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A decision model for information technology selection using AHP integrated TOPSIS-Grey: The case of content management systems

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ABSTRACT

Content Management System (CMS) is an information system that allows publishing, editing, modifying content over internet through a central interface. By the evolution of internet and related communication technologies, CMS has become a key information technology (IT) for organizations to communicate with its internal and exterior environment. Just like any other IT projects, the selection of CMS consists of various tangible and intangible criteria which contain uncertainty and incomplete information. In this paper the selection of CMS among available alternatives is regarded as a multi criteria decision making problem. A decision model which consists of seven criteria and four alternatives is built, AHP (Analytic Hierarchy Process) integrated Grey-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is proposed, and applied in a Turkish foreign trade company. In the proposed model, the weights of the criteria are determined by AHP method and the alternatives are evaluated by Grey-TOPSIS. Due to the uncertainties, grey numbers are used for evaluations of the alternatives. One at a time sensitivity analysis is also provided in order to monitor the robustness of the method. Besides, the effects of using different distance functions, such as Manhattan, Euclidian and Minkowski distance functions on the results are examined.

1. Introduction

Information systems (IS) are critical instruments for companies to achieve competitive advantage, organizational learning and innovation [3,40]. One of the important aspects of IS management is the selection of the most suitable software from many competing alternatives [48]. In the context of organizational IS, enterprise resource planning, customer relationship management and supply chain management, are the pioneering applications that grasp attention [27,51]. However, in the recent years, content management systems have become a vital technology for companies both for internal and external communications. With the emergence of internet, building and managing websites and establishing an efficient communication with employers, customers and suppliers has become an inevitable strategy for companies. As a response to management difficulties of websites which contain many pages, CMS software has emerged in mid-1990s for easy management of the content [6]. As a core definition, CMSs are software applications for creating, publishing, editing and managing content, but as new web technologies emerge, the CMS software gained new features and functionalities [26,36]. Today, CMSs are widely used by the news and media organizations, e-commerce websites, libraries, broadcasting and film industry, and educational institutions to handle the content efficiently [25].

Content management systems need considerable financial investment for implementation and bear some potential risks. Thus the selection of the proper CMS solution is a critical issue for organizations. The selection process can be modelled as a multi criteria decision making (MCDM) problem which can handle various different and conflicting criteria for making a selection among predetermined decision alternatives. The literature does not provide studies that directly focus on CMS selection; however MSCD methods are widely used in the field of information systems selection. Some recent methods can be listed as follows: Weighted Sum Method [5,35] Analytic Hierarchy Process [46,39], Analytic Network Process [57,21], TOPSIS [34] and ELECTRE [49]. In this study AHP and TOPSIS methods are integrated and extended so as to utilize grey numbers for the evaluation of the alternatives.

IS selection decisions contain high levels of intangibility and uncertainty which make them difficult to assess and quantify. What is more, the reliability of the technology, capabilities and life

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time of new technologies increase the uncertainty and make the decision more complex. In the traditional formulation of MCDM problems exact numbers are used to represent a judgment or a score. However, in many practical cases, usage of exact numbers may not be possible, the data can be imprecise, or the decision makers might be unable to assign exact numerical values to the evaluation. In such cases, Grey systems theory, developed by Deng [12] provides a practical alternative to handle uncertainty. Grey systems provide a methodology for problems involving incomplete and poor information using grey numbers. In this context, grey refers to partially known and partially unknown information and a grey number is a number whose exact value is unknown, but a range within which the value lies is known.

In this study, AHP and TOPSIS methods are integrated to determine the most suitable CMS alternative. AHP, known for its flexibility and ability to decompose a decision problem, is used to determine the weights of the criteria and these weights are later used in TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique which takes into account the best and worst ideals when evaluating the alternatives. While the AHP part of the study uses classical approach, the alternative evaluations utilize Grey numbers in order to handle the uncertainty and vagueness. TOPSIS-Grey is used to process the evaluations expressed as grey numbers and to provide a ranking for the alternatives.

The inspiration for this study is to provide decision support to the web publishers in selecting content management system via a systematic approach. When considering the large body of literature, it can be concluded that to the best of our knowledge, this paper is the first to identify CMS selection criteria and utilize grey multi criteria decision making technique in a CMS selection problem. The sensitivity analysis are applied for the criteria weight and it is concluded that the proposed method provide robust results. Finally, different distance functions are applied to detect the effect of the distance functions on the results. When the proposed method is compared with the existing studies in the literature, it can be concluded that the proposed method can incorporate uncertainty in a practical way using Grey numbers and more accurate results can be acquired with the integration of AHP and TOPSIS methods. The rest of this paper is organized as follows. In Section 2, the relevant literature on information systems selection and Grey theory is reviewed. TOPSIS-Grey technique is explained in Section 3. The literature review on CMS and decision criteria for CMS selection are expressed in Section 4. The application study of the proposed methodology to a real life company is presented in Section 5. Finally in Section 6 conclusions are given.

2. Literature review

In the last two decades, information systems (IS) have gained increased attention of companies and the selection of the projects has been in the focus of various academic studies. The list of the techniques and related references are presented in Table 1.

As shown in Table 1 most of the techniques in the literature are from multicriteria decision making (MCDM) domain. Since the IS alternatives can be evaluated from several different perspectives, the selection problem is generally modelled as a MCDM problem [48]. Some of the latest studies from IT selection literature are listed in this section. Liang and Li [29] use Analytic Network Process (ANP) combined with BOCR technique which evaluates the alternative from various perspectives such as Benefits, Opportunities, Costs and Risks. The method is applied to four enterprise information system alternative. Wu and Ong [55] propose Real Options analysis in conjunction with the Mean–Variance (MV) model to help managers evaluate alternative projects and present a case study that is focused on five IT projects. Mao et al. [34] integrate balanced scorecard approach with TOPSIS for information systems selection. Yazgan et al. [57] on the other hand suggest integrating artificial neural networks and ANP to make an ERP software selection. Chen et al. [9] propose using real options for evaluating the information technology projects in order to deal with multiple risk situations. Asosheh et al. [3] propose a Data Envelopment Analysis (DEA) technique integrated with Balanced Scorecard (BSC) to rank IT projects using cardinal and ordinal data and use the technique in a real life case study. Nazari et al. [38] propose a methodology based on Fuzzy group decision making approach to evaluate and select the appropriate information system project for outsourcing decisions. Kop et al. [21] evaluate the various risk perspectives including executive, organizational, project management and technical risks of ERP projects using fuzzy ANP. Hannu et al. [15] propose a model using AHP in order to prioritize IT projects and apply the model to a company for prioritizing suppliers for adopting electronic invoicing. Tolga [49] integrates ELECTRE with real options approach in order to evaluate software development projects. You et al. [58] suggest using real options in fuzzy environment for the evaluation of ERP investments.

Table 1
Selected the techniques and related references form IS selection literature.

Techniques	References	Application area
Weighted sum Method	Blanc and Jelassi [5]	DSS software
	Morisio and Tsoukis [35]	Software packages
Analytic Hierarchy Process	Sarkis and Talluri [46]	E-commerce software selection
	Ngai and Chan [39]	Knowledge management systems
Analytic Network Process	Yazgan et al. [57]	ERP software
	Kop et al. [21]	ERP projects
TOPSIS	Mao et al. [34]	IS selection
ELECTRE	Tolga [49]	Software development projects
Data Envelopment Analysis	Bernroider and Stix [4]	Software packages
	Asosheh et al. [3]	IT Project Evaluation
Real Options	Wu and Ong [55]	Evaluation of IT investments
	Chen et al. [9]	

In IS selection problems, evaluation and quantification of the alternatives is generally hard because the decision model may contain intangible criteria. Besides, the selection problem contains uncertainties such as reliability and precision of the technology. What is more, the technology can be absolute in a short period after the selection decision is given. Jinlan and Deepak [18] analyze the investment decision under asymmetric information caused by market uncertainty and show that managers try to minimize the uncertainties by acquiring information about the IS investment to give better decisions, however it may not be possible to reduce uncertainty. In the IS selection literature, fuzzy sets are generally integrated with the existing techniques to deal with uncertainty [8,20,47,19]. In these studies linguistic terms are used to evaluate alternatives so as to improve decision making procedure by accommodating the vagueness and ambiguity in human decision making. In this study, Grey System Theory is integrated with MCDM techniques so as to deal with both the different evaluation criteria and the uncertainties.

The grey systems theory, developed by Deng [10,12] is a methodology that focuses on problems involving incomplete and poor information. In Grey systems, white represents complete information while black indicates unknown information. Grey refers to partially known and partially unknown information. A grey number is defined as a number whose exact value is unknown, but a range within which the value lies is known [30]. Deng [11] adopts grey theory for decision making problems and many other authors later used Grey System Theory in decision making. Grey Relational

Analysis (GRA) technique is one of the most popular approaches used for decision making in the literature. Haq and Kannan [16] propose using GRA and AHP for vendor selection problem. Kuo et al. [23] apply GRA to facility layout and dispatching rules selection problem. Wei [54] proposes a GRA for multiple attribute decision making with incomplete weight information. Gang et al. [14] compare five MCDM methods including grey relational analysis for the selection of classification methods. Grey numbers have also been used in combination with other techniques to make decisions with incomplete information. Lin et al. [32] design a decision algorithm for a billiard robot by using grey theory. Zhang et al. [62] propose a method of grey related analysis to multi attribute decision making problem with interval numbers. Kung and Kun-Li [22] use grey decision making to evaluate the relationship between company attributes and its financial performance. Li et al. [28] develop a grey decision making model to supplier selection problem with six supplier and four criteria. Lin et al. [30] propose a dynamic decision making model which integrates TOPSIS technique with Grey numbers using Minkowski distance function and apply the model to subcontractor selection example. Tseng [50] develops a real estate agent service quality expectation ranking using a combined grey-fuzzy DEMATEL method. Zavadskas et al. [60] compare TOPSIS-Grey and SAW-G techniques in a contractor selection problem. In another study, Zavadskas et al. [61] compare TOPSIS-Grey with COPRAS-G technique in the field of risk evaluation for construction projects. Zhi-Xin [63] propose a hybrid fuzzy approach to multi attribute group decision making using VIKOR and GRA.

The current grey systems studies uncover the potential of using grey numbers in decision making problems. In this study, AHP technique is integrated with TOPSIS-Grey in order to produce a more reliable decision making approach which can use evaluations expressed as grey numbers. In this study, the proposed approach is introduced and a sample application is given from a CMS selection case.

3. Methodology

In this study, two techniques, namely AHP and TOPSIS-Grey are used to decide the most suitable CMS system among the alternatives. AHP is used to determine the weight of decision criteria which are later used in TOPSIS-Grey. In this section a brief summary about the AHP and TOPSIS techniques are given and finally AHP integrated TOPSIS technique is introduced in detail.

3.1. Analytic Hierarchy Process

Analytic Hierarchy Process (AHP), developed by Saaty [43], structures a decision problem as a hierarchy with an overall goal, a group of alternatives, and of a group of criteria which link the alternatives to the goal. Saaty [45] identifies two types of measurements in AHP method; absolute and relative measurement. In the absolute measurement, the alternative is compared with an ideal alternative that is known of or can be imagined; however in relative measurement an alternative is compared with other alternatives one by one which is called pairwise comparison. Pairwise comparisons are classically carried out by asking the decision maker how valuable a criterion (C1) when compared to another criterion (C2) with respect to overall goal. Also the alternatives can be pairwise compared by asking the comparison of an alternative A with alternative B with respect to a specified criterion. The verbal judgments of the decision maker are then transformed into numerical values using the scale presented in Table 2.

Using the pairwise comparison judgments of the decision maker, a pairwise comparison matrix is formed as seen in Fig. 1. While the diagonal elements of the matrix are equal to 1, the other ones change between the values defined in Table 2 and the inverse of these values. As the pairwise comparison matrix is formed, the priorities can be calculated using the eigenvalues.

Table 2
Verbal judgments and numerical rate.

Verbal judgment of preference	Numerical rate
Equal importance	1
Weak importance of one over another	3
Essential or strong importance	5
Demonstrated importance	7
Absolute importance	9
Intermediate values between the two adjacent judgments	2, 4, 6, 8

In order to measure the subjective evaluation of the decision maker, Saaty [44] proposes a consistency index (CI). CI is calculated for each pairwise comparison matrix and checked for consistency using a random index (RI). If the calculated ratio is significantly small (10% or less), the priorities are accepted otherwise, the DM is asked to revise the pairwise comparisons.

AHP can be used to solve a MCDM problem. As the criteria are defined and the weights are calculated using pairwise comparison matrix, similar procedure can be applied to calculate the weight of the alternatives. The pairwise comparison matrix of alternatives is formed with respect to one criterion. The result is a new reciprocal square matrix for each criterion, with its corresponding eigenvector. The procedure is repeated for all criteria and the value of each alternative and criterion is calculated. Afterwards, the value of each alternative is multiplied by the weight of the corresponding criterion. Finally, all the values for an alternative are summed up to find the overall score, the final calculation results indicate the importance of each alternative. The alternatives are then ranked according to their calculated values.

Although AHP technique is used to solve selection problems, in this study it is only utilized to determine the weight of the criteria, not to evaluate the alternatives. The calculated weights are later used in the TOPSIS-Grey technique.

3.2. TOPSIS technique

TOPSIS is a multiple criteria decision making method which is initially proposed by Hwang and Yoon [17]. The technique is based on the idea that the optimal solution should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution. A solution is determined as a positive ideal solution if it maximizes the benefit criteria or minimizes the cost criteria. On the other hand, the solution which maximizes the cost criteria or minimizes the benefit criteria is called the negative ideal solution [52].

In the initial step of the technique, the positive and negative ideal solutions are determined. To determine these values, the decision matrix is formed and normalized. Then, the positive ideal solution (A^+) is determined by selecting the largest normalized and weighted score for each criterion. Similarly, the negative ideal

$$\begin{bmatrix} 1 & a_{12} & a_{13} & a_{1j} & .. & a_{1n} \\ 1/a_{12} & 1 & a_{23} & a_{2j} & .. & .. \\ 1/a_{13} & 1/a_{23} & 1 & a_{3j} & .. & .. \\ 1/a_{1j} & 1/a_{2j} & 1/a_{3j} & 1 & .. & a_{jn} \\ .. & .. & .. & .. & .. & .. \\ 1/a_{1n} & .. & .. & 1/a_{jn} & .. & 1 \end{bmatrix}$$

Fig. 1. AHP pairwise positive reciprocal comparison matrices.

solution (A^-) is determined by selecting the least normalized and weighted score of each criterion [42].

In the second step, the distances of each alternative to the positive ideal solution R^+ and negative ideal solution R^- calculated.

$$R_j^+ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^+)^2} \quad i = 1,2,\ldots,J \tag{3.1}$$

$$R_j^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2} \quad i = 1,2,\ldots,J \tag{3.2}$$

where v_j^+ is the positive ideal, v_j^- is the negative ideal for the criteria j.

Using these calculated values closeness index (C.I.) for each alternative is computed using Eq. (3.3):

$$\text{Closeness index (C.I.)} = \frac{(R)^-}{(R)^+ + (R)^-} \tag{3.3}$$

The closeness index can get values between 0 and 1 and the alternative which has the highest C.I. is selected as the best alternative.

3.3. AHP integrated TOPSIS-Grey

Many decision making and problem solving tasks are too complex to be understood quantitatively; however, people are more familiar to use imprecise knowledge rather than precise knowledge. Thus, in the literature MCDM methods are integrated with fuzzy and grey theory. In this paper, TOPSIS-Grey [30,31,60,61] methodology is integrated with AHP to provide a powerful method that can handle uncertainties.

Grey number is a concept from grey theory, proposed by Deng [10,12] to deal with insufficient an incomplete information. A grey number is defined as $\otimes X = [\underline{x}, \bar{x}]$ where $\underline{x}$ is a real number showing the lower limit, and $\bar{x}$ is the real number that shows the upper limit for the grey number. If both the lower and upper limits are unknown the number is called black number showing no meaningful information. If the upper limit and the lower limits are equal then it is called white number which means complete information. A grey number defined as $\otimes X = [\underline{x}, \bar{x}]$ means that the value of the number is not known for certain but it is known that the number is not lower than $\underline{x}$ and not higher than $\bar{x}$.

The addition, subtraction, multiplication and division operator for grey numbers $\otimes a$ and $\otimes b$ are given as follows [56].

$$\otimes a + \otimes b = [\underline{a} + \underline{b}, \bar{a} + \bar{b}] \tag{3.4}$$

$$\otimes a - \otimes b = [\underline{a} - \underline{b}, \bar{a} - \bar{b}] \tag{3.5}$$

$$\otimes a * \otimes b = [\min(\underline{ab}, \overline{ab}, \bar{a}\underline{b}, \underline{a}\bar{b}),\ \max(\underline{ab}, \bar{a}b, \bar{a}\underline{b}, \underline{a}\bar{b})] \tag{3.6}$$

$$\otimes a : \otimes b = \otimes a * \left[\frac{1}{\bar{b}}, \frac{1}{\underline{b}}\right], \quad 0 \notin \otimes b \tag{3.7}$$

Grey numbers can be considered as a special case of fuzzy number, a triangular fuzzy numbers $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ can be transformed into grey numbers $\otimes a = [a_1, mhboxa_3]$ and $\otimes b = [b_1, b_3]$. Flowing from the fuzzy number literature, the Euclidean distance between the grey numbers can be calculated as shown in Eq. (3.8)

$$d(\otimes a, \otimes b) = \sqrt{\frac{1}{2}[(\underline{a} - \underline{b})^2 + (\bar{a} - \bar{b})^2]} \tag{3.8}$$

Based on this definitions and operations, the procedure of applying the TOPSIS-Grey integrated with AHP method consists of the following steps:

Step 1: Determining the decision criteria, the set of most important attributes and describing the alternatives.

Step 2: Determining the decision making matrix D,

$$D = \begin{bmatrix} \otimes x_{11} & \cdots & \otimes x_{1m} \\ \vdots & \ddots & \vdots \\ \otimes x_{n1} & \cdots & \otimes x_{nm} \end{bmatrix}; \quad i = \overline{1,n}; \quad j = \overline{1,m}$$

where $\otimes x_{ij}$ denotes the grey evaluations of the ith alternative with respect to the jth attribute by the decision maker.

Step 3: Establishing the weights of the attributes w_j using AHP..

- Construct the pairwise comparison matrix considering the decision criteria with the diagonal elements are equal to 1.
- Using the decision makers' pairwise judgments fill the comparison matrix with the values in Table 2.
- Find the weight of each alternative with computing the eigenvalue of the matrix.

Step 4: Constructing the normalized grey decision matrices: For the benefit type of criteria, Eq. (3.9) is used for the normalization, and for the cost type of criteria Eq. (3.10) is used [61].

$$\otimes r_{ij} = \frac{\otimes x_{ij}}{\max_i(\bar{r}_{ij})} = \left(\frac{\underline{x}_{ij}}{\max_i(\bar{x}_{ij})}; \frac{\bar{x}_{ij}}{\max_i(\bar{x}_{ij})}\right) \tag{3.9}$$

$$\otimes r_{ij} = 1 - \frac{\otimes x_{ij}}{\max_i(\bar{x}_{ij})} = \left(1 - \frac{x_{ij}}{\max_i(\bar{x}_{ij})}; 1 - \frac{\underline{x}_{ij}}{\max_i(\bar{x}_{ij})}\right) \tag{3.10}$$

where $\underline{x}_{ij}$ represents the lower value of the interval and $\bar{x}_{ij}$ represents the higher value of the interval.

Step 5: Determining the positive and negative ideal alternatives. The positive ideal alternative A^+, and the negative ideal alternative A^-, can be defined as [30]:

$$\begin{aligned} A^+ &= \{(\max_i \bar{r}_{ij} |\, j \in J), (\min_i \underline{r}_{ij} |\, j \in J') |\, i \in n\} \\ &= [r_1^+, r_2^+, \ldots, r_m^+] \end{aligned} \tag{3.11}$$

and

$$\begin{aligned} A^- &= \{(\min_i \underline{r}_{ij} |\, j \in J), (\max_i \bar{r}_{ij} |\, j \in J') |\, i \in n\} \\ &= [r_1^-, r_2^-, \ldots, r_m^-] \end{aligned} \tag{3.12}$$

where

$J = \{j = 1, 2, \ldots, n |\, j$ associated with benefit criteria$\}$
$J' = \{j = 1, 2, \ldots, n |\, j$ associated with cost criteria$\}$

Using Eq. (3.10) as the normalization operator, the cost type of criteria is transformed to benefit criteria. Thus, the cost criteria should be handled as benefit criteria.

Step 6: Calculating the separation measure of the positive and negative ideal alternatives, d_i^+ and d_i^- using Eqs. (3.13) and (3.14). In the equations w_i represents the weight of each criterion.

$$d_i^+ = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i[|r_j^+ - \underline{r}_{ij}|^2 + |r_j^+ - \bar{r}_{ij}|^2]} \tag{3.13}$$

$$d_i^- = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i[|r_j^- - \underline{r}_{ij}|^2 + |r_j^- - \bar{r}_{ij}|^2]} \tag{3.14}$$

Step 7: Calculating the relative closeness, C_i^+, to the positive ideal alternative is calculated using Eq. (3.15).

$$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} \tag{3.15}$$

where $0 \leqslant C_i^+ \leqslant 1$. The larger the index value is the better the evaluation of alternative will be.

Step 8: Ranking the preference order. A set of alternatives now can be preference ranked by the descending order of the value of C_i^+.

4. Content management systems and decision criteria

With the emergence of internet technologies, CMSs have become a vital IT tool for companies. CMS is a server program that stores web page content and publishing details in a database, instead of separate webpages [6]. The main function of CMS is to separate the content from the presentation, the content and the presentation details are stored in a database and can be easily changed. This brings agility and flexibility to website management since in the traditional way of publishing the content and design are coded together in a single file. As a whole system, Friedlein [13] defines three parts of a CMS; collecting, managing and publishing. Collecting activities contain; authoring, syndicating in, reformatting, adding content objects and adding metadata. Managing activities on the other hand, contain; storing, versioning, rolling back, archiving, search and workflow. The final activity, publishing consists of deployment, template creation and usage and integration with other systems. CMS software handles all the activities within this process.

The development of CMS software goes back to mid-1990s, as the organizations face with the difficulty to manage corporate web pages with many pages and content [6,37]. The corporate web pages started to become an international source of information for companies and their customers. As a result the CMS systems started to merge with traditional document management functionality and groupware systems. Besides web content management systems are also used for information sharing within companies. Enterprise information portals are developed to integrate transactional data systems and data warehouses with web-based interfaces [36]. Nowadays, modern mobile devices such as tablet PC, smart phone and PDAs have provided new interfaces to access information [26]. These new requirements caused the CMS software to gain new capabilities and functionalities. When building a website for internet or intranet, CMS software has become the preferred choice for those who want easy content changes, simplified control of large amounts of content and easily manage many other tasks.

In the literature yet there has not been much interest on researches that focus on organizational utilization of content management technology. Some of the latest studies in the literature are as follows: Zardini et al. [59] investigate the correlation between competitive advantage, associated with the improvement of the decision-making process, and knowledge management through enterprise CMS. Laleci et al. [25] develop a set of tools which explicate the content repository semantics to a knowledge-base and establish semantic bridges between this backend knowledge-base and the content repository. Rojas-Sola et al. [41] proposed integrating content management system with a virtual museum applications and applied industrial heritage of windmills in Andalusia, Spain. Alalwan and Weistroffer [1] provide a comprehensive literature review of published enterprise content management research by analyzing, 91 publications between the years 2001 and 2011. Lust et al. [33] examine the potential usage of CMS for learning practices. And finally, Alalwan [2] investigates the possibility of enterprise CMS to have the capabilities of classic decision support systems, executive information systems, and expert systems. As a result of the literature review, to the best of our knowledge this is the first paper that focuses on selection of content management technology.

In order to construct the decision model for CMS selection, the information system selection literature is investigated and short list of criteria are determined based on selected studies [53,20,8,19]. Later these criteria are modified according to content management context and final criteria are concluded as follows:

(1) *Technological Infrastructure (TEC)* is the integration level of CMS software with the technological infrastructure of the organization. If the integration is low, this may lead to many malfunctions and additional database and server costs. Since CMS can be used by different users from different departments, the integration of authorization and authentication system is one of the critical issues for the success of the project.
(2) *Project Duration (DUR)* refers to the accordance between the system provider's project plan and the needs of the organization. In the simplest form, it shows the time interval between the start of the project and the establishment of the website. The project duration covers the activities such as; the database and software installations, system training, conceptual design, graphical design, content migration from the former system, uploading new content, tests and going live with the website.
(3) *Budget (BUD)* is the total cost of ownership of the CMS. This cost contains the initial license fee of the software, cost of the required server hardware and software. The budget criterion also covers the implementation and supporting costs.
(4) *After Sales Support (SUP)*, in the context of CMS selection, after sales support refers to availability of support alternatives and channels for the customer. Absence of technical support may cause a system to malfunction which may lead to many other negative outcomes. Systems usage manuals, commercial support/training and software development can be listed as components of this criterion.
(5) *Usability (USB)* is one of the most important issues for users to accept a new information system. If the users experience difficulties in using CMS software then their attitude towards it may change and the project may fail to reach its goals. In the scope CMS, usability refers to critical functionalities as spell check, undo/redo function and WYSWYG (what you see is what you get) interface for content management.
(6) *Capabilities (CAP)* are the functions that CMS software provides to the users. In CSM software there are; (i) built-in applications which are directly installed; (ii) optional applications which the organization may select to install or (iii) custom made applications which are new interfaces developed for specific requirements. In order to test the functionality of an alternative, a pilot project can be requested from the service provider and the capabilities of the software can be checked.
(7) *Service Provider (SPR)* is the company which implements the project. Besides the criteria that are about the software to be used, the competencies and reputation of the service provider is a vital point in the selection process. For an accurate evaluation, the references of the company should be investigated; the prior websites developed by the CMS should be visited. This information leads to an insight about the vendor, its capabilities and potential to successfully accomplish the project.

5. Numerical case study

5.1. Case study

To demonstrate the flow of the MCDM methodology, a case study in a foreign trade company is given. The alternatives are selected from the Turkey market but the names are not given. The defined criteria for CMS selection consist of both cost and benefit attributes which have different assessment characteristics. Properties of the criteria are summarized in Table 3.

In this study, two tangible values, duration (DUR) and budget (BUD) are used. DUR is presented as the expected duration of the project and BUD is presented as the expected total budget of the project. For other criteria, expert evaluations are represented in 1–10 scale. The evaluations of the alternative software are given in Table 4.

After the decision matrix is formed, the next step is to determine the importance of the criteria. AHP is used to find the weights of the seven decision criteria. In this manner the pairwise comparison matrix is formed as shown in Table 5. For a better understanding of the table an example can be given as follows; the value in third row and first column is 3, which means that Budget criterion (BUD) is three times as important as technological infrastructure criterion (TEC). All the values in the diagonal are set to one, since they represent the values of comparison between same criteria. The consistency ratio of the pairwise comparison matrix is found to be 0.0568 and as the value is under 0.10 it is concluded that the comparison matrix is consistent. Since the matrix is consistent, the steps of classical AHP are applied to find the weights of each criterion. The calculated weights are also represented in Table 5.

Following Eqs. (3.9) and (3.10) the normalized grey values are determined. To this end, the maximum upper limit of alternatives is determined, and all evaluation values are divided by the maximum value. For example; for TEC the highest upper limit is found as 9.0, thus each evaluation in this row is divided by this value. The normalized values of Alt. 1 is found as (6/9; 7/9) which equals (0.67; 0.78). For the cost criteria Eq. (3.10) is used. For project duration criteria (DUR) the maximum upper limit is 16 (Table 4), the normalized value of Alt 1 is calculated as $(1-(11/16); 1-(9/6))$ which is equal to (0.31; 0.44). The normalized values of alternatives are shown in Table 6.

Negative and positive ideals are calculated using Eqs. (3.11) and (3.12) and shown in Table 6. For the criteria TEC, the maximum value of the upper limit is 1 and the lowest value at the lower limit is equal to 0.44, thus the positive ideal value is set to 1 and the negative ideal value is determined as 0.44 and shown at the last two columns of Table 6.

The next step is calculating the separation measure of the positive and negative ideal alternatives. Using Eqs. (3.13) and (3.14), d_i^+ and, d_i^- values are found and represented in Table 7. For Alt1, d_1^- and d_1^+ are calculated as follows:

$$d_1^- = \Big[\frac{1}{2}\Big[\Big(0.07(|0.44-0.67|^2+|0.44-0.78|^2)\Big) +\Big(0.07(|0-0.31|^2+|0-0.44|^2)\Big)+(0.28(|0-0.22|^2 +|0-0.33|^2))+(0.07(|0.39-0.5|^2+|0.39-0.61|^2)) +(0.13(|0.63-0.75|^2+|0.63-0.88|^2))+(0.13(|0.50-0.63|^2 +|0.50-0.75|^2))+(0.13(|0.67-0.67|^2+|0.67-0.87|^2))\Big]\Big]^{1/2} =0.235$$

Table 3
Properties of criteria.

Criteria	Assessment	Values	Type
TEC	Intangible	Scale	Benefit
DUR	Tangible	Weeks	Cost
BUD	Tangible	Dollars	Cost
SUP	Intangible	Scale	Benefit
USB	Intangible	Scale	Benefit
CAP	Intangible	Scale	Benefit
SPR	Intangible	Scale	Benefit

Table 4
The evaluations about CMS software alternatives.

Criteria	Unit	Alt. 1	Alt. 2	Alt. 3	Alt. 4
TEC	Score	[6.0; 7.0]	[6.0; 7.0]	[4.0; 5.0]	[8.0; 9.0]
DUR	Weeks	[9; 11]	[14:16]	[10; 12]	[7; 9]
BUD	Dollars	[6000; 7000]	[7500; 8500]	[3500; 5000]	[6500; 9000]
SUP	Score	[4.5; 5.5]	[4.0; 5.0]	[3.5; 4.5]	[8.0; 9.0]
USB	Score	[6.0; 7.0]	[6.0; 7.0]	[5.0; 6.0]	[7.0; 8.0]
CAP	Score	[5.0; 6.0]	[4.0; 5.0]	[4.0; 5.0]	[7.0; 8.0]
SPR	Score	[5.0; 6.5]	[6.5; 7.5]	[5.5; 6.5]	[6.0; 7.0]

Table 5
The pairwise comparison matrix.

	TEC	DUR	BUD	SUP	USB	CAP	SPR	Weights
TEC	1	1	0.33	1	0.33	0.33	0.5	0.07
DUR	1	1	0.33	1	0.33	0.33	0.5	0.07
BUD	3	3	1	3	5	5	1	0.28
SUP	1	1	0.33	1	0.33	0.33	0.5	0.07
USB	3	3	0.2	3	1	1	0.2	0.13
CAP	3	3	0.2	3	1	1	0.2	0.13
SPR	2	2	1	2	5	5	1	0.25

$$d_1^+ = \Big[\frac{1}{2}\Big[\Big(0.07\Big(|1-0.67|^2+|1-0.78|^2\Big)\Big) +\Big(0.07\Big(|0.56-0.31|^2+|0.56-0.44|^2\Big)\Big) +\Big(0.28\Big(|0.61-0.22|^2+|0.61-0.33|^2\Big)\Big) +\Big(0.07\Big(|1-0.5|^2+|1-0.61|^2\Big)\Big) +\Big(0.13\Big(|1-0.75|^2+|1-0.88|^2\Big)\Big) +\Big(0.13\Big(|1-0.63|^2+|1-0.75|^2\Big)\Big) +\Big(0.13\Big(|1-0.67|^2+|1-0.87|^2\Big)\Big)\Big]\Big]^{1/2} = 0.297$$

Finally the calculated d_i^- and d_i^+ values are used to find the relative closeness C_i^+. The calculated relative closeness values are shown in Table 7. As an example, the relative closeness of Alternative 1 is calculated as follows:

$$C_1^+ = \frac{0.235}{0.235+0.297} = 0.441$$

According to the results of Table 7, the priority of the alternatives are determined as Alt. 4 > Alt. 3 > Alt. 1 > Alt. 2. The calculation results showed that the forth software is the best alternative, the first and second alternative are the worst CMS alternatives for the company. As a conclusion; Alternative 4 should be selected by the company.

5.2. Sensitivity analysis

In this subsection a sensitivity analysis is performed in order to show the robustness of the technique. To this end, the weight of one criterion is gradually changed while keeping all other weights the same and the influence on the final decisions are investigated. The operation is done respectively for each criterion and the results are shown in Fig. 2.

In Fig. 2, the results of the sensitivity analysis for seven criteria are shown. In each diagram the *y*-axis represents the final priority of the alternatives and *x*-axis represents different weights of the selected criteria. In order to represent the trend, priorities of the alternatives are calculated for each different weight value for the selected criteria. As an example, in Fig. 2a, one can realize that Alternative 4 is the best alternative for the different weights of

Table 6
Normalized values of alternatives and positive/negative ideal values.

Criteria	Weight	Alt. 1	Alt. 2	Alt. 3	Alt. 4	A^+	A^-
TEC	0.07	(0.67; 0.78)	(0.67; 0.78)	(0.44; 0.56)	(0.89; 1)	1.00	0.44
DUR	0.07	(0.31; 0.44)	(0; 0.13)	(0.25; 0.38)	(0.44; 0.56)	0.56	0.00
BUD	0.28	(0.22; 0.33)	(0.06; 0.17)	(0.44; 0.61)	(0; 0.28)	0.61	0.00
SUP	0.07	(0.5; 0.61)	(0.44; 0.56)	(0.39; 0.5)	(0.89; 1)	1.00	0.39
USB	0.13	(0.75; 0.88)	(0.75; 0.88)	(0.63; 0.75)	(0.88; 1)	1.00	0.63
CAP	0.13	(0.63; 0.75)	(0.5; 0.63)	(0.5; 0.63)	(0.88; 1)	1.00	0.50
SPR	0.25	(0.67; 0.87)	(0.87; 1)	(0.73; 0.87)	(0.8; 0.93)	1.00	0.67

Table 7
Separation measures and the relative closeness of each alternative.

	d^+	d^-	C^+	Rank
Alt. 1	0.297	0.235	0.441	3
Alt. 2	0.377	0.191	0.337	4
Alt. 3	0.312	0.307	0.496	2
Alt. 4	0.275	0.343	0.554	1

technology criteria. Besides, it can also be realized that Alternative 1 and Alternative 4 shows an increasing trend as the weight of technology increase. However the other alternatives shows a negative trend as the weight of the technology increases. As a summarization of the results, for five of the criteria; namely TEC, DUR, SUP, USB and CAP; the increase in the weights of the criteria also increase the priority of Alternative 4, thus the decision does not change. However for SPR and BUD criteria, the priority of Alternative 4 decreases as the weights increase. For SPR criteria Alternative 4 is the best alternative for all values, for criteria BUD as the weight reaches to 40% the best alternative changes to Alternative 3.

In sensitivity analysis, we point out that Alternative 4 remains the best decision for the majority of the situations. Among the different scenarios only in cases where BUD gets a weight value greater than 40%, another alternative becomes the best one. As a result, it can be concluded that the decision model is robust since best alternative decision is insensitive to the changes in the experts' weights.

5.3. Effects of distance measures on the results

In this subsection, different distance measurement operators are used in Grey-TOPSIS with the intention to investigate their effect on the results. The generalized form of distance measure used to find the distance between two grey numbers is the Minkowski's metric given in Eq. (3.16). In this equation $p = 1$ represents the Manhattan distance, and $p = 2$ represents Euclidian distance and $p = \infty$ gives the Tchebycheff distance.

$$d(\otimes a, \otimes b) = \sqrt[p]{\frac{1}{2}[(\underline{a} - \underline{b})^p + (\bar{a} - \bar{b})^p]} \tag{3.16}$$

In the literature the values of p are generally set to 2 [60,61,30,31], thus in this study, Eq. (3.8) which is based on Euclidian distance is used. But in order to see the effects of distance measurement operator, the same calculations are also applied using Manhattan distance, Minkowski distance of order 3, 4 and 5 and the results are represented in Table 8.

The results shown in Table 8 indicate that when Manhattan, Euclidian and Minkowski ($p = 3$) distances are used Alternative 4 remains the best alternative which is followed by Alternative 3. However the difference between these two alternatives decreases as p increases, and for value greater than 3 ($p > 3$) Alternative 3 outperforms Alternative 4. For all measurement operators the ranking for Alternative 1 and Alternative 2 are the same. In order to understand the reason for the change in the rankings, d^+ and d^- values of the alternatives are represented in Table 9.

It can be directly seen from the values in Table 9 that, the both of the distance between positive and negative ideal values increase as p increases. However the distance values do not increase proportionally, while minimum increase is %19 (Alt. 1, d^+) the maximum increase is %115 (Alt. 4, d^+). Lai et al. [24] state that as p increases, greater emphasis is given to the largest deviation in forming the total distance value. The variation among the observed increase values can be clarified by this explanation.

The closeness value of each alternative is calculated using Eq. (3.15), which shows that the closeness value is inversely proportional to d^+. One can easily see from Table 9 that d_4^+ (value of Alternative 4) represents the highest increase. On the other hand, the increase in d_3^- (value of Alternative 3) is higher that the increase of Alternative 4. These two issues are the main reasons for the change in the rankings.

As a result it can be concluded that the resulting ranks can change based on the distance measure used in the calculation. As the p value increases, higher emphasis is given to larger deviations. In the literature, Euclidian distance based approaches are generally used in TOPSIS studies. In MCDM problems, since it is not possible to build a unique mathematical model to determine which distance measure performs better than the others, selecting a distance measure depends on the decision makers' assessments.

5.4. Comparison with existing studies

In this subsection, the results of this case study is compared with the results of other similar methods namely; TOPSIS [17] and Fuzzy TOPSIS [7]. For TOPSIS method, the mean values of CMS evaluation data, shown in Table 10, are used for calculations.

In order to maintain a better comparison of the result, the weights determined in this study are directly used in TOPSIS application. The results of the TOPSIS application, shown in Table 11, reveal that the best alternative is Alt. 3 and it is followed by Alt. 4. The ranking of the remaining alternatives are the same with the results of the existing study.

The type of evaluation data needed for Fuzzy TOPSIS is different from the other techniques. Fuzzy TOPSIS [7] use linguistic variables both for determining importance of criteria and for alternative evaluations. Thus, new linguistic evaluations are collected as shown in Table 12.

The application steps of Fuzzy TOPSIS are not given here since the purpose of this section is to compare the results. The results of Fuzzy TOPSIS, given in Table 13 shows that the best alternative is Alt4 which is same with the original results.

The results of the three compared methods are not the same, but the alternative which is the best one in the original study is again selected as the best one in Fuzzy TOPSIS and has the second place in classical TOPSIS method. Thus it can be concluded that the results are consistent with each other and they partially approve

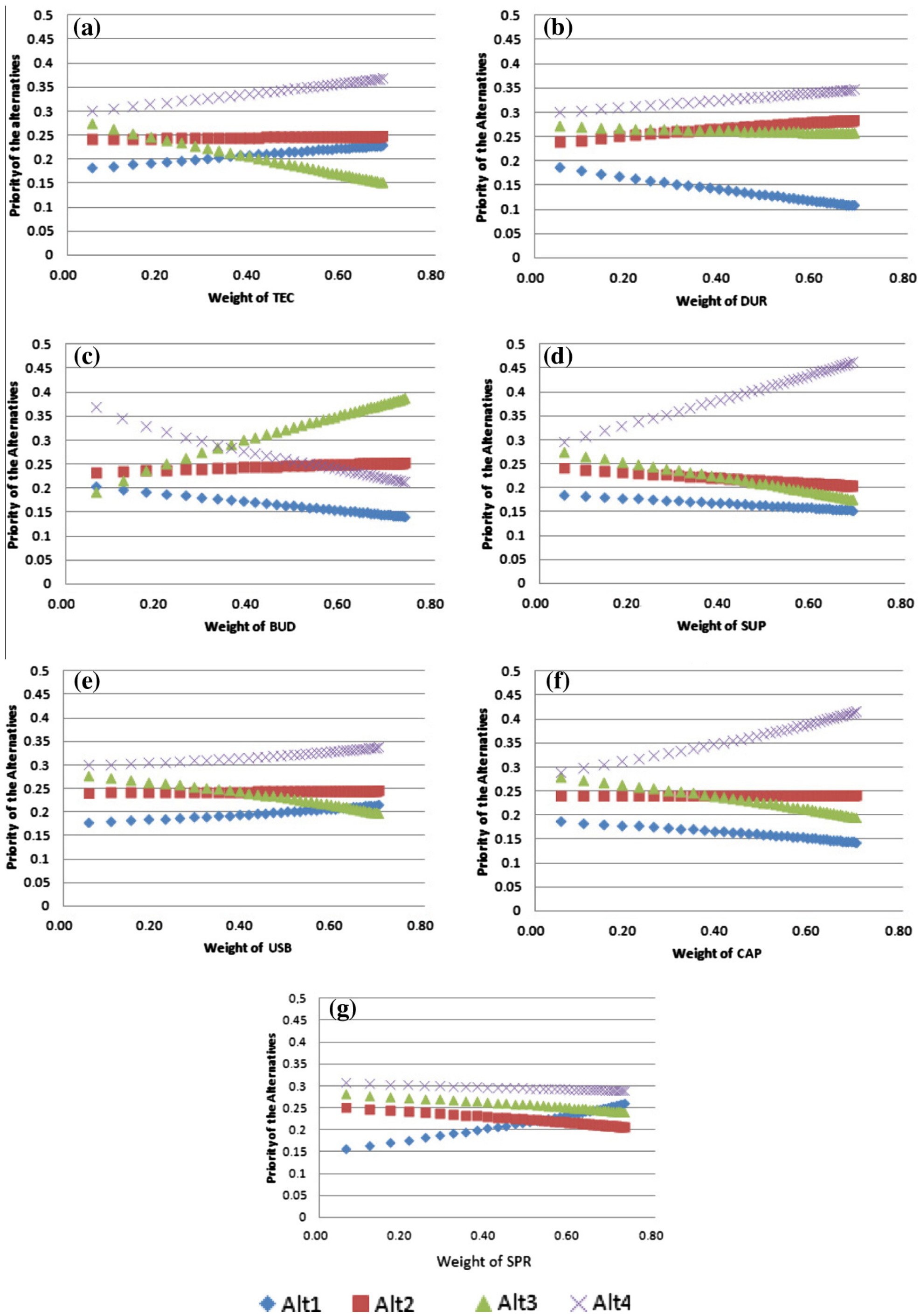

Fig. 2. Sensitivity analysis for criteria weights.

Table 8
The resulting values and ranks of the alternatives using different distance measures.

	Manhattan dist.	Euclidian dist.	Minkowski dist. ($p = 3$)	Minkowski dist. ($p = 4$)	Minkowski dist. ($p = 5$)
Alt. 1	0.428 (3)	0.442 (3)	0.447 (3)	0.451 (3)	0.454 (3)
Alt. 2	0.335 (4)	0.337 (4)	0.342 (4)	0.347 (4)	0.352 (4)
Alt. 3	0.463 (2)	0.497 (2)	0.511 (2)	0.517 (1)	0.519 (1)
Alt. 4	0.604 (1)	0.554 (1)	0.526 (1)	0.510 (2)	0.501 (2)

the results of the original study. Compared with TOPSIS, Fuzzy TOPSIS and Fuzzy AHP the proposed methodology has the following advantages.

(i) In classical TOPSIS method [17], the evaluations are done using single crisp numbers. However in the proposed methodology, grey numbers are used for evaluations which

Table 9
$d+$ and $d-$ values for alternatives using different distance measures.

	Manhattan dist.	Euclidian dist.	Minkowski dist. ($p = 3$)	Minkowski dist. ($p = 4$)	Minkowski dist. ($p = 5$)
d− values					
Alt. 1	0.209	0.235	0.252	0.266	0.278
Alt. 2	0.163	0.192	0.212	0.228	0.240
Alt. 3	0.226	0.308	0.362	0.401	0.429
Alt. 4	0.295	0.343	0.374	0.398	0.417
d+ values					
Alt. 1	0.279	0.297	0.312	0.324	0.334
Alt. 2	0.324	0.377	0.408	0.428	0.443
Alt. 3	0.262	0.312	0.347	0.375	0.397
Alt. 4	0.193	0.276	0.337	0.382	0.416

Table 10
Mean values of alternative evaluations.

Criteria	Alt. 1	Alt. 2	Alt. 3	Alt. 4
TEC	6.5	6.5	4.5	8.5
DUR	10	15	11	8
BUD	6500	8000	4250	7750
SUP	5	4.5	4.0	8.5
USB	6.5	6.5	5.5	7.5
CAP	5.5	4.5	4.5	7.5
SPR	5.75	7	6	6.5

Table 11
Results of TOPSIS application.

	d^-	d^+	C^+	Rank
Alt. 1	0.04	0.063	0.386	3
Alt. 2	0.029	0.092	0.238	4
Alt. 3	0.078	0.057	0.579	1
Alt. 4	0.059	0.073	0.448	2

Table 12
Linguistic variables and ratings for Fuzzy TOPSIS application.

Criteria	Importance	Ratings			
		A1	A2	A3	A4
TEC	L	MG	MG	MP	G
DUR	L	MG	P	MG	G
BUD	VH	G	P	VG	MP
SUP	ML	F	MP	MP	G
USB	M	MG	MG	F	G
CAP	M	F	F	F	G
SPR	H	F	MG	F	MG

Table 13
Result of Fuzzy TOPSIS application.

	d^-	d^+	C^+	Rank
Alt. 1	2.698	4.782	0.361	2
Alt. 2	2.036	5.415	0.273	3
Alt. 3	2.538	4.862	0.343	4
Alt. 4	2.764	4.779	0.366	1

enable decision makers to incorporate uncertainty in their evaluations. Another advantage of the proposed methodology is utilizing AHP as a formal method of determining the criteria weights. In classical TOPSIS, weights of the criteria are either omitted or explicitly assigned by the decision maker. Thus, when compared with classical TOPSIS method, the proposed method leads to better results since the weights of the criteria can be better identified.

(ii) Fuzzy TOPSIS [7] uses linguistic variables both for importance and ratings of the alternatives, and later these linguistic variables are transformed to triangular fuzzy numbers for further calculations. Using linguistic variables for decision making can be easier for decision makers however the evaluations may be inaccurate. For example, the grey evaluations for duration criteria of Alternative 1 and Alternative 3 are [9–11] and [10–12] consequently. While these two values are different the linguistic variables associated with them are same (MG). This shows that especially for quantitative values using linguistic terms can cause lack of information and mislead the results. The proposed methodology has the advantage of enabling more accurate evaluations.

(iii) Fuzzy AHP is another method that is close to the proposed method. In fuzzy AHP, pairwise comparisons are used to identify both the importance of the criteria and the priorities of the alternatives. Pairwise comparisons are done using linguistic variables just like in Fuzzy TOPSIS which causes the accuracy problem. Another disadvantage of Fuzzy AHP is that to reach the desired outcomes many pairwise comparisons has to be made. For the given case study, the decision maker has to answer 42 additional pairwise comparisons questions to reach the desired outcomes. Thus when compared with Fuzzy AHP the proposed method is much more practical.

6. Conclusion

In this paper, AHP integrated TOPSIS-Grey technique is proposed to be used in an IS selection problem. AHP is used to determine the weights of the decision criteria and TOPSIS is used to rank the alternatives. Grey numbers are included in TOPSIS method in order to deal with the uncertainties embedded in the selection problem. In the proposed approach, the tangible and intangible criteria evaluations are determined by Grey numbers as a representation of incomplete information. To the best of our knowledge this is the first study that uses Grey systems in an IS selection problem.

The focal point of the study is the selection of content management system which is an important system for organizational communications. In order to demonstrate effectiveness of the proposed approach, it is applied in a real life company. Seven criteria are determined for the selection of CMS. According to the results of AHP application the most important criteria are determined as budget (0.28) which represents the total cost of ownership, followed by vendor reputation (0.25). Usability and capabilities criteria share the third place with the weight of 0.13. The least important criteria are found as technological infrastructure, duration and support criteria. However, the generalizability of the criteria weights is low and when similar studies are applied to other companies; different results can be detected based on the perception and the situation of the organization. According to these weights it can be concluded that the company searches for an economic solution from a well known vendor. On the other hand, the company does not concern the technology behind the interface and the duration of the project. In this method, the uncertainty associated with the alternative evaluations is handled by using grey numbers. Each alternative is evaluated using grey numbers and later the alternatives are ranked. The results show that Alternative 4 is the best alternative among the others.

The main contribution of this paper is twofold, utilizing Grey numbers with TOPSIS and AHP to deal with the selection problem and determining the criteria for CMS selection. The comparison of the proposed method with the existing ones reveal that, the proposed method can incorporate uncertainty in a practical way, the expert evaluations can be done more accurately when compared with linguistic variables, and the procedures of proposed methodology are less time consuming for experts. There are several research directions to be pursued in future. The proposed method can be compared with other crisp, fuzzy and grey decision making techniques. Fuzzy AHP can be used instead of crisp one, and the results can be compared. Finally, the model can be modified for group decision making allocating different decision makers from the company.

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