types of clustering techniques can be distinguished as Partitional and Hierarchical techniques.

Partitional clustering algorithms find all the clusters simultaneously as a partition of the data and divide a given data set into clusters so that each data point is in exactly one cluster. Given a data set of N data points, $D = (x_1, x_2, \ldots, x_N)$, the task is to find K clusters, $C = (\pi_1, \pi_2, \ldots, \pi_K)$, so that each data point is assigned to a unique cluster π_K. The partitioning algorithms usually attempt to minimize or maximize a performance function (or objective function) defined for clustering and do not impose a hierarchical structure. K-Means [23], K-Means++ [24], K-Medoids, or Partition Around Medoids – PAM, [25], Fuzzy C-Means (FCM) [26], Soft K-Means [27], K-Harmonic Means (KHM) [28], Kernel K-Means [67] and Spectral [29,30] clustering algorithms are among the major standard clustering algorithms found in the literature.

On the other hand, hierarchical clustering algorithms [31] find nested clusters. There are two types of hierarchical clustering algorithms. Divisive algorithm [25,32] is a top down clustering method, which starts with all the data points contained as one cluster and recursively divides each cluster into smaller clusters. Agglomerative algorithm [25,32] is a bottom up method of clustering, which starts with a single data point as its own cluster and merges the most similar pair of clusters successively till a final cluster containing all the data points is obtained. Some reason for a hierarchical agglomerative clustering algorithm being used in our work here is as follows [31]:

1. First, the proximity (dissimilarity) matrix is computed. The proximity matrix is an $N \times N$ matrix which defines the distances (or similarities) among all data points.
2. Each data point represents a cluster.
3. The closest (or most similar) two clusters are found and merged into one cluster.
4. The proximity matrix is updated and the distances between the new cluster and each of the old clusters are computed.
5. Steps 3 and 4 are repeated until all the data points lie in a single cluster of size N.

Step 4 can be performed in various ways. These different ways lead to different hierarchical algorithms. Most hierarchical clustering algorithms differ only in their definition of distances (or similarities) between clusters. There are several ways to compute the distance between a group and a point. This equivalent distance can be done in more than one ways, i.e., either to take the minimum distance, the average distance or the maximum distance. If we choose single linkage clustering [25], we tend to choose the minimum distance. Average linkage clustering [32] chooses average distance within the cluster to some other point outside the cluster. Complete linkage [32] chooses the longest distance from any member of one cluster to any member of another cluster. A set of solutions is given if we are given a way to find distance and a way to relate group distance versus individual distance. A large number of hierarchical clustering algorithms exist in the literature, but they only differ in two respects, firstly, the way similarity coefficient or distance measure is calculated and secondly, single linkage, complete linkage or average linkage may be considered.

Recently, cluster analysis is used as a suitable tool in handling the supplier selection problems. Hong et al. [33] applied a clustering technique to group customers which can then be used for supplier selection. Bottani and Rizzi [34] presented an integrated method, including CA and the AHP, to evaluate and rank the alternatives to select the suppliers. They pointed out that suppliers with similar characteristics could be clustered using CA to reduce supplier combinations. Fazel Zarandi and Gamasaee [35] developed an interval type-2 fuzzy order policy to determine orders in supply chain. They clustered the demand data of a real steel industry in Canada with an interval type-2 fuzzy c-regression clustering algorithm. Khaleie et al. [36] demonstrated the use of a clustering-based method to solve a group decision making problem. Intuitionistic fuzzy value was used to show the decision makers' (DMs') preferences and clustering method was utilized to cluster around the DMs' preferences. Akman [37] selected suppliers involved in green supplier development programs and applied two-step supplier evaluation via fuzzy c-means clustering and evaluated suppliers using performance criteria and green criteria. After that, the VIKOR method [38,39] was used to sequence the suppliers.

The main purpose of our work here is to present a suitable distance formula for interval type-2 fuzzy sets (IT2-FSs) with an application to decision making. In reality, group decision making has been found to have great significance and important applications. Our attitude or opinion is usually expressed with uncertain and indecisive statements. The word "good" is vague to the extent that the associated uncertainty or certainty, to say, is not the same for different people. Hence, if we have more than one DM, then type-1 fuzzy sets may not be appropriate. Since the group members are expected to have different senses of linguistic variables to express their preferences, usage of type-2 fuzzy values for the data is deemed to be useful.

Our proposed distance method here is used in agglomerative hierarchical clustering technique, using average linkage clustering to deal with the supply chain. The aforementioned method based on IT2-FSs is used to select high-ranked suppliers providing the most customer satisfaction for the specified criteria. In practice, as reliance on a single selected supplier may not always be guaranteed (due to some unexpected circumstance at the time of contract with the first supplier), selection of only one supplier is not reasonable. By using this clustering method, we can find the proximity of the suppliers in addition to the ordering ranking. In other words, this method can determine how far or close the successive high ranked suppliers are. Hence, considering a cluster of suppliers seems to be