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Development of a hybrid methodology for ERP system selection: The case of Turkish Airlines

Huseyin Selcuk Kilic [a], Selim Zaim [b], Dursun Delen [c,*]

[a] Department of Industrial Engineering, Engineering Faculty, Marmara University, Kadikoy, Istanbul 34722, Turkey
[b] Department of Industrial Engineering, Faculty of Management, Istanbul Technical University, Macka, Istanbul 34367, Turkey
[c] Department of Management Science and Information Systems, Spears School of Business, Oklahoma State University, Tulsa, OK 74106, USA

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ABSTRACT

Enterprise resource planning (ERP) systems that aim to integrate, synchronize and centralize organizational data are generally regarded as a vital tool for companies to be successful in the rapidly changing global marketplace. Due to its high acquisition—purchasing, installation and implementation—cost and the wide range of offerings, the selection of ERP systems is a strategically important and difficult decision. Since there is a wide range of tangible and intangible criteria to be considered, it is often defined as a multi-criteria decision making problem. To overcome the challenges imposed by the multifaceted nature of the problem, herein a three-stage hybrid methodology is proposed. The process starts with the identification of most prevailing criteria through a series of brainstorming sessions that include people from different organizational units. Then, due to the varying importance of the criteria, a fuzzy Analytic Hierarchy Process, which handles the vagueness inherent in the decision making process, is used to obtain the relative importance/weights of the criteria. These weighted criteria are then used as input to the Technique for Order Preference by Similarity to Ideal Solution method to rank the decision alternatives. As a real-world illustrative case, the proposed methodology is applied to the ERP selection problem at Turkish Airlines. Because of the collaborative and systematic nature of the methodology, the results obtained from the process were found to be highly satisfactory and trustworthy by the decision makers.

1. Introduction

Undoubtedly, one of the most important and impactful developments in information technology in 1990s is the advent of ERP systems. Transforming the organizational structure of enterprises from functionally-focused to process-driven infrastructures, ERP has turned out to be one of the most extensively adopted/used business solutions of the recent history [3]. Although the positive effect of ERP-based IT systems became clear in the late 1990's [48], the importance of inventory control—which can be regarded as one of the first main activity of modern manufacturing systems—has taken place in 1960s. That was followed by Materials Requirement Planning (MRP), in 1970s and Manufacturing Resources Planning (MRP II) in 1980s [45]. As a result, the use and the importance of computing information systems and their applications to improve effectiveness and efficiency of business functions have increased significantly. Furthermore, because of the exponential increase in the competition in the globalized economy, coupled with ever so changing customer needs and wants, the complexity of the business processes has also risen. These all have led to ERP systems becoming an essential part of any modern day solution to the increasingly complex business environment [20].

By adopting ERP, it is aimed to plan and integrate the related resources of all the departments in an organization by combining the applications and work processes [16]. In other words, controlling the information within the whole company is considered as the main objective of ERP implementation [15,31]. The benefits that can be obtained by implementing a successful ERP system are automated business process, timely access to management information and improved supply chain management through the use of e-commerce [26]. Moreover, productivity and working quality are increased via ERP systems by providing integration, standardization and simplification of processes [28]. Mostly because of these advantages, ERP systems are also being used in the small and medium enterprise and are regarded as a way of becoming and maintaining competitiveness [10].

Generally speaking, there are three phases that constitute ERP system life cycle. These phases are selection, implementation and use. Problem identification, requirements specification, evaluation of options and selection of system can be regarded as the activities within the ERP selection process. ERP selection is the first phase and is regarded as the most critical success factor for ERP implementation [14].

There have been a number of methods used in the selection of the best ERP system for an organization. Some of the most popular ones

* Corresponding author. Tel.: +1 918 594 8283; fax: +1 918 594 8281.
E-mail address: dursun.delen@okstate.edu (D. Delen).

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are the scoring and ranking methods, mathematical optimization models and multi-criteria decision making models [44]. In addition to these individual models, hybrid methodologies are also used for selecting the best ERP systems [35]. Regardless of the method, during the selection process many criteria are taken into consideration. Some of the most prevailing criteria used in the selection of ERP system included product functionality, product quality, implementation speed, implementation approach, organizational credibility, experience, flexibility, interface with other systems, price, market leadership, corporate image, and international orientation [33,46]. The nature and the importance given to each selection criterion change among these studies. As Baki and Çakar [4] stated, in some of the studies, the most important criteria are functionality and system reliability while, according to the other studies, the most important criterion is technical support for large firms and adaptability and flexibility of software for small-to-medium sized companies.

Due to the crucial role that ERP systems play in today's organizations, the selection of the "right" system—that fits the needs and capabilities of the enterprise—is regarded as a critical and complex decision problem. With this study, we propose a fuzzy AHP weighted TOPSIS methodology to overcome the complexities of this decision making process. Even though there are a number of studies where Fuzzy, AHP and TOPSIS techniques are used individually or in some combination in the literature, this study offers additional contributions to the extant literature. First, to the best of our knowledge, this study is the first to offer a systematic, easy to understand/apply three-stage MCDM methodology that consists of pre-evaluation, fuzzy AHP, and TOPSIS. Second, although there are a lot of successful applications of TOPSIS and/or AHP to wide range of MCDM problems in various industries/fields, there is not an application of Fuzzy AHP weighted TOPSIS methodology for the ERP selection problem (as can be inferred from the 266 articles analyzed in the study conducted by Behzadian et al. [5]). Third, an application case of the hybrid methodology is performed in a large-scale high-stake decision situation for an airline company (i.e., Turkish Airlines) to select the best possible ERP system. As it is known, case studies play a significant role in demonstrating the efficacy of new and improved methodologies in real life contexts. The chief reason is that the vast majority of real-world MCDM decision making problems are too complex to be solved "optimally" using closed-form solutions. At best, what we can do is to represent as much of the fuzzy/multifaceted nature of the real-world situation as we possibly can, and employ proven heuristic techniques in combination to solve the problem at its richest and most realistic representation. By doing so, we would hope to achieve a good solution that not only addresses the problem but also fosters high level of trust and confidence in everyone involved in the decision making process. Overtime, successful implementation of real-world cases such as the one included in this study help build knowledge repositories for specific problem types (ERP selection problem, in this case) to learn from and to benchmark against.

The rest of the paper is organized as follows. A comprehensive literature review is provided in Section 2. The fundamentals about Fuzzy AHP and TOPSIS are explained in Section 3 and Section 4, respectively. Proposed hybrid methodology is presented and explained in Section 5. A detailed application case is provided in Section 6, and finally the conclusions and future research directions of the study are given in Section 7.

2. Literature review

Since the earliest developments of ERP systems have only emerged in the 1990s [3], the ERP studies and related literature are not old, but rather large. The literature about ERP systems can be analyzed under four main categories: ERP selection, ERP implementation, ERP risk management and general ERP projects. The published research on ERP system selection (as is the case in this study) and implementations constitute roughly about 75% of all published studies [2]. In order to provide a good coverage of the related literature in a concise manner, the scope of the review will be focused on the studies related specifically to ERP system selection problem (however, as needed for completeness sake, other studies that relate to different but associated areas will also be cited).

There are a large number of research studies that investigate ERP related issues, from selection to adaption, while others study the research landscape of the phenomenon. For instance, Al-Mashari [3] provided a research agenda and a timeline for the need for further studies about ERP systems by investigating the published studies. He particularly focused on three subject areas: ERP adoption, technical aspects of ERP and ERP in IS curricula. Wei and Wang [50] developed a comprehensive methodology which considers both subjective and objective criteria while choosing the ERP software. By benefiting from the fuzzy set theory, quantitative criteria are regarded. An indicator called "fuzzy ERP suitability index" was used for determining the suitability of ERP alternatives and criteria importance weights. Baki and Çakar [4] determined the ERP selection criteria and obtained the importance/weights of the criteria by a survey among the firms in Turkey. A methodology including the critical factor assessment for the success of ERP implementation was proposed by Sun et al. [41].

Genoulaz et al. [15] performed a literature review about ERP systems. The literature was analyzed with respect to six categories such as implementation of ERP, optimization of ERP, management through ERP, the ERP software, ERP for supply chain management and case studies. Motwani et al. [32] firstly analyzed the properties and problems of the ERP implementation based on literature and case studies and then presented a framework showing the critical factors to be considered during all the phases of the implementation process. Verville et al. [49] investigated the critical success factors for the successful acquisition of ERP systems by conducting a survey among three organizations. Wei et al. [51] proposed an AHP based methodology for supplier selection problem. Ziaee et al. [56] presented a two stage approach. In the first stage, ERP system properties are determined by collecting information about the possible ERP sellers. In the second stage, a mathematical model was proposed for minimizing the total cost related with procurement and integration.

Finney and Corbett [13] provided a literature review about the critical success factors in ERP implementation and analyzed them. Liao et al. [26] developed an ERP system selection model based on linguistic information processing. A survey was conducted by Velcu [48] to investigate the effects of ERP systems on the organization performance. Wu et al. [53] proposed an ERP selection methodology based on the task-technology fit theory. With the help of the proposed methodology, it became easier to determine the locations of possible misfit. Factors important for the successful implementation of ERP systems were determined and discussed by Yang et al. [54].

Chou and Chang [9] determined the factors influencing the ERP selection. Deep et al. [10] investigated the factors in the ERP selection for SME sector. Analytic Network Process (ANP) was used as a decision making tool for ERP selection problem by Perçin [35]. Razmi et al. [36] used fuzzy ANP for determining the readiness of an organization for ERP implementation. Saatçioğlu [37] analyzed the effects of benefits, barriers and risks to the user satisfaction in ERP systems. Ünal and Güner [46] used AHP for ERP supplier selection in clothing industry. Şen et al. [42] proposed a combined decision making methodology handling both quantitative and qualitative factors via fuzzy set theory and random experiment based solution. Yazgan et al. [55] developed an ERP software selection methodology based on artificial neural network and analytic network process.

A strategic modeling plan for the evaluation and selection of ERP systems was presented by Hakim and Hakim [17]. Best practices for the critical decisions in ERP selection and implementation were offered by Malhotra and Temponi [30]. Doom et al. [11] identified the success factors for ERP implementations in Belgian SMEs. Forslund and Jonsson [14] performed a study for obtaining the effects of different ERP life cycle phases on supply chain performance management. Maguire et al. [29] analyzed the environmental factors that are effective on the ERP implementation by conducting a case study in a firm. Schlichter and Kraemmergaard [39] presented a methodological framework for performing literature review about ERP studies. With respect to the proposed framework, the situation of ERP studies was determined. Şen and Baraçlı [43] developed a methodology based on fuzzy quality function deployment for determining the non-functional requirements in the ERP selection process. Factors affecting ERP system implementation effectiveness were investigated by Maditinos et al. [28]. Wickramasinghe and Karunasekara [52] determined the post-implementation effect of ERP systems on work regarding factors such as "problem solving support", "job discretion, management visibility and cross-functionality", and "authority and decision rights".

The literature cited herein is just an exemplary sample of what has been studied in the area of ERP system selection. The quantity and quality of the published articles in this field are a testament to both importance and the complexity of the ERP system selection problem. What differentiates our approach from the ones conducted previously is the following: first, we developed and presented a systematic three-stage hybrid methodology to better guide the section process. Second, we combined the strengths and mitigated the weaknesses of two popular decision making methods—fuzzy AHP and TOPSIS—to better capture and represent the richness of the reality in the decision making process. Finally, we applied the proposed hybrid methodology to a high-stake real-world decision making situation at a large airline company (i.e., Turkish Airlines) to illustrate its applicability and utility.

3. Fuzzy AHP

Analytic Hierarchy Process (AHP) developed by Saaty [38] has been one of the most widely used techniques for multi-criteria decision making problems. The priority values of both objective and subjective factors are obtained via pair-wise comparisons. There are mainly four consecutive levels in the AHP method. In the first level, there is the objective function. In the second level, there are the attributes. In the third level, there are the sub-attributes and finally, in the last level, there are the alternatives [25].

Since crisp values are used in the AHP method, it is unable to handle the vagueness in the fuzzy decision making environment. Due to this reason, Fuzzy Analytic Hierarch Process (F-AHP) which utilizes fuzzy set theory introduced by Zadeh (1965) [57] was developed. There are numerous F-AHP approaches proposed by various authors. The earliest one is presented by van Laarhoven & Pedrycz [47] comparing fuzzy ratios described by triangular membership functions. Buckley [7] determined fuzzy priorities of comparison ratios having trapezoidal membership functions. Chang [8] proposed a new approach utilizing triangular fuzzy numbers for pair-wise comparison scale of F-AHP. Similar approaches are then proposed by different authors as well [6]. F-AHP with these various approaches are used in numerous studies including different applications such as job selection [22], energy alternatives selection [19], performance assessment systems in municipalities [21,23], supplier selection [25], among others.

Table 1
Triangular fuzzy preference scale.

Saaty's scale	Definition	Triangular fuzzy scale
1	Equally importance	(1, 1, 1)
3	Moderate importance of one over another	(2–4)
5	Essential or strong importance	(4–6)
7	Demonstrated importance	(6–8)
9	Extreme importance	(9, 9, 9)
2	Intermediate values between two adjacent judgments	(1–3)
4	Intermediate values between two adjacent judgments	(3–5)
6	Intermediate values between two adjacent judgments	(5–7)
8	Intermediate values between two adjacent judgments	(7–9)

In this study, F-AHP is used to find the importance/weights of the selection criteria for ERP systems. To apply F-AHP, the procedure proposed by Buckley [7] is used and the steps of the procedure are as follows:

Step 1: Two elements (criteria or alternatives) are compared by the decision makers at each time by the linguistic scale which consists of the fuzzy preference scale as shown in Table 1 [34].
Let $\tilde{d}_{ij}^k$ represent a set of the kth decision maker's preference of one element (i) over another (j) then; the pair-wise comparison matrices are constructed as shown in the Eq. (1).

$$\tilde{A}^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{11}^k & \dots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \dots & \dots & \tilde{d}_{2n}^k \\ \vdots & \vdots & \dots & \vdots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \dots & \tilde{d}_{nn}^k \end{bmatrix}. \tag{1}$$

Step 2: The arithmetic average ($\tilde{d}_{ij}$) of K decision makers' judgment values are computed as stated in the Eq. (2).

$$\tilde{d}_{ij} = \frac{\sum_{k-1}^{K} \tilde{d}_{ij}^k}{K}. \tag{2}$$

Step 3: The fuzzy weights of each criterion are obtained via the geometric mean method proposed by Buckley [7].
Firstly, the geometric mean of fuzzy comparison value of criterion i to each criterion is computed as shown in the Eq. (3).

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, i = 1, 2, \dots, n. \tag{3}$$

Then, the fuzzy weight of the ith criterion represented by a triangular fuzzy number is found as in the Eq. (4).

$$\begin{aligned} \tilde{w}_i &= \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \\ &= (lw_i,\ mw_i,\ uw_i). \end{aligned} \tag{4}$$

Step 4: Centre of Area (COA) method is used as the defuzzification method [9]. The nonfuzzy value M_i of the fuzzy number $\tilde{w}_i$ can be obtained via the Eq. (5):

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{5}$$

M_i is a nonfuzzy number. The normalized weights N_i are found by normalization.
Step 5: After obtaining each N_i, the global weights of all criteria W_i are obtained by multiplying the local normalized weights of criteria by the normalized weights of the related dimension.

4. TOPSIS

One of the famous multi criteria decision making techniques is perhaps the TOPSIS method, which is first proposed by Hwang and Yoon [18]. In this method, the alternatives are ranked based on the distances from positive and negative ideal solutions. The best alternative is deemed to be the one having the nearest distance to the positive ideal solution and the farthest distance from the negative one [40]. Similar to AHP, there are a lot of applications of TOPSIS in various fields such as customer driven product design process [27], performance evaluation of cement firms [12], machine layout in cellular manufacturing system [1], and supplier selection [24]. The specific steps of the methodology applied in the study are as follows:

Step 1: A decision matrix consisting of the evaluation values (x_{ij}) of each alternative with respect to each criterion is normalized and r_{ij} which represents the normalized criteria rating (i represents alternatives, j represents criteria) is obtained as in Eqs. (6) and (7).

$$r_{ij} = \frac{\frac{1}{x_{ij}}}{\sqrt{\sum_{i=1}^{m} \frac{1}{x_{ij}^2}}}, i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \text{ for minimization objective} \quad (6)$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \text{ for maximization objective} \quad (7)$$

Step 2: Weighted normalized decision matrix is computed by applying the Eq. (8).

$$v_{ij} = r_{ij} * w_j, i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \quad (8)$$

Step 3: Positive ideal solution (PIS, A^*) and negative ideal solution (NIS, A^-) are determined as indicated in the Eqs. (9) and (10).

$$A^* = \{v_1^*, \ldots, v_n^*\} \text{ maximum values} \quad (9)$$

$$A^- = \{v_1^-, \ldots, v_n^-\} \text{ minimum values} \quad (10)$$

Step 4: The distance of each alternative from positive ideal solution and negative ideal solution is computed as in the Eqs (11) and (12).

$$d_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2}, i = 1, \ldots, m \quad (11)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, i = 1, \ldots, m \quad (12)$$

Step 5: The relative closeness of each alternative with respect to the ideal solution is computed as in the Eq. (13).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1, \ldots, m \quad (13)$$

Step 6: The alternatives are ranked with respect to the values of CC_i and the biggest one is chosen as the best alternative.

5. Proposed hybrid methodology

The proposed hybrid methodology, consisting of three stages, has two main modeling components which are named as fuzzy AHP (a combination of fuzzy logic and AHP methods) and TOPSIS approaches. Since the decision making environment is usually fuzzy/uncertain in most multi-criteria decision making problems (with respect to the subjectivity of the criteria to be included in the process), instead of making unrealistic assumptions to justify a simplified non-fuzzy solution, we choose to use fuzzy logic and by doing so we aimed to capture the imprecision inherent in the decision situation. Furthermore, in order to cope with the size and complexity of the multi-criteria nature of the decision situation, we employed a hybrid methodology that takes advantage of the strengths of multiple complementary methods. The reason behind choosing the combination of fuzzy AHP and TOPSIS is based on these modeling techniques' strengths and suitability to the current decision situation. Selecting the most suitable (i.e., "the best") ERP system is a complex and challenging decision in any industry. Each of these techniques brings capabilities as well as shortcomings to address specific characteristics of this decision situation, including it being a highly complex multi criteria decision situation that requires the involvement of a group of decision makers and is mostly characterized by a number of non-deterministic (i.e., fuzzy) measures. Even though individually these MCDM techniques have their shortcomings, a methodology that synergistically combines the strengths of these techniques while mitigating the shortcomings is what is proposed herein as a logical MCDM solution to this complex problem. The specific reason for systematically combining these techniques in our study can be explained as follows: within the first stage of the problem, where the structure of the problem is determined, the decisions/tasks/criteria are naturally judgmental. This is where we determine the weights of the criteria, a technique that is capable of evaluating both tangible and intangible factors is needed, and at this point a highly regarded technique "fuzzy AHP" which is also capable of incorporating vagueness/imprecision of the decision situation is employed. In the following stage, another popular technique "TOPSIS" is used to evaluate and rank decision alternatives (using 1–10 evaluation scale). In short, they are complementary techniques and as explained, each of them provides a solution to different requirements of the decision making process. Besides the strength and suitability of these techniques, another motivation for using these techniques collectively is that, to the best of our knowledge, this is the first study that uses fuzzy logic, AHP and TOPSIS for a complex and high-stake decision situation like ERP system selection problem. In a recent study Behzadian et al. [5] reviewed the use of these MCDM techniques in a variety of applications. Their study indicated that although there are a number of applications using TOPSIS and AHP either individually or collectively, there is not an application where all three are used collectively and/or on the ERP selection problem, based on the 266 articles that they had analyzed in their study.

The main stages of the proposed methodology (which shown in Fig. 1) can briefly be summarized as follows: The first stage is to determine the criteria with respect to the requirements (needs and wants) of the company. The second stage is where the importance/weights of all the criteria are obtained via fuzzy AHP methodology, output of which is then used as input to the TOPSIS method. The third and the final stage is where the best ERP software package is determined by utilizing TOPSIS methodology.

6. Application case

An application of the proposed hybrid methodology is performed at Turkish Airlines (THY), which is the largest airline company in Turkey, and one of the largest airlines in Europe. THY wanted to select an ERP system/package/vendor specifically for its maintenance center, which is located at its hub Atatürk International Airport in Istanbul. The Turkish Airlines Maintenance Center, called THY Technic, is responsible for the maintenance, repair, and overhaul of THY's aircrafts, engines, and components.

To get the process started, first of all, within the pre-evaluation stage, a focus group (it was also called the steering committee) consisting of managers at different managerial levels within the organization who are related to and are interested in the ERP system selection process is formed. Throughout the study, the decisions are made within this focus group of 35 people. After forming the focus group, firstly the criteria that represent the rich set of requirements and demands of the company executives are determined and organized under three main groups: technical criteria, corporate criteria and financial criteria.

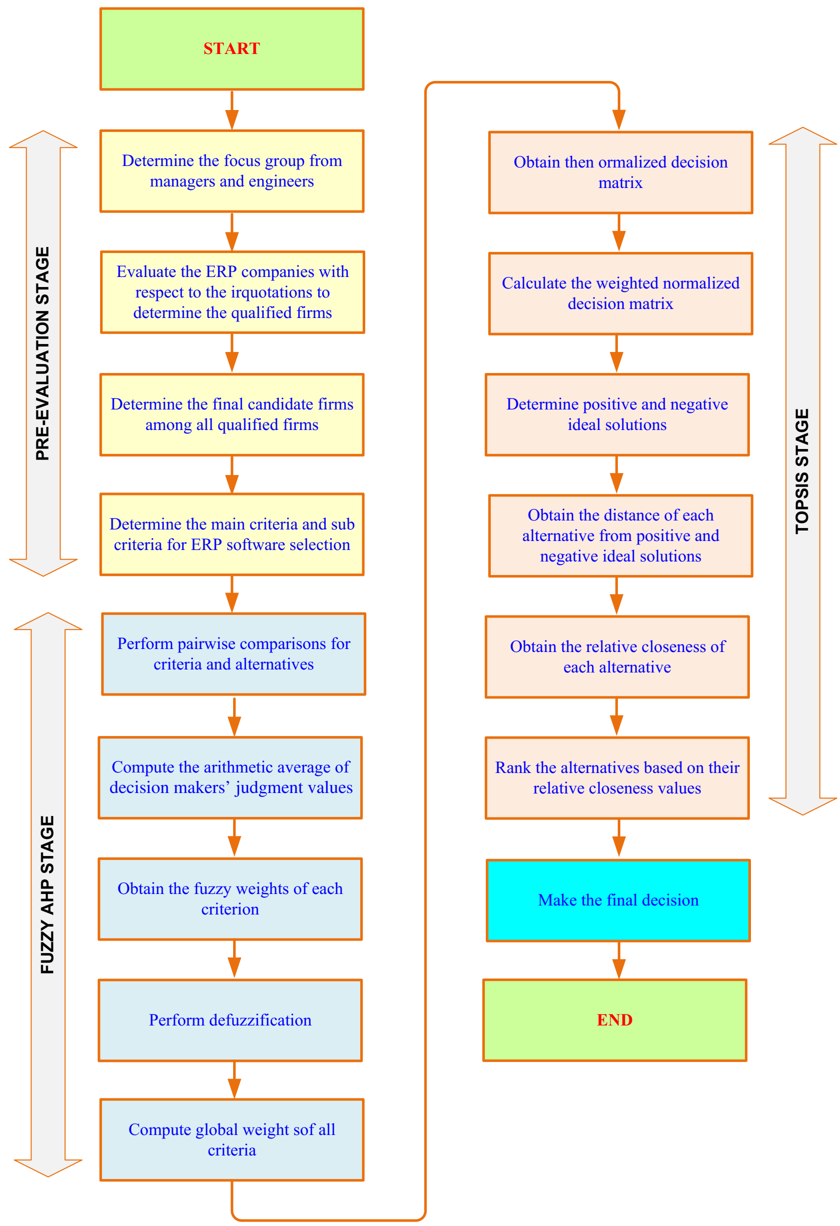

Fig. 1. The main structure of the proposed hybrid methodology.

The sub-criteria under each main group/criterion are listed and briefly described here:

6.1. Technical criteria

Functionality: Under the functionality sub-criterion:

- The ERP package should be operable on multi-language and multi-currency basis.
- It should have such a structure as to enable running of certain applications or obtaining certain reports in a periodic manner.
- There should be structures recording many different characteristics of the materials and searching accordingly.
- Without destroying data integrity and coherence, it should be possible to make retroactive changes on data such as switching a completed purchase order to "open" status.

Compatibility: Under the compatibility sub-criterion:

- The program should be runnable on any Java Application Server, and reach the application via any internet browser.
- It should run on every operating system and should be compatible with all relational databases.
- It should be able to support applications such as SMS and should enable communication with customers and suppliers via e-mail or facsimile.
- It should run in an integrated manner with other software currently in use. In data communication, it should be able both to receive data from outside, as well as send data to external programs.
- It should be possible to transfer existing data in the current information systems to the new system initially.
- The software should consist of independent modules, and such modules should run both in integration as well as independent from one another. Within the framework of project plan, certain modules should possibly be put into operation later. All modules shall be fully compatible to each other.

Usability: Under the usability sub-criterion:

- Screen ergonomics of the software should be simple and consistent; all screens should have similar structures. It should be possible that

more than one transaction is open at the same time, and it should be possible to shift between open transactions.
- Users should have access related help file from any transaction, helps files should relate in a simple wording understandable to the user.
- User should be capable of changing standard reports and forms. Data fields in the reports shall been able to be switched on and off.
- It should be possible to use visual elements such as charts, tables, and graphics when preparing a report for the results of data analysis and outputs of plan.
- Visual reporting should possibly be made. Gantt charts, graphics and such similar structures should possibly be created by users in a parametric manner.

Accessibility: Under the *accessibility* sub-criterion:

- The client should be able to access the ERP software without loading any program, over any hardware (desktop, hand terminal or notebook).
- Open source program codes are a substantial reason for preference.
- At later stages of the project, the software should provide access for customers and suppliers for external utilization, as well as data input via barcode.

Security: Under the *security* sub-criterion:

- It should have at least 128 bit SSL Technology in terms of security.
- With respect to user authorization, authorization should be possible both in transaction basis as well as all fields or controls on the relevant transaction basis.
- Unused or expired data's should be removed from up to dated system and be archived without damaging the integrity of data.
- Operation performance of the software under a specific user number and specific data intensity should be good enough.

6.2. Corporate criteria

References: Under the *references* sub-criterion:

- Number of users using software of the company and number of projects realized should be good enough.
- In the event it is requested, the company shall provide letters of reference in connection with the projects it gave as reference, and relevant company shall be visited together for project investigation.

Adequacy of advisors and developers: Under the *adequacy of advisors and developers* sub-criterion:

- Number of the company's advisor and developers shall be sufficient that whenever required there shall be no problem in timely getting the service.
- Besides quantity, quality of advisors should be sufficient.

After sales service: Under the *after sales service* sub-criterion:

- The company should undertake to hold a consultancy and development office in Istanbul for a period of 3 years.
- It shall continue to develop and release new versions of the software and shall undertake to provide technical, maintenance and consultancy support to the existing version to be utilized in the project for a period of at least 10 years.
- Any working error to occur on the software and arising from codes shall be intervened within shortest notice and solution shall be provided as soon as possible.
- The company shall also respond to support requirements which may arise at new locations or locations abroad in the future.

Know-how sharing policy: Under the *know-how sharing policy* sub-criterion:

- Development environment utilized by the company is important, and by means of providing development training the company shall transfer such know-how to THY.

6.3. Financial criteria

Cost of the project should be assessed as the total of software, hardware and network costs. *License cost*, *consultancy and training cost* and *maintenance cost* comprising the software cost are such criteria to be assessed in detail.

Besides the criteria, four alternative firms are considered for the evaluation process. These four finalists were determined out of 12 firms that submitted full proposal to the formal RFP. Evaluation process included a thorough investigation of the firms' past performances, self-references, and independent industry studies. The final four firms were AMOS, MXI, SAP and TRAX (listed alphabetically). In order to provide objectivity among the participants and the confidentiality of the firms, the alternatives were not explicitly named in the evaluation process, instead represented by letters A, B, C and D. The analytic hierarchy tree constructed for this problem is shown as in Fig. 2.

After the pre-evaluation stage, the steps of fuzzy AHP and TOPSIS are performed sequentially as explained in the following sub-sections.

Fuzzy AHP — Step 1: The steps of fuzzy AHP are performed to obtain the importance/weights of the criteria. The pair-wise comparisons for main criteria and the sub-criteria under each main criterion are determined.

The pair-wise comparisons based on the triangular fuzzy numbers for the three main criteria are determined as shown in Table 2 with the consensus of the decision makers.

The pair-wise comparisons based on the triangular fuzzy numbers for the sub-criteria under the technical main criterion are determined as shown in Table 3 with the consensus of the decision makers.

The pair-wise comparisons based on the triangular fuzzy numbers for the sub-criteria under the corporate main criterion are determined as shown in Table 4 with the consensus of the decision makers.

The pair-wise comparisons based on the triangular fuzzy numbers for the sub-criteria under the financial main criterion are determined as shown in Table 5 with the consensus of the decision makers.

Fuzzy AHP — Step 2: For main and sub-criteria, the fuzzy weights ($\widetilde{w}_i$) are obtained after finding the geometric mean of fuzzy comparison values ($\widetilde{r}_i$) for each criterion.

The related $\widetilde{r}_i$ and $\widetilde{w}_i$ values for each main criterion are shown in Table 6.

The related $\widetilde{r}_i$ and $\widetilde{w}_i$ values for each sub-criterion are shown in Table 7.

Fuzzy AHP — Step 3: The non-fuzzy values (M_i) of $\widetilde{w}_i$ values and the normalized weights N_i are obtained for the main and sub-criteria. The related M_i and N_i values for each main criterion are shown in Table 8.

The related M_i and N_i values for each sub-criterion are shown in Table 9.

Fuzzy AHP — Step 4: The global weights of all criteria W_i are computed by multiplying the local normalized weights of the criteria by the related dimension's normalized weights which are shown in Table 10.

For example, for obtaining the global importance weight of "functionality", the local importance weight of functionality (0.369) is multiplied by the weight of the related dimension which is the importance weight of the technical criterion (0.405) and the global importance weight of functionality is obtained as 0.149 as shown in Table 11.

After obtaining the weights of the criteria via fuzzy AHP, TOPSIS methodology is performed to select the best alternative.

TOPSIS — Step 1: In this step, decision matrix as shown in Table 12 including the ratings of alternatives with respect to each criterion from 1 to 10 scales is normalized. While Company A was found to have a relatively better performance in terms of usability and accessibility, Company C had a better performance in terms of license, consultancy and maintenance. Company D, however, outperformed the other three companies in terms of functionality and references.

Using Eq. (7), normalized decision matrix is obtained depending on the maximization of selection criterion. The normalized decision matrix is shown in Table 13.

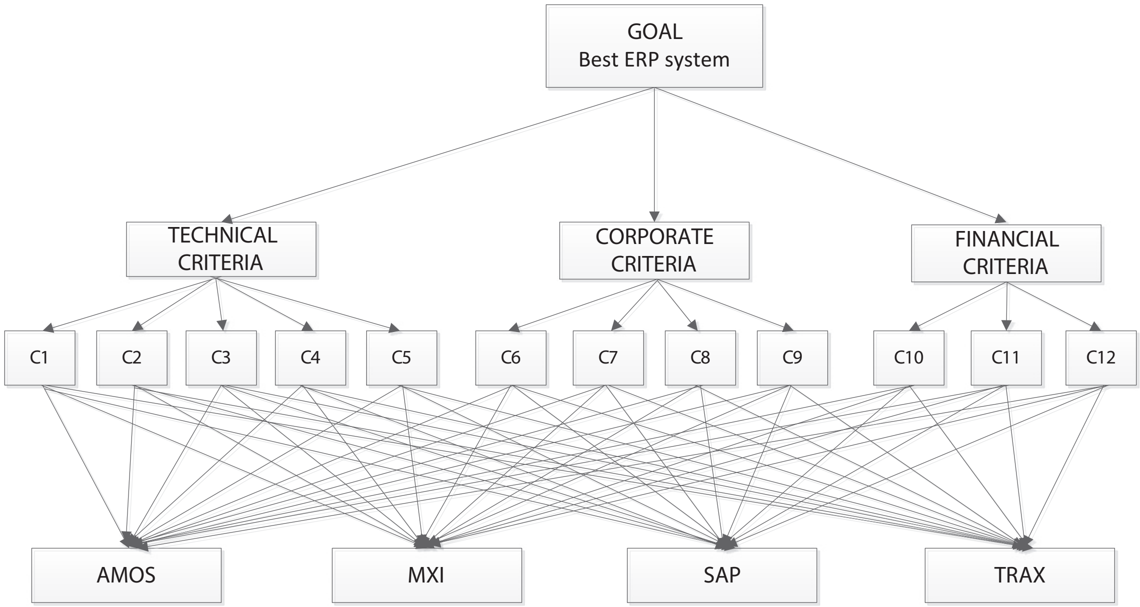

Fig. 2. The hierarchical structure for the selection of ERP system.

TOPSIS — Step 2: Within the second step, the weighted normalized decision matrix is obtained as shown in Table 14.

TOPSIS — Step 3: The positive and negative ideal solutions are obtained for each criterion as shown in Table 15.

TOPSIS — Step 4: The distances of each alternative from positive and negative ideal solutions are obtained as shown in Table 16.

TOPSIS — Step 5: The relative closeness of each alternative with respect to the ideal solution is obtained as in Table 17.

TOPSIS — Step 6: The alternatives are ranked with respect to the values of CC_i from biggest to the smallest one and the ranking is obtained as A, D, C and B.

Regarding the last step of TOPSIS methodology, the alternative A is decided to be chosen as the ERP software for Turkish Airlines. This finding is not particularly surprising, as most ERP software evaluation decisions in maintenance are made today in increasingly complex environments where the theory of fuzzy decision-making can be of significant use. In this study, the fuzzy AHP weighted TOPSIS methodology has been employed instead of using conventional TOPSIS approach.

7. Discussion and conclusion

Enterprise resource planning systems are making the enterprises more efficient by integrating their cross-functional business processes over a common information system infrastructure. Having such an integrated information system allows stake holders to use the single version of the truth throughout the enterprise—small or large, local or multinational. Despite the obvious benefits of an ERP system, many companies have failed to successfully implement it. In fact, many industry experts claim that about two-thirds of all ERP system initiatives were classified as unsuccessful; some are terminated before the completion, others were canceled shortly after the implementation. Some of the major reasons include higher than expected cost/time of implementation and the lack of suitability for the existing business practices.

Because of the fact that there are a large number of ERP system offerings in the market place, each having different qualities and limitations, having a scientifically sound selection process is a critical part of ERP system adoption/implementation. Depending on the size of the enterprise, and ERP system implementation may cost a few million dollars and may last up to six months to implement for smaller sizes, to costing hundreds of millions of dollars and lasting several years to fully implement for the large ones. Because it costs a great deal and it takes a long time to fully implement, ERP systems are among the most risky IT investment. Therefore, a thorough consideration of all options and criteria is not only an option but also a critical requirement to increase the likelihood of success.

Since there are a lot of criteria to be considered during this selection process, multi criteria decision making tools are widely to overcome this problem. In this study, an ERP system selection problem at a large airline company in Turkey is considered. First, based on the requirements and the demands of the company executives, the ERP selection criteria are determined. Then, the alternative ERP firms and their offerings are investigated and determined. After determining the criteria and solution alternatives, the proposed hybrid methodology, consisting of fuzzy AHP which incorporates the vagueness of the decision making process and TOPSIS, is applied and validated. Specifically, the importance/weights of the selection criteria are obtained via fuzzy AHP based on the triangular fuzzy preference scales. Then these weights are used in the TOPSIS methodology to reach the ranking of alternative ERP system suppliers.

The use of a hybrid selection/evaluation methodology proved to produce results that are both technically sound and organizationally acceptable. Knowing that the vagueness and complexity of the decision situation are handled using the strengths of two popular decision support methods makes the decision makers confident in their final selection. They feel that by breaking the complex problem space into smaller pieces, dealing with them at that granular level, and then aggregating them at the higher decision level have a much better chance of producing optimal (or near optimal) decisions.

It should be acknowledged that the present study is subject to some limitations. Perhaps the most serious limitation of this study is its narrow focus on a single case study in aviation industry. To generalize on the findings and the viability/validity/value of the methodology, more

Table 2
Pairwise comparisons of the main criteria based on the triangular fuzzy numbers.

Main criteria	Technical criteria	Corporate criteria	Financial criteria
Technical criteria	(1, 1, 1)	(1–3)	(1, 1, 1)
Corporate criteria	(1/3, 1/2, 1)	(1, 1, 1)	(1, 1, 1)
Financial criteria	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)

Table 3
Pairwise comparisons of the technical criteria based on the triangular fuzzy numbers.

Technical criteria	Functionality	Compatibility	Usability	Accessibility	Security
Functionality	(1, 1, 1)	(2–4)	(1–3)	(2–4)	(2–4)
Compatibility	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)
Usability	(1/3, 1/2, 1)	(1–3)	(1, 1, 1)	(1, 2, 3,)	(1–3)
Accessibility	(1/4, 1/3, 1/2)	(1–3)	(1/3, 1/2, 1)	(1, 1, 1)	(1/3, 1/2, 1)
Security	(1/4, 1/3, 1/2)	(1–3)	(1/3, 1/2, 1)	(1–3)	(1, 1, 1)

Table 4
Pairwise comparisons of the corporate criteria based on the triangular fuzzy numbers.

Corporate criteria	References	Adequacy	After sales	Know-how
References	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1–3)
Adequacy	(1, 2 ,3)	(1, 1, 1)	(1/3, 1/2, 1)	(1–3)
After sales	(1–3)	(1–3)	(1, 1, 1)	(1–3)
Know-how	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)

real-world cases need to be performed. Another limitation of the individual methods is the independent structure of the selection criteria. Since the comparisons are made in a piece-meal/pairwise fashion, reaching the true optimal may not be possible. Also, for manageability purposes, various low-level criteria are grouped in clusters, by doing so, some detailed specifications may have been lost. Finally, the methodology proposed in this study, as systematics as it may sound, is a heuristic one. That is, it does not guarantee finding the optimal solution. The "optimality" of the results is often subject to the richness (in terms of quantity and quality) of the participants; positively influenced by their knowledge, experience and dedication.

For further studies, some of the other multi-criteria decision making techniques such as PROMETHEE, VIKOR and/or ELECTRE can be used in combination of (or with replacement to) the ones used in this study to assess the viability and utility of new hybrid methodologies. Another research direction would be to apply the proposed hybrid methodology to other MCDM situation to confirm its utility and generalizability.

Table 5
Pairwise comparisons of the financial criteria based on the triangular fuzzy numbers.

Financial criteria	License	Consultancy	Maintenance
License	(1, 1, 1)	(1/3, 1/2, 1)	(1–3)
Consultancy	(1–3)	(1, 1, 1)	(1–3)
Maintenance	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)

Table 6
The $\widetilde{r}_i$ and $\widetilde{w}_i$ values for the main criteria.

Main criteria	$\widetilde{r}_i$	$\widetilde{w}_i$
Technical criteria	(1, 1.26, 1.44)	(0.29, 0.41, 0.54)
Corporate criteria	(0.69, 0.79, 1)	(0.20, 0.26, 0.37)
Financial criteria	(1, 1, 1)	(0.29, 0.33, 0.37)

Table 7
The $\widetilde{r}_i$ and $\widetilde{w}_i$ values for the sub-criteria.

Sub-criteria	$\widetilde{r}_i$	$\widetilde{w}_i$
Functionality	(1.52, 2.22, 2.86)	(0.19, 0.39, 0.75)
Compatibility	(0.39, 0.53, 0.87)	(0.05, 0.09, 0.23)
Usability	(0.80, 1.32, 1.93)	(0.1, 0.23, 0.51)
Accessibility	(0.49, 0.70, 1.08)	(0.06, 0.12, 0.28)
Security	(0.61, 0.92, 1.35)	(0.08, 0.16, 0.35)
References	(0.58, 0.84, 1.32)	(0.09, 0.20, 0.47)
Adequacy	(0.76, 1.19, 1.73)	(0.12, 0.28, 0.62)
After sales	(1, 1.68, 2.28)	(0.16, 0.39, 0.82)
Know-how	(0.44, 0.59, 1)	(0.07, 0.14, 0.36)
License	(0.69, 1, 1.44)	(0.15, 0.31, 0.66)
Consultancy	(1, 1.59, 2.08)	(0.22, 0.49, 0.96)
Maintenance	(0.48, 0.63, 1)	(0.11, 0.2, 0.46)

Table 8
The M_i and N_i values for the main criteria.

Main criteria	M_i	N_i
Technical criteria	0.413	0.405
Corporate criteria	0.278	0.272
Financial criteria	0.330	0.323

Table 9
The M_i and N_i values for the sub-criteria.

Sub-criteria	M_i	N_i
Functionality	0.443	0.369
Compatibility	0.123	0.102
Usability	0.280	0.233
Accessibility	0.156	0.130
Security	0.197	0.164
References	0.254	0.205
Adequacy	0.340	0.274
After sales	0.457	0.368
Know-how	0.189	0.153
License	0.376	0.317
Consultancy	0.557	0.469
Maintenance	0.254	0.214

Table 10
The importance/weights of the main criteria.

Main criterion	Importance weight
Technical	0.405
Corporate	0.272
Financial	0.323
TOTAL	1

Table 11
The local and global importance/weights of the sub-criteria.

Main criteria	Sub-criteria	Local importance weight (N_i)	Global importance weight (W_i)
Technical	Functionality	0.369	0.149
	Compatibility	0.103	0.042
	Usability	0.233	0.094
	Accessibility	0.13	0.053
	Security	0.165	0.067
Corporate	References	0.205	0.056
	Adequacy	0.274	0.075
	After sales	0.368	0.100
	Know-how	0.153	0.042
Financial	License	0.317	0.102
	Consultancy	0.469	0.151
	Maintenance	0.214	0.069

Table 12
Decision matrix including the ratings of alternatives with respect to each criterion.

Alternative	Criteria											
	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10	Cr11	Cr12
A	7	8	9	9	6	8	8	7	8	7	6	5
B	4	6	5	6	6	5	6	7	8	8	7	6
C	6	4	3	5	6	3	5	7	8	9	9	7
D	9	8	7	8	6	9	8	7	8	6	5	4
Weight	0.149	0.042	0.094	0.053	0.067	0.056	0.075	0.100	0.042	0.102	0.151	0.069

Table 13
Normalized decision matrix including the ratings of alternatives with respect to each criterion.

Alternative	Criteria											
	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10	Cr11	Cr12
A	0.519	0.596	0.703	0.627	0.500	0.598	0.582	0.500	0.500	0.462	0.434	0.445
B	0.297	0.447	0.390	0.418	0.500	0.374	0.436	0.500	0.500	0.528	0.507	0.535
C	0.445	0.298	0.234	0.348	0.500	0.224	0.364	0.500	0.500	0.593	0.651	0.624
D	0.667	0.596	0.547	0.557	0.500	0.673	0.582	0.500	0.500	0.396	0.362	0.356
Weight	0.149	0.042	0.094	0.053	0.067	0.056	0.075	0.100	0.042	0.102	0.151	0.069

Table 14
Weighted normalized decision matrix.

Alternative	Criteria											
	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10	Cr11	Cr12
A	0.078	0.025	0.066	0.033	0.033	0.033	0.043	0.050	0.021	0.047	0.066	0.031
B	0.044	0.019	0.037	0.022	0.033	0.021	0.033	0.050	0.021	0.054	0.077	0.037
C	0.066	0.012	0.022	0.018	0.033	0.013	0.027	0.050	0.021	0.061	0.099	0.043
D	0.099	0.025	0.051	0.029	0.033	0.038	0.043	0.050	0.021	0.041	0.055	0.025
Weight	0.149	0.042	0.094	0.053	0.067	0.056	0.075	0.100	0.042	0.102	0.151	0.069

Table 15
Positive ideal solution (A^*) and negative ideal solution (A^-) for each criterion.

Ideal solution	Criteria											
	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10	Cr11	Cr12
A^*	0.099	0.025	0.066	0.033	0.033	0.038	0.043	0.050	0.021	0.061	0.099	0.043
A^-	0.044	0.012	0.022	0.018	0.033	0.013	0.027	0.050	0.021	0.041	0.055	0.025

Table 16
The distance of each alternative from positive and negative ideal solutions.

Alternative	d^*	d^-
A	0.044	0.066
B	0.071	0.034
C	0.066	0.056
D	0.054	0.071

Table 17
The relative closeness (CC_i) value for each alternative.

Alternative	CC_i
A	0.600
B	0.326
C	0.461
D	0.570

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Dr. Huseyin Selcuk Kilic is currently an instructor in the Department of Industrial Engineering in Marmara University. He received the BSc, MSc and PhD degrees in Industrial Engineering from Istanbul Technical University. He studied in-plant logistics design for his PhD dissertation. His main research areas are plant logistics, reverse logistics, lean production, decision making and ergonomics. He has research papers in journals that include Applied Mathematical Modelling, International Journal of Advanced Manufacturing Technology, and Assembly Automation.

Dr. Selim Zaim has received his B.S. degree in Mechanical Engineering from Istanbul Technical University and his Ph. D. degree in Production and Operations Management from Istanbul University. Selim Zaim has been serving as a professor in the Faculty of Management at Istanbul Technical University. Zaim has published over 100 articles and papers in various journals and congress proceedings. His current scholarly interests focus on multivariate data analysis, supply chain management, data mining and multi-criteria decision making. Zaim reviews papers for a variety of journals. He is a member of Industrial Management and Development Associations and Quality Association in Turkey (KALDER).

Dr. Dursun Delen is the William S. Spears Endowed Chair in Business Administration, Neal Patterson Chair in Business Analytics, Research Director for the Center for Health Systems Innovation, and Professor of Management Science and Information Systems in the Spears School of Business at Oklahoma State University (OSU). He received his Ph.D. in Industrial Engineering and Management from OSU in 1997. Prior to his appointment as an Assistant Professor at OSU in 2001, he worked for a privately-owned research and consultancy company, Knowledge Based Systems Inc., in College Station, Texas, as a research scientist for five years, during which he led a number of decision support and other information systems related research projects funded by federal agencies, including DoD, NASA, NIST and DOE. His research has appeared in major journals including Decision Support Systems, Decision Sciences, Communications of the ACM, Computers and Operations Research, Computers in Industry, Journal of Production Operations Management, Artificial Intelligence in Medicine, Expert Systems with Applications, among others. He recently published four books: Advanced Data Mining Techniques with Springer, 2008; Decision Support and Business Intelligence Systems with Prentice Hall, 2010; Business Intelligence: A Managerial Approach, with Prentice Hall, 2010; and Practical Text Mining and Statistical Analysis for Non-structured Text Data Applications, with Elsevier, 2012. He is often invited to national and international conferences for keynote addresses on topics related to Data/Text Mining, Business Intelligence, Decision Support Systems, and Knowledge Management. He served as the general co-chair for the 4th International Conference on Network Computing and Advanced Information Management (September 2–4, 2008 in Soul, South Korea), and regularly chairs tracks and mini-tracks at various information systems conferences. He is the associate editor-in-chief for International Journal of Experimental Algorithms, associate editor for International Journal of RF Technologies, and is on editorial boards of five other technical journals. His research and teaching interests are in data and text mining, decision support systems, knowledge management, business intelligence and enterprise modeling.