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EVALUATION OF SUPPLY CHAIN PERFORMANCE USING AN INTEGRATED TWO-STEP CLUSTERING AND INTERVAL TYPE-2 FUZZY TOPSIS METHOD: A CASE STUDY

Mehmet ERDEM*, Turan Erman ERKAN**

Abstract

Supply chain management (SCM) is an important subject for many researchers and organizations striving to improve performance within different contexts. Various metrics and decision making methodologies have been proposed to evaluate supply chain (SC) performance in different sectors. This paper introduces an integration of the Two-Step Clustering and the interval type-2 (IT2) Fuzzy TOPSIS methods for the SC performance evaluation process. In the first step of the proposed integrated approach, Two-Step Clustering analysis (CA) is employed not only to classify the sectors, i.e., manufacturing and service, but also to decrease the dimension of the problem. After obtaining the results, IT2 Fuzzy TOPSIS is used to evaluate each company within its cluster. The results of the integrated approach offer a macro perspective on some issues, such as organizational efficiency and performance. Moreover, valuable insight is provided that each company can have the opportunity to evaluate itself both against the rivals within clusters and inter-sectoral rivals.

Keywords: *Supply chain performance evaluation, Two-Step Clustering, TOPSIS.*

TEDARİK ZİNCİRİ PERFORMANSININ ENTEGRE İKİ AŞAMALI KÜMELEME VE ARALIK TİP-2 BULANIK TOPSİS YÖNTEMİ KULLANARAK DEĞERLENDİRİLMESİ: BİR VAKA ÇALIŞMASI

Özet

Tedarik zinciri (TZ) yönetiminde birçok araştırmacı ve kuruluş sistemin performansını iyileştirmek için farklı perspektiflerde çaba sarfetmektedir. Farklı sektörlerde TZ performansını değerlendirmek için çeşitli metrikler ve karar verme metodolojileri önerilmiştir. Bu çalışmada, TZ performans değerlendirme süreçleri için bütünleşik iki aşamalı kümeleme ve aralık tip-2 bulanık TOPSIS yöntemi önerilmektedir. Önerilen bu yaklaşımın ilk adımında, iki aşamalı kümeleme analizi ile sektörlerin homojen olarak bölümlendirilmesi ve aynı zamanda problemin boyutunun azaltılması sağlanmaktadır. İkinci adımda, bulanık TOPSIS ile oluşturulan kümeler değerlendirilmektedir. Yaklaşımın sonuçları, örgütsel etkinlik ve şirket performansı gibi konularda makro bakış açısı sağlamaktadır. Ayrıca sonuçlar, her şirketin bulunduğu kümelerdeki rakipleri arasında ve diğer sektörlerdeki rakiplere karşı kendini değerlendirme fırsatı sağlamaktadır.

Anahtar Kelimeler: *Tedarik zinciri performans değerlendirmesi, İki Aşamalı Kümeleme, TOPSIS.*

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1. INTRODUCTION

Supply Chain (SC) is a network structure in which organizations, people, information, and materials take part in achieving some of the specific objectives. Although in the 1980s Supply Chain Management (SCM) solely referred to the physical distribution of goods, nowadays it is a global network integrating many organizations so as to achieve tasks more efficiently in the competitive market. SC becomes more complex and vulnerable to different types of risks (Heckmann et al., 2015: 119-132); yet, it is perceived as a key driving factor for keeping organizations competitive, sustaining the growth pace, and raising profits not only at a local, but also global scale (Li et al., 2006: 107-124). Therefore, SCM performance evaluation is a prerequisite and a vital topic for achieving the aforementioned objectives.

Multi-criteria decision making (MCDM) or multi-criteria decision analysis (MCDA) is an approach used by many managers or decision-makers (DMs) to choose a best candidate from a set of alternatives by means of evaluating the related attributes. Today, organizations face a broad variety of complex decisions in SC, and they have to take part in evaluation processes with respect to multiple attributes, criteria, and factors. During the evaluation process, it is obvious that a degree of uncertainty can affect these decisions (Bai et al., 2014: 4186-4196).

In this paper, we integrate the Two-Step Clustering and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) based on the interval type-2 fuzzy sets (IT2-FSs) to aid DMs during the SC performance evaluation process. Here, the aim is to benefit from the strengths of these two techniques while dealing with real-world performance evaluation processes. The integrated approach not only minimizes the computational efforts during the ranking stage, but also proposes a homogeneous differentiation for the sectors at issue, namely manufacturing and service. Initially, the Two-Step clustering is used to classify the companies into groups and, then, IT2 Fuzzy TOPSIS is employed to calculate the rankings for the companies.

It is obvious that the manufacturing and service sectors have different characteristics such as output tangibility, inventory, processes, customer-centered production, facility locations, machinery and information technology (IT) usage, etc. As a part of this research, the similarities and differences among the organizations from both sectors will be uncovered as a case study. In light of this crucial information, after obtaining homogenous clusters, evaluating and ranking of the companies will provide an insight into these similarity and differences. As a results, each company will be able to assess its progress, improve key processes, identify problems, and gain valuable insight into future courses of action (Ahi and Searcy, 2015: 2882-2896).

Our study is different from the current literature in the following ways:

• In terms of the real-world applications, mostly studies only focus on automotive, food, electric-electronic, and chemical industries (Lima-Junior and Carpinetti, 2017: 333-346), implying that they are limited to sectors and/or companies only, the present study, however, takes into account the supply chain from a holistic perspective.

• The proposed method investigates different sizes companies operating in the service and manufacturing sectors (in Ankara).

• Our suggested integrated approach addresses the evaluation of SC performance. In addition, the proposed approach is able to classify companies into miscellaneous groups.

The remainder of our study is organized as follows. Section 2 gives a brief review of SC performance evaluation models and MCDM methods used in this context. Section 3 covers the methods of the Two-Step CA and a brief definition of IT2-FSs and TOPSIS. In Section 4, the proposed integrated approach is presented in a case application, and the assessment results are given in the Discussion in Section 5. Finally, the conclusions of this work appear in Section 6.

2. BACKGROUND

2.1. SC Performance Evaluation

SC performance evaluation is an important topic for many researchers and organizations due to the increasing competition and globalization of markets. It is now recognized that improvement solely within the current structure limits the effects on the desired outcomes. Therefore, in order to be more efficient and competitive, SC has to be considered as a whole.

Performance evaluation can be described as the feedback on activities to satisfy customer demands and achieve predetermined strategic goals. It represents the condition of the current systems; therefore, the quality level can be increased in the lieu of the performance measurement systems (Chan, 2003: 534-548). SC performance evaluation is an topic on which many studies have been proposing new metrics in different dimensions (Angappa Gunasekaran and Kobu, 2007: 2819-2840; A. Gunasekaran et al., 2004: 333-347) to evaluate the current condition of systems and establish new systems. In order to investigate SC relations, Martin and Patterson (2009) proposed inventory, cycle time and financial measurements. A. Gunasekaran et al. (2005) made a literature review of cost management and performance measures in the manufacturing and service sectors. The authors offered a concept for a future competitive environment to measure the costs and performance systems. Yao and Liu (2006) introduced an integrated approach that considers economic value added, balanced scorecards, and activity-based costing for SC performance evaluation. C.-J. Ho (2007) also proposed an integrated approach based on enterprise resource planning. Bernardes and Zsidisin (2008) made a survey to cover 204 manufacturing firms in the United States based on relational embeddedness and network scanning concepts.

Akyuz and Erkan (2010) made a taxonomic research on SC performance measurement. The authors emphasized that this topic must be fully understood for continuous improvement, and should be integrated into IT, also highlighting partnership, collaboration, agility, flexibility, and productivity topics to be covered in this framework. Estampe et al. (2013) made a literature survey to investigate 16 different models and presented their characteristics and implemented cases. These are as follows: ABC, Framework for Logistics Research, BSC, SC Operation Reference model, GSCF framework, ASLOG audit, Strategic Audit SC, Global EVALOG, World Class Logistics model, AFNOR FD X50-605, SCM/SME, APICS, Efficient Customer Response, EFQM: Excellence model, SC Advisor Level Evaluation, and the Strategic Profit Model.

2.2. MCDM methods in SC Performance Evaluation

Using quantitative and qualitative performance metrics, researchers have proposed a variety of different methods. These are: analytic hierarchy process (AHP) (Lima Junior et al., 2014: 194-209; Peric et al., 2013: 816-829; Tam and Tummala, 2001: 171-182), analytic network process (Gencer and Gürpinar, 2007: 2475-2486; Kirytopoulos et al., 2008: 494-516; R. H. Lin, 2009: 2730-2736), TOPSIS (Boran et al., 2009: 11363-11368; C. T. Chen, 2000: 1-9; C. T. Chen et al., 2006: 289-301; S.-M. Chen and Lee, 2010: 2790-2798; Mokhtarian and Hadi-Vencheh, 2012: 2496-2505), VIKOR (Shemshadi et al., 2011: 12160-12167), DEMATEL (Buyukozkan and Cifci, 2012: 3000-3011), data envelopment analysis (Liu et al., 2000: 143-150; Saen, 2007: 741-747), linear programming (Talluri and Narasimhan, 2003: 543-552), integer programming (Hong et al., 2005: 629-639), nonlinear programming (Ghodsypour and O'Brien, 2001: 15-27), case-based reasoning (Faez et al., 2009: 395-408; W. Ho et al., 2010: 16-24), genetic algorithm (Ding et al., 2005: 210-224), simulated annealing (Che and Wang, 2010: 745-763), particle swarm optimization (Che and Wang, 2010: 745-763), support vector machines (Guo et al., 2009: 6978-6985), others.

W. Ho et al. (2010) made a literature survey of MCDM approaches for supplier evaluation, covering 78 articles between the 2000 and 2008. The authors did not only classified the approaches as individual and integrated, but also considered a series of criteria mostly considered during the evaluation processes. A recent literature review on quantitative models for SC performance evaluation was also carried out by Lima-Junior and Carpinetti (2017). The authors focused on some important factors, such as the type and purpose of the model, techniques, applications, metrics, etc. After reviewing the literature on supplier segmentation and selection, J. Rezaei and Ortt (2012) developed an approach that depends on a set of capabilities and willingness criteria. The proposed approach was tested by a real world problem in the food industry. Based on the same criteria, a Fuzzy AHP that employs Fuzzy preference relations (Jafar Rezaei and Ortt, 2013: 75-84), and a Fuzzy rule-based method (Jafar Rezaei and Ortt, 2013: 507-517) were proposed so as to classify the suppliers of companies. Bottani and Rizzi (2008) applied an integrated Fuzzy AHP clustering technique to group and rank the alternatives for a manufacturing company in Italy. Ninety-two suppliers were clustered based on customer satisfaction, technical and organizational capabilities, supplier's willingness, and firm's interest criteria. Bai et al. (2014) developed an integrated approach for supplier evaluation. The approach integrated a Fuzzy C-means clustering and TOPSIS to rank the performance of companies based on a set of criteria. They made an application on 20 e-commerce companies for the year 1999. After obtaining the clustering results, TOPSIS was applied to rank 20 e-commerce companies. The authors also made a prediction for the companies' future performance using the Fuzzy C-means clustering and TOPSIS technique. In order to evaluate green suppliers, Akman (2015) developed an approach that employs Fuzzy C-means clustering and VIKOR. Initially, clustering was used to group the objects/ companies with respect to the main criteria of delivery, cost, quality, and service. Then, the VIKOR method was applied to the cluster with lower performance to be ranked. Heidarzade et al. (2016) developed a hierarchical clustering based on IT2-FSs for the evaluation and identification of suppliers. In the first stage of their method, the clusters were created according to the predetermined criteria. The next step was to rank these clusters, and the last step was an evaluation of suppliers. Concerning the recent SC evaluation models, sustainability concepts are receiving increasing attention. To evaluate automotive manufacturing industry, Khan et al. (2018) defined several sustainability performance factors. The authors applied a hybrid Fuzzy Shannon Entropy method to rank suppliers in terms of social, environmental, and economic criteria. dos Santos et al. (2019) made a literature survey and defined a set of environmental criteria, then, a furniture industry was assessed using an Entropy-TOPSIS-F method. In a different work, a set of resilience and sustainability factors was also considered to evaluate the performance of an automotive industry (Ramezankhani et al., 2018: 531-548).

3. **METHODOLOGY**

In this study, we propose an integrated Two-Step Clustering and IT-2 fuzzy TOPSIS method as represented in Figure 1, here the first three steps refer to the clustering stage and the remaining steps are about assessing stage. First, a predetermined number of features is taken into account as the input (step one in stage one). The aim of the second step in stage one is to decrease the dimension of the matrix involving the distances between all possible pairs of cases. The third step in stage one can be defined as clustering step, here, the sub-clusters generated from the previous step are taken as input. The hierarchical clustering algorithm forms the clusters. The next step in stage two is the identified the performance evaluation criteria. The IT-2 fuzzy TOPSIS method is applied to each cluster in the second step in the second stage. Finally, in step 3 the companies are sorted in terms of their ranks. A detailed description of these steps is explained in the following subsections.

3.1. **The Two-Step CA**

The CA is a statistical technique that divides data into meaningful and useful sub-groups based on variables. Clustering is widely used in a variety of fields such as biology, psychology, medicine and other social sciences, business, data mining, statistics, and machine learning. (Boley et al., 1999: 329-341; Matas and Kittler 1995: 162-173; Petrakis and Faloutsos, 1997: 435-447; Tan et al., 2005: 769). The objective of CA is to make the instances within a group similar to one another and different from the instances in other groups. Greater similarity (or difference) means better (or more distinct) clustering results (Tan et al., 2005: 769). In the CA, the Two-Step clustering method is chosen for analysis that can handle not only large data, but also continuous and categorical variables/attributes. Moreover, it automatically guarantees an optimum number of clusters with data is not necessary to be normally distributed. In the present study, the considered data sets have an arbitrarily-shaped clusters, i.e. scattering in irregular patterns. For this reason we used Two-Step CA which employs a hierarchical agglomerative method (Madhukumar and Santhiyakumari, 2015: 475-479; Panda et al., 2012: 451-460; Zeynel and Figen, 2015: 13-23).

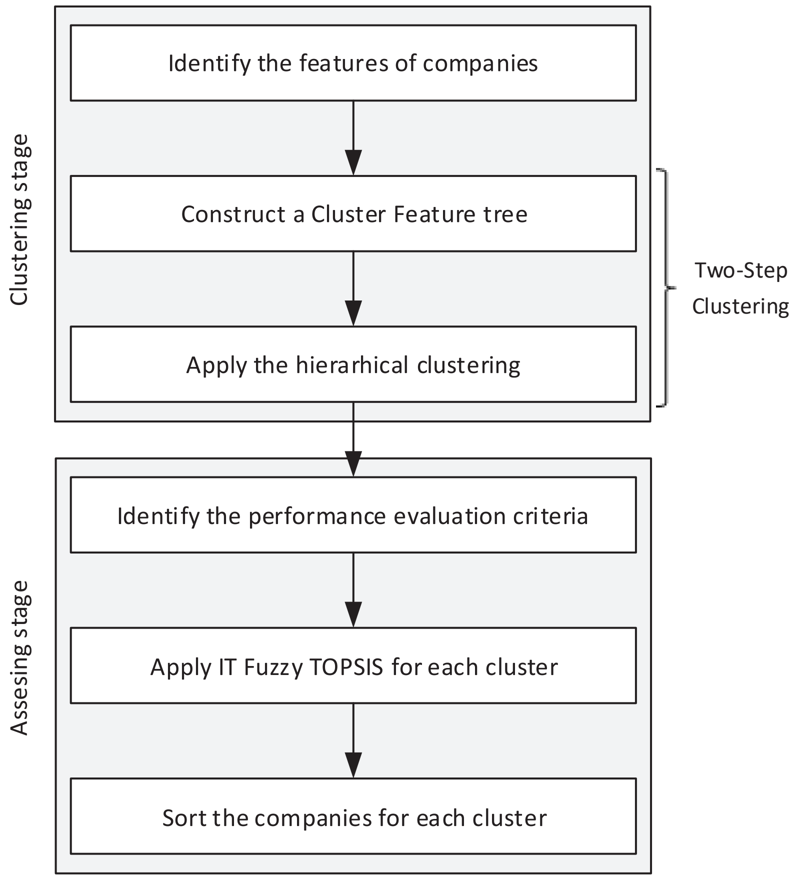

Figure 1. The procedure of the proposed method

In the Two-Step clustering method, we first begin with the construction of a Cluster Feature (CF) tree. An algorithm scans each case successively, then determines whether each successive case should be added to a previously existing cluster or should form a new one based upon the distance (similarity) criterion. A cluster that comprises of multiple cases contains a summary of variable information about those cases. The advantage of the CF is proposing an efficient representation of cases due to the fact that it occupies less memory. Hence, the CF tree decreases the dimension of the problem (Chiu et al., 2001: 263-268; Michailidou et al., 2009: 163-177).

The cases are assigned into pre-clusters in the first step, and these pre-clusters are act as a single case in the second step. A hierarchical algorithm is used to progressively receive the pre-clusters from the larger clusters in the second step. The advantage of this algorithm is that does not to require the number of clusters in advance. The initial step of the Two-Step clustering makes hierarchical clustering fast for large datasets. The Schwarz Bayesian Criterion (BIC) or the Akaike Information Criterion (AIC) is employed to determine the number of clusters by taking into account the lowest information criterion measure (BIC or AIC) and the highest ratio of distance measures (Chiu et al., 2001: 263-268; Satish and Bharadhwaj, 2010: 5-15; Zhang et al., 1996: 103-114). Here, BIC is used as a clustering criterion measure.

In the Two-Step clustering process, the Log-likelihood function is used as a distance measure to handle both continuous and categorical variables. It is a probability-based distance between clusters and is connected with a decrease in its value. While calculating this function, it is assumed that all the variables are independent, the continuous variables have a normal distribution and the categorical variables have a multinomial distribution.

3.2. **IT2-FSs**

In many of the real-world applications, DMs evaluate the alternatives depending on different qualitative and quantitative criteria. It is obvious that an exact relative crisp scale may not be used during some decision making procedures. In our study qualitative criteria are expressed by using a fuzzy linguistic approach which depends on Fuzzy set theory presented by Zadeh (1965). However, experts and DMs face difficulties in expressing their preferences using a fuzzy membership function of type-1 fuzzy sets (T1-FSs). Hence, linguistic interval scales are employed for this purpose. Wu (2013) proposed the IT2-FSs scale since it provides more flexibility to express uncertainties than T1-FSs (Gong et al., 2017: 1891-1902). In addition, IT2-FSs have a larger length of interval than T1-FSs, thus increasing the ability to capture uncertainties during the information gathering process. The basic definitions that are used in IT2-FSs theory are given in Appendix A.

3.3. **IT2 Fuzzy TOPSIS**

TOPSIS presented by Hwang and Yoon (1981), is one of the popular MCDM methods and depends on the principle that the selected alternative should be the nearest distance to the positive ideal solution, meanwhile the farthest to the negative ideal solution. Although the performance ratings and the weights of the attributes were initially defined as crisp values, the TOPSIS was extended to the fuzzy environment (C. T. Chen, 2000: 1-9). A fuzzy version of the TOPSIS method, depending on fuzzy arithmetic operations, was proposed by Triantaphyllou and Lin (1996). Furthermore, some methods (Fu, 2008: 145-149; Hwang and Yoon, 1981; C.-J. Lin and Wu, 2008: 205-213; Shyi-Ming, 1988: 1012-1016; Tsabadze, 2006: 1346-1361; T.-C. Wang and Chang, 2007: 870-880; Y.-M. Wang and Parkan, 2005: 331-346, 2006: 1333-1345; Yager and Xu, 2006: 1393-1402) have been presented for handling multi criteria group decision-making based on T1-FSs (Zadeh, 1965: 338-353). S.-M. Chen and Lee (2010) developed TOPSIS for fuzzy multiple attributes group decision making based on the IT2-FSs (Mendel et al., 2006: 808-821).

In this section, the TOPSIS method which was extended to the fuzzy multiple group decision making based on IT2-FSs is employed in our solution approach. It is supposed that there is a set F of attributes where $F=\{f_1, f_2, \ldots, f_m\}$, and there are *k* decision makers $D_1, D_2, \ldots, D_k$. The set F of attributes consists of F_1 and F_2, which correspond to the set of benefit and cost attributes/criteria, respectively. The proposed approach is as follow:

Step 1. Construct the decision matrix Y_p of the criteria of the p^{th} decision-maker and construct the average decision matrix $\overline{Y}$, respectively, via the formulas below:

$$Y_p = (\tilde{\tilde{v}}_i^p)_{1\times m} = \begin{array}{c} \begin{matrix} f_1 & f_2 & \cdots & f_m \end{matrix} \\ \begin{bmatrix} \tilde{\tilde{v}}_1^p & \tilde{\tilde{v}}_2^p & \cdots & \tilde{\tilde{v}}_m^p \end{bmatrix} \end{array} \tag{1}$$

$$\overline{Y} = (\tilde{\tilde{v}}_i)_{1\times m} \quad , \quad \tilde{\tilde{v}}_i = \frac{\tilde{\tilde{v}}_i^1 \oplus \tilde{\tilde{v}}_i^2 \oplus \ldots \oplus \tilde{\tilde{v}}_i^k}{k} \tag{2}$$

where $\tilde{\tilde{v}}_i$ is an IT2-FSs, ($1 \le i \le m$), $1 \le p \le k$ and *k* denotes the number of decision-makers.

Step 2. Calculate the rank of the IT2-FSs $(Rank(\tilde{\tilde{v}}_i))$ for each cluster via the formula in Appendix A, and construct the ranking decision matrix $\overline{Y}^*$,

$$\overline{Y}^* = (Rank(\tilde{\tilde{v}}_i))_{m\times 1} \tag{3}$$

where ($1 \le i \le m$).

Step 3. Sort the values of ranks in a descending order within the clusters.

4. **EVALUATION OF SC PERFORMANCE**

The data used in the present study is obtained from a questionnaire, through which the SC performance of the companies (in Ankara) is evaluated in terms of manufacturing and service. The questionnaire was answered by 133 companies and consisted of 34 criteria designed for assessment. The set of evaluation criteria was determined based on the most considered topics in the literature which are quality, price, delivery, service, flexibility, technology, performance, technique, distance, finance, risk, relations, innovation, profile, and facility (Akyuz and Erkan, 2010: 5137-5155; Angappa Gunasekaran and Kobu, 2007: 2819-2840; W. Ho et al., 2010: 16-24). Each company that answered the questionnaire also has its own features, by whose utilization we gathered certain attributes during the initial step of the research. The features are as follows: the type of company, number of staff, number of suppliers, amount of exportation, use of ERP software and Documents Management System (DMS), use of manufacturing technology, and being a family business.

In order to group the companies, the aforementioned features were transformed to ten attributes to be used as input variables. Using the Two-Step CA, three clusters are formed by means of an SPSS software. Clusters 1, 2, and 3 consist of 21, 57, and 47 companies, and the distribution of these takes up 21.8%, 42.9%, and 35.3% of all the companies, respectively. When results are further examined, the following conclusions are reached in terms of each cluster. The distribution of companies in Cluster 1 has 21 manufacturing, 4 service, and 4 manufacturing-service industries. Cluster 2 is the largest cluster, where most of the members deal with manufacturing. Only 4 companies in this cluster are operating in both (manufacturing and service) industries. Cluster 3 is composed of 35.3% of the total respondents, and the members of this group work only in the service sector. The importance of input variables is indicated in Figure 2. Manufacturing has been found to have the highest importance, and followed by service. The feature of being a family business has not been found as important as the others during the clustering process.

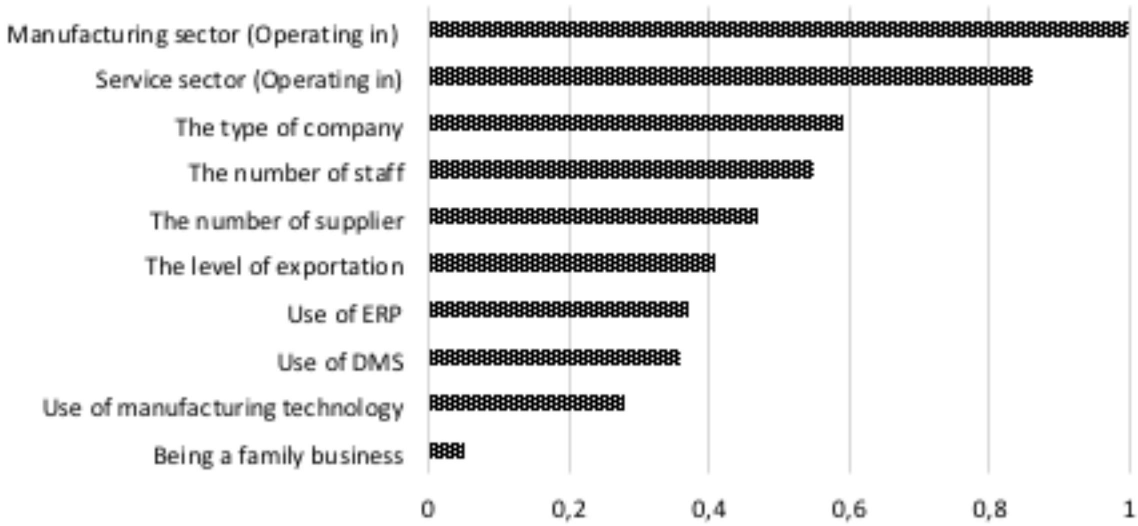

Figure 2: The Importance of the features

After segmentation of the companies into manufacturing and service sectors, depending on some of the features with Two-Step CA, the next step is to sequence these companies within the clusters via TOPSIS based on IT2 FSs.

The evaluations of the criteria were made by the DMs. Table 1 illustrates the linguistic terms and corresponding IT2 FSs. A seven-point linguistic scale was used in this study. However, a different number of linguistic variables and trapezoidal IT-2 fuzzy scales were proposed by (Celik and Akyuz, 2018: 371-381; Kahraman et al., 2014: 48-57; Zamri et al., 2015: 1-9).

Table 1: Linguistic terms of the criteria and their corresponding IT2-FSs

Linguistic terms	IT2-FSs
Very Low (VL)	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))
Low (L)	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))
Medium Low (ML)	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
Medium (M)	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
Medium High (MH)	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
High (H)	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Very High (VH)	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))

Initially, the decision matrices of the criteria were constructed and, then, the average decision matrices were calculated for each cluster based on Eq. (1-2). The average decision matrices are summarized in Table 2 for Cluster 1, and in Appendix B for Clusters 2 and 3. The ranking values were calculated based on the rank formula in Appendix A. For , rank calculation is shown below (Eq. 4), and the results of the ranking values are summarized in Table 2 for Cluster 1.

$$\begin{aligned}
Rank(\tilde{\tilde{v}}_1) &= M_1(\tilde{v}_1^U) + M_1(\tilde{v}_1^L) + M_2(\tilde{v}_1^U) + M_2(\tilde{v}_1^L) + M_3(\tilde{v}_1^U) + M_3(\tilde{v}_1^L) \\
&\quad - \frac{1}{4}(S_1(\tilde{v}_1^U) + S_1(\tilde{v}_1^L) + S_2(\tilde{v}_1^U) + S_2(\tilde{v}_1^L) + S_3(\tilde{v}_1^U) + S_3(\tilde{v}_1^L) \\
&\quad + S_4(\tilde{v}_1^U) + S_4(\tilde{v}_1^L)) + H_1(\tilde{v}_1^U) + H_1(\tilde{v}_1^L) + H_2(\tilde{v}_1^U) + H_2(\tilde{v}_1^L) \\
&= 0.79+0.83+0.87+0.87+0.92+0.89 \\
&\quad - \frac{1}{4}(0.11+0.06+0+0+0.1+0.03+0.11+0.05) \\
&\quad +1+0.9+1+0.9=8.88
\end{aligned} \tag{4}$$

In the same way, we can obtain the rest of the calculation results for clusters (in Appendix B). The ranking results of calculations for high and low performance companies with respect to each cluster are illustrated in Table 3 in a descending order. Furthermore, the distribution of each cluster with respect to the range of the ranking results is shown in Table 4.

When Table 3 is further investigated, companies 22, 7, and 99 have the highest ranking, while companies 82, 83, and 81 have the lowest ranking within Clusters 1, 2, and 3, respectively. Cluster 1 comprises mostly high rank companies, although Cluster 2 and 3 mostly cover a ranking value between 7 and 8. The structure of Cluster 1 has some similarities to Cluster 2 with respect to some of the features. However, the members of Cluster 2 have lower performance than Cluster 1. Moreover, Cluster 3 consisting of service companies, and Cluster 2 consisting of manufacturing companies have nearly the same distribution according to the ranking in Table 4.

5. **DISCUSSION**

The results with the ranking values show that each cluster has different characteristics and capabilities. Cluster 1, comprising mostly joint-stock companies, is characterized by having a higher level of exportation, employing a higher number of employees, and utilizing ERP software. The members of Cluster 1 benefitted from manufacturing technologies and all the members have DMSs. Cluster 2 is the largest cluster, comprising 42.9% of the total companies. Most of the members deal with manufacturing and 4 companies operate in both industries (manufacturing and service), the level of exportation is lower than Cluster 1, and limited-liability companies are dominant. All the members utilize technological machines, tools, etc., and the number of employees is nearly the same as in Cluster 3. Most of the members of Cluster 2 use DMSs, while most companies do not make use of ERP. Cluster 3 is composed of 35.3% of the total respondents, and the members of this group work only in the service sector. Nearly none of the companies in Cluster 3 deal with exporting, and they are mostly limited-liability companies. More than half of the members of Cluster 3 do not employ DMSs and ERP. More than half of the members run family businesses.

Table 2: The ranking decision matrix for Cluster 1

Company	The average decisions values of the criteria	Ranking Values
Comp.10	((0.71,0.87,0.87,0.96;1.00,1.00), (0.79,0.87,0.87,0.92;0.90,0.90))	8.88
Comp.22	((0.88,0.99,0.99,1.00;1.00,1.00), (0.93,0.99,0.99,0.99;0.90,0.90))	9.60
Comp.27	((0.68,0.84,0.84,0.93;1.00,1.00), (0.76,0.84,0.84,0.89;0.90,0.90))	8.69
Comp.28	((0.65,0.83,0.83,0.94;1.00,1.00), (0.74,0.83,0.83,0.88;0.90,0.90))	8.59
Comp.29	((0.66,0.83,0.83,0.92;1.00,1.00), (0.75,0.83,0.83,0.88;0.90,0.90))	8.61
Comp.30	((0.63,0.81,0.81,0.93;1.00,1.00), (0.72,0.81,0.81,0.87;0.90,0.90))	8.51
Comp.31	((0.65,0.83,0.83,0.93;1.00,1.00), (0.74,0.83,0.83,0.88;0.90,0.90))	8.59
Comp.32	((0.76,0.89,0.89,0.93;1.00,1.00), (0.83,0.89,0.89,0.91;0.90,0.90))	9.00
Comp.33	((0.61,0.80,0.80,0.93;1.00,1.00), (0.71,0.80,0.80,0.87;0.90,0.90))	8.43
Comp.46	((0.80,0.93,0.93,0.97;1.00,1.00), (0.86,0.93,0.93,0.95;0.90,0.90))	9.22
Comp.47	((0.67,0.82,0.82,0.91;1.00,1.00), (0.74,0.82,0.82,0.87;0.90,0.90))	8.57
Comp.48	((0.44,0.61,0.61,0.76;1.00,1.00), (0.53,0.61,0.61,0.69;0.90,0.90))	7.32
Comp.49	((0.57,0.76,0.76,0.90;1.00,1.00), (0.66,0.76,0.76,0.83;0.90,0.90))	8.17
Comp.50	((0.54,0.68,0.68,0.79;1.00,1.00), (0.61,0.68,0.68,0.74;0.90,0.90))	7.77
Comp.60	((0.42,0.62,0.62,0.81;1.00,1.00), (0.52,0.62,0.62,0.71;0.90,0.90))	7.34
Comp.65	((0.83,0.96,0.96,0.99;1.00,1.00), (0.89,0.96,0.96,0.98;0.90,0.90))	9.41
Comp.68	((0.42,0.62,0.62,0.80;1.00,1.00), (0.52,0.62,0.62,0.71;0.90,0.90))	7.34
Comp.71	((0.80,0.94,0.94,0.99;1.00,1.00), (0.87,0.94,0.94,0.97;0.90,0.90))	9.30
Comp.82	((0.26,0.46,0.46,0.65;1.00,1.00), (0.36,0.46,0.46,0.55;0.90,0.90))	6.37
Comp.84	((0.33,0.52,0.52,0.71;1.00,1.00), (0.43,0.52,0.52,0.62;0.90,0.90))	6.78
Comp.85	((0.42,0.62,0.62,0.78;1.00,1.00), (0.52,0.62,0.62,0.70;0.90,0.90))	7.33
Comp.105	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.110	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.113	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.115	((0.54,0.73,0.73,0.89;1.00,1.00), (0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.123	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.124	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.131	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.132	((0.84,0.96,0.96,0.99;1.00,1.00), (0.90,0.96,0.96,0.98;0.90,0.90))	9.43

Table 3: Sequence of high-low performed companies within clusters

Company	Ranking Values	Cluster	Company	Ranking Values	Cluster	Company	Ranking Values	Cluster
Comp.22	9.6	1	Comp.7	9.51	2	Comp.99	9.43	3
Comp.105	9.43	1	Comp.8	9.15	2	Comp.102	9.43	3
Comp.110	9.43	1	Comp.19	9.15	2	Comp.103	9.43	3
Comp.113	9.43	1	Comp.12	9.08	2	Comp.104	9.43	3
Comp.123	9.43	1	Comp.5	8.96	2	Comp.111	9.43	3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Comp.68	7.34	1	Comp.70	7.34	2	Comp.90	6.88	3
Comp.85	7.33	1	Comp.63	7.27	2	Comp.73	6.88	3
Comp.48	7.32	1	Comp.34	6.78	2	Comp.89	6.33	3
Comp.84	6.78	1	Comp.24	6.71	2	Comp.88	6.01	3
Comp.82	6.37	1	Comp.83	6.51	2	Comp.81	5.42	3

Table 4: Distribution of clusters

Ranking Results	Cluster 1		Cluster 2		Cluster 3	
9-10	12	41.38%	4	7.02%	8	17.02%
8-9	9	31.03%	17	29.82%	10	21.28%
7-8	6	20.69%	33	57.89%	24	51.06%
6-7	2	6.90%	3	5.26%	4	8.51%
5-6	-		-		1	2.13%

Although the members of Clusters 1 and 2 operate in the manufacturing sector, the outcome of these clusters is different when the results are further investigated based on the integrated Two-Step CA IT2 Fuzzy TOPSIS approach. It is obvious that the members of Cluster 1 performed very well because of utilizing ERP, having a higher level of exportation, and employing more staff. In terms of comparing manufacturing and service, companies with lower performance have the opportunity to compare themselves and to set strategic goals for the medium-term and long-term. Companies with higher levels of performance in Cluster 1 serve as a road map for rival as regards issues such as increasing the level of exportation, employing more staff, and utilizing technological machines, tools and the appropriate ERP software for the future.

When the members of Cluster 2 and 3 are considered as components of SC, their low performances may affect the whole SC performance negatively. Within these two clusters, those with a score 7 or 8 are able to investigate their current status so as to increase not only effective and competitiveness, but also their entire SC performance.

6. **CONCLUSION**

In this study, an integrated approach for the SC performance evaluation was proposed by employing the Two-Step CA and TOPSIS based on IT2-FSs. The proposed approach was applied to the real-world case (in Ankara, the capital of Turkey). Firstly, a survey is conducted with 133 companies operating in both manufacturing and service industries. Then, the Two-Step CA was used for the utilization of the qualitative and quantitative features of the companies which were segmented into three clusters. After the manufacturing and service sectors were clustered, the IT2-FSs TOPSIS method was used to rank each cluster depending on the 34 criteria. Therefore, after applying the IT2 Fuzzy TOPSIS method, the performances of the clusters were evaluated and the companies were sequenced from the best to the worst.

SCM is a vital factor for companies to be competitive and innovative, and maintain a sustainable growth; therefore, it should be considered as a whole. The results of the proposed study demonstrate some valuable insights about sectors. At the micro-level, the low-performance companies have the opportunity to benchmark themselves. In order to take more advantage from SC, collaboration, and integration of high performance companies are a necessity for achieving better results at the macro-level. The proposed integrated methodology is recommended not only for a homogenous segmentation, but also in the SC performance evaluation processes.

As for limitation, the lack of data related to different years was an obstacle for our study to observe the improvement trend/phase of the clusters and companies. If our obtained data had covered different years, the estimation of future SC performance could have been carried out as a predictive analysis. Moreover, it is obvious that not being able to deal with all sectors such as financial, healthcare, entertainment, etc. prevents us from having a perspective of other sectors.

As a future research, we can apply the proposed method to aforementioned missing industries. Taking into account the interdependencies among the criteria may also affect the results. Different MCDMs can be used to evaluate the interdependency among the criteria for further research. In addition, it could be interesting to deal with a series of bench markings, such as considering different cities, regions, and countries.

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APPENDIX A.

Definition A.1 (Mendel et al., 2006: 808-821). A type-2 fuzzy set $\tilde{\tilde{A}}$ in universe of discourse X can be represented by type-2 fuzzy membership function $\mu_{\tilde{\tilde{A}}}$ as follows:

$$\tilde{\tilde{A}} = \left\{ (x,u), \mu_{\tilde{\tilde{A}}}(x,u) \middle| \forall x \in X, \forall u \in J_x \subseteq [0,1], 0 \leq \mu_{\tilde{\tilde{A}}} \leq 1 \right\} \tag{A.1}$$

where J_x denotes an interval in [0, 1]. Type-2 fuzzy set $\tilde{\tilde{A}}$ also can be represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u \in J_x} \mu_{\tilde{\tilde{A}}}(x,u) / (x,u) \quad , J_x \subseteq [0,1] \tag{A.2}$$

where $\iint$ denotes the union over all admissible x and u.

Definition A.2 (Mendel et al., 2006: 808-821). Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in universe of discourse X which is represented by type-2 membership function $\mu_{\tilde{\tilde{A}}}$. $\tilde{\tilde{A}}$ is an IT2-FSs if all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$. This special case of a type-2 fuzzy set can be represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u \in J_x} 1 / (x,u) \quad , J_x \subseteq [0,1] \tag{A.3}$$

Definition A.3 (Mendel et al., 2006: 808-821). The IT2-FSs $\tilde{\tilde{A}}$, can be represented as $\tilde{\tilde{A}} = (\tilde{A}^U, \tilde{A}^L)$ where $\tilde{A}^U$, $\tilde{A}^L$ are upper membership function and lower membership function, respectively. Note that $\tilde{A}^U$ and $\tilde{A}^L$ are type-1 fuzzy sets (Figure A.1).

Definition A.4 (S.-M. Chen and Lee, 2010: 2790-2798; Mendel et al., 2006: 808-821). The trapezoidal IT2-FSs $\tilde{\tilde{A}}$ can be represented as follows:

$$\tilde{\tilde{A}} = \left((\tilde{A}^U, \tilde{A}^L) = \left((a_1^U, a_2^U, a_3^U, a_4^U); H_1(\tilde{A}^U), H_2(\tilde{A}^U) \right), \left((a_1^L, a_2^L, a_3^L, a_4^L); H_1(\tilde{A}^L), H_2(\tilde{A}^L) \right) \right) \tag{A.4}$$

where a_i^U and a_i^L, ($1 \leq i \leq 4$) are the parameters of a_i^U and a_i^L respectively, and $H_i(\tilde{A}^U)$ and $H_i(\tilde{A}^L)$, ($1 \leq i \leq 2$) denote the membership values of elements a_i^U and a_i^L, ($2 \leq i \leq 3$), respectively, $H_i(\tilde{A}^U) \in [0,1]$ and $H_i(\tilde{A}^L) \in [0,1]$, ($1 \leq i \leq 2$) (Figure A.1).

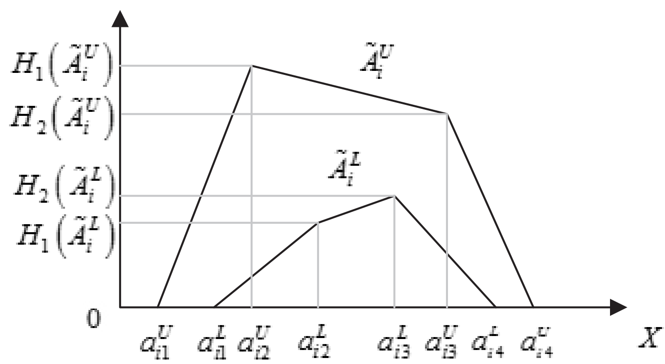

Figure A.1. A trapezodial IT2-FSs of (Li-Wei and Shyi-Ming, 2008: 3260-3265)

Definition A.5 (S.-M. Chen and Lee, 2010: 2790-2798). The mathematical operations between two trapezoidal IT2-FSs

$$\tilde{\tilde{A}}_1 = \left((\tilde{A}_1^U, \tilde{A}_1^L) = \left((a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U); H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \right), \left((a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L); H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \right) \right) \quad (A.5)$$

and

$$\tilde{\tilde{A}}_2 = \left((\tilde{A}_2^U, \tilde{A}_2^L) = \left((a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U); H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U) \right), \left((a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L); H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L) \right) \right) \quad (A.6)$$

are defined as follows:

Addition operation

$$\begin{aligned}\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 &= (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L) \\ &= ((a_{11}^U \oplus a_{21}^U, a_{12}^U \oplus a_{22}^U, a_{13}^U \oplus a_{23}^U, a_{14}^U \oplus a_{24}^U; \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)); \\ &\quad (a_{11}^L \oplus a_{21}^L, a_{12}^L \oplus a_{22}^L, a_{13}^L \oplus a_{23}^L, a_{14}^L \oplus a_{24}^L); \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))\end{aligned} \quad (A.7)$$

Multiplication operation

$$\begin{aligned}\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 &= (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_2^L) \\ &= ((a_{11}^U \otimes a_{21}^U, a_{12}^U \otimes a_{22}^U, a_{13}^U \otimes a_{23}^U, a_{14}^U \otimes a_{24}^U; \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)); \\ &\quad (a_{11}^L \otimes a_{21}^L, a_{12}^L \otimes a_{22}^L, a_{13}^L \otimes a_{23}^L, a_{14}^L \otimes a_{24}^L); \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))\end{aligned} \quad (A.8)$$

Scalar multiplication

$$\begin{aligned}c\tilde{\tilde{A}}_1 &= ((c \times a_{11}^U, c \times a_{12}^U, c \times a_{13}^U, c \times a_{14}^U; \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)), \\ &\quad (c \times a_{11}^L, c \times a_{12}^L, c \times a_{13}^L, c \times a_{14}^L; \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)))\end{aligned} \quad (A.9)$$

Definition A.6 (S.-M. Chen and Lee, 2010: 2790-2798). The rank of the $\tilde{\tilde{A}}_i$ can be represented as follows:

$$\begin{aligned}Rank(\tilde{\tilde{A}}_i) &= M_1(\tilde{A}_i^U) + M_1(\tilde{A}_i^L) + M_2(\tilde{A}_i^U) + M_2(\tilde{A}_i^L) + M_3(\tilde{A}_i^U) + M_3(\tilde{A}_i^L) \\ &\quad - \frac{1}{4}(S_1(\tilde{A}_i^U) + S_1(\tilde{A}_i^L) + S_2(\tilde{A}_i^U) + S_2(\tilde{A}_i^L) + S_3(\tilde{A}_i^U) + S_3(\tilde{A}_i^L) \\ &\quad + S_4(\tilde{A}_i^U) + S_4(\tilde{A}_i^L)) + H_1(\tilde{A}_i^U) + H_1(\tilde{A}_i^L) + H_2(\tilde{A}_i^U) + H_2(\tilde{A}_i^L)\end{aligned} \quad (A.10)$$

where $M_p(\tilde{A}_i^j)$ is the mean of the elements a_{ip}^j and $a_{i(p+1)}^j$, ($1 \le p \le 3$), $S_p(\tilde{A}_i^j)$ is the standard deviation of the elements a_{ip}^j and $a_{i(p+1)}^j$,($1 \le q \le 3$), and $S_4(\tilde{A}_i^j)$ denotes the standard deviation of the elements a_{ip}^j ($1 \le q \le 4$).

APPENDIX B.

Table B.1: The ranking decision matrix for Cluster 2

Company	The average decisions values of the criteria	Ranking Values
Comp.1	((0.64,0.81,0.81,0.92;1.00,1.00),(0.73,0.81,0.81,0.86;0.90,0.90))	8.49
Comp.2	((0.63,0.80,0.80,0.92;1.00,1.00),(0.71,0.80,0.80,0.86;0.90,0.90))	8.45
Comp.3	((0.68,0.86,0.86,0.96;1.00,1.00),(0.77,0.86,0.86,0.91;0.90,0.90))	8.76
Comp.4	((0.64,0.80,0.80,0.90;1.00,1.00),(0.72,0.80,0.80,0.85;0.90,0.90))	8.44
Comp.5	((0.72,0.89,0.89,0.97;1.00,1.00),(0.80,0.89,0.89,0.93;0.90,0.90))	8.96
Comp.7	((0.86,0.97,0.97,0.99;1.00,1.00),(0.92,0.97,0.97,0.98;0.90,0.90))	9.51
Comp.8	((0.76,0.92,0.92,0.98;1.00,1.00),(0.84,0.92,0.92,0.95;0.90,0.90))	9.15
Comp.9	((0.46,0.66,0.66,0.85;1.00,1.00),(0.56,0.66,0.66,0.76;0.90,0.90))	7.62
Comp.12	((0.77,0.90,0.90,0.96;1.00,1.00),(0.84,0.90,0.90,0.93;0.90,0.90))	9.08
Comp.14	((0.47,0.67,0.67,0.86;1.00,1.00),(0.57,0.67,0.67,0.76;0.90,0.90))	7.65
Comp.15	((0.44,0.64,0.64,0.81;1.00,1.00),(0.54,0.64,0.64,0.72;0.90,0.90))	7.46
Comp.17	((0.49,0.68,0.68,0.83;1.00,1.00),(0.59,0.68,0.68,0.76;0.90,0.90))	7.72
Comp.18	((0.49,0.67,0.67,0.82;1.00,1.00),(0.58,0.67,0.67,0.75;0.90,0.90))	7.67
Comp.19	((0.76,0.92,0.92,0.98;1.00,1.00),(0.84,0.92,0.92,0.95;0.90,0.90))	9.15
Comp.20	((0.61,0.76,0.76,0.85;1.00,1.00),(0.69,0.76,0.76,0.80;0.90,0.90))	8.20
Comp.21	((0.52,0.66,0.66,0.77;1.00,1.00),(0.59,0.66,0.66,0.72;0.90,0.90))	7.65
Comp.23	((0.73,0.88,0.88,0.95;1.00,1.00),(0.81,0.88,0.88,0.92;0.90,0.90))	8.94
Comp.24	((0.32,0.51,0.51,0.70;1.00,1.00),(0.42,0.51,0.51,0.61;0.90,0.90))	6.71
Comp.25	((0.49,0.67,0.67,0.82;1.00,1.00),(0.58,0.67,0.67,0.75;0.90,0.90))	7.67
Comp.34	((0.36,0.52,0.52,0.67;1.00,1.00),(0.44,0.52,0.52,0.59;0.90,0.90))	6.78
Comp.37	((0.58,0.75,0.75,0.87;1.00,1.00),(0.66,0.75,0.75,0.81;0.90,0.90))	8.14
Comp.39	((0.55,0.71,0.71,0.84;1.00,1.00),(0.63,0.71,0.71,0.78;0.90,0.90))	7.94
Comp.40	((0.68,0.83,0.83,0.91;1.00,1.00),(0.76,0.83,0.83,0.87;0.90,0.90))	8.64
Comp.43	((0.61,0.79,0.79,0.91;1.00,1.00),(0.70,0.79,0.79,0.85;0.90,0.90))	8.34
Comp.44	((0.54,0.72,0.72,0.86;1.00,1.00),(0.63,0.72,0.72,0.79;0.90,0.90))	7.94
Comp.45	((0.74,0.86,0.86,0.90;1.00,1.00),(0.80,0.86,0.86,0.88;0.90,0.90))	8.83
Comp.51	((0.64,0.80,0.80,0.90;1.00,1.00),(0.72,0.80,0.80,0.85;0.90,0.90))	8.44
Comp.52	((0.46,0.66,0.66,0.85;1.00,1.00),(0.56,0.66,0.66,0.75;0.90,0.90))	7.58
Comp.53	((0.43,0.62,0.62,0.80;1.00,1.00),(0.52,0.62,0.62,0.71;0.90,0.90))	7.36
Comp.54	((0.44,0.64,0.64,0.81;1.00,1.00),(0.54,0.64,0.64,0.72;0.90,0.90))	7.46
Comp.55	((0.49,0.67,0.67,0.82;1.00,1.00),(0.58,0.67,0.67,0.75;0.90,0.90))	7.68
Comp.56	((0.42,0.62,0.62,0.81;1.00,1.00),(0.52,0.62,0.62,0.71;0.90,0.90))	7.34
Comp.57	((0.50,0.68,0.68,0.82;1.00,1.00),(0.59,0.68,0.68,0.75;0.90,0.90))	7.70
Comp.58	((0.44,0.64,0.64,0.81;1.00,1.00),(0.54,0.64,0.64,0.72;0.90,0.90))	7.46
Comp.59	((0.48,0.66,0.66,0.81;1.00,1.00),(0.57,0.66,0.66,0.73;0.90,0.90))	7.58
Comp.61	((0.48,0.66,0.66,0.82;1.00,1.00),(0.57,0.66,0.66,0.74;0.90,0.90))	7.61
Comp.62	((0.62,0.82,0.82,0.95;1.00,1.00),(0.72,0.82,0.82,0.88;0.90,0.90))	8.52
Comp.63	((0.42,0.61,0.61,0.78;1.00,1.00),(0.51,0.61,0.61,0.69;0.90,0.90))	7.27
Comp.66	((0.42,0.62,0.62,0.81;1.00,1.00),(0.52,0.62,0.62,0.71;0.90,0.90))	7.34
Comp.69	((0.47,0.66,0.66,0.82;1.00,1.00),(0.56,0.66,0.66,0.74;0.90,0.90))	7.57
Comp.70	((0.42,0.62,0.62,0.81;1.00,1.00),(0.52,0.62,0.62,0.71;0.90,0.90))	7.34

Comp.74	((0.65,0.82,0.82,0.93;1.00,1.00),(0.74,0.82,0.82,0.88;0.90,0.90))	8.57
Comp.75	((0.73,0.88,0.88,0.95;1.00,1.00),(0.81,0.88,0.88,0.92;0.90,0.90))	8.94
Comp.76	((0.49,0.69,0.69,0.84;1.00,1.00),(0.59,0.69,0.69,0.76;0.90,0.90))	7.74
Comp.77	((0.61,0.79,0.79,0.91;1.00,1.00),(0.70,0.79,0.79,0.85;0.90,0.90))	8.39
Comp.78	((0.58,0.77,0.77,0.92;1.00,1.00),(0.68,0.77,0.77,0.85;0.90,0.90))	8.27
Comp.83	((0.31,0.47,0.47,0.64;1.00,1.00),(0.39,0.47,0.47,0.56;0.90,0.90))	6.51
Comp.100	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.106	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.116	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.118	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.121	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.126	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.127	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.128	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.129	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.130	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99

Table B.2. The ranking decision matrix for Cluster 3

Company	The average decisions values of the criteria	Ranking Values
Comp.6	((0.52,0.69,0.69,0.82;1.00,1.00),(0.60,0.69,0.69,0.76;0.90,0.90))	7.79
Comp.11	((0.80,0.92,0.92,0.96;1.00,1.00),(0.86,0.92,0.92,0.94;0.90,0.90))	9.19
Comp.13	((0.52,0.69,0.69,0.83;1.00,1.00),(0.61,0.69,0.69,0.76;0.90,0.90))	7.81
Comp.16	((0.62,0.81,0.81,0.94;1.00,1.00),(0.71,0.81,0.81,0.88;0.90,0.90))	8.46
Comp.26	((0.59,0.76,0.76,0.86;1.00,1.00),(0.68,0.76,0.76,0.81;0.90,0.90))	8.18
Comp.35	((0.73,0.86,0.86,0.92;1.00,1.00),(0.80,0.86,0.86,0.89;0.90,0.90))	8.85
Comp.36	((0.64,0.80,0.80,0.89;1.00,1.00),(0.72,0.80,0.80,0.85;0.90,0.90))	8.43
Comp.38	((0.64,0.80,0.80,0.90;1.00,1.00),(0.72,0.80,0.80,0.85;0.90,0.90))	8.46
Comp.41	((0.39,0.59,0.59,0.79;1.00,1.00),(0.49,0.59,0.59,0.69;0.90,0.90))	7.19
Comp.42	((0.50,0.68,0.68,0.82;1.00,1.00),(0.59,0.68,0.68,0.75;0.90,0.90))	7.70
Comp.64	((0.76,0.91,0.91,0.98;1.00,1.00),(0.84,0.91,0.91,0.94;0.90,0.90))	9.11
Comp.67	((0.50,0.68,0.68,0.82;1.00,1.00),(0.59,0.68,0.68,0.75;0.90,0.90))	7.70
Comp.72	((0.74,0.90,0.90,0.97;1.00,1.00),(0.82,0.90,0.90,0.94;0.90,0.90))	9.02
Comp.73	((0.34,0.54,0.54,0.73;1.00,1.00),(0.44,0.54,0.54,0.64;0.90,0.90))	6.88
Comp.79	((0.56,0.76,0.76,0.91;1.00,1.00),(0.66,0.76,0.76,0.84;0.90,0.90))	8.20
Comp.80	((0.55,0.75,0.75,0.92;1.00,1.00),(0.65,0.75,0.75,0.84;0.90,0.90))	8.14
Comp.81	((0.16,0.29,0.29,0.45;1.00,1.00),(0.23,0.29,0.29,0.37;0.90,0.90))	5.42
Comp.86	((0.61,0.71,0.71,0.76;1.00,1.00),(0.66,0.71,0.71,0.73;0.90,0.90))	7.94
Comp.87	((0.55,0.74,0.74,0.88;1.00,1.00),(0.64,0.74,0.74,0.81;0.90,0.90))	8.05
Comp.88	((0.24,0.39,0.39,0.55;1.00,1.00),(0.32,0.39,0.39,0.47;0.90,0.90))	6.01
Comp.89	((0.35,0.43,0.43,0.53;1.00,1.00),(0.39,0.43,0.43,0.48;0.90,0.90))	6.33
Comp.90	((0.35,0.54,0.54,0.73;1.00,1.00),(0.44,0.54,0.54,0.64;0.90,0.90))	6.88
Comp.91	((0.57,0.75,0.75,0.90;1.00,1.00),(0.66,0.75,0.75,0.82;0.90,0.90))	8.13
Comp.92	((0.51,0.68,0.68,0.81;1.00,1.00),(0.60,0.68,0.68,0.75;0.90,0.90))	7.72
Comp.93	((0.72,0.87,0.87,0.94;1.00,1.00),(0.80,0.87,0.87,0.91;0.90,0.90))	8.88

Comp.94	((0.42,0.59,0.59,0.75;1.00,1.00),(0.51,0.59,0.59,0.67;0.90,0.90))	7.19
Comp.95	((0.57,0.71,0.71,0.82;1.00,1.00),(0.64,0.71,0.71,0.77;0.90,0.90)	7.95
Comp.96	((0.55,0.67,0.67,0.76;1.00,1.00),(0.61,0.67,0.67,0.71;0.90,0.90))	7.73
Comp.97	((0.49,0.66,0.66,0.80;1.00,1.00),(0.58,0.66,0.66,0.73;0.90,0.90))	7.60
Comp.98	((0.51,0.66,0.66,0.78;1.00,1.00),(0.59,0.66,0.66,0.72;0.90,0.90))	7.63
Comp.99	((0.84,0.96,0.96,0.99;1.00,1.00),(0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.101	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.102	((0.84,0.96,0.96,0.99;1.00,1.00),(0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.103	((0.84,0.96,0.96,0.99;1.00,1.00),(0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.104	((0.84,0.96,0.96,0.99;1.00,1.00),(0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.107	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.108	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.109	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.111	((0.84,0.96,0.96,0.99;1.00,1.00),(0.90,0.96,0.96,0.98;0.90,0.90))	9.43
Comp.112	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.114	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.117	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.119	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.120	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.122	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.125	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99
Comp.133	((0.54,0.73,0.73,0.89;1.00,1.00),(0.63,0.73,0.73,0.81;0.90,0.90))	7.99