Proposing a new hybrid multi-criteria decision-making approach for road maintenance prioritization

Article *in* International Journal of Quality & Reliability Management · December 2020

DOI: 10.1108/IJQRM-01-2020-0020

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RELIABILITY PAPER

Proposing a new hybrid multi-criteria decision-making approach for road maintenance prioritization

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Received 16 January 2020
Revised 12 October 2020
Accepted 7 December 2020

Abstract

Purpose – The purpose of this paper is to present a hybrid multi-criteria decision-making (MCDM) method, by combining the AHP, ELECTRE II, ELECTRE III, ELECTRE IV and Copeland techniques for road maintenance prioritization, in which the roads are evaluated and ranked based on various criteria. The proposed method is applied to four streets in Tehran, as a case study.

Design/methodology/approach – First, a set of criteria for road maintenance was determined and their weights were obtained using the AHP method. Four streets in Tehran, Iran were considered as alternatives and prioritized using the ELECTRE II, ELECTRE III and ELECTRE IV methods. Finally, the results of employing the three methods were integrated using the Copeland method and a final result was obtained.

Findings – The findings of the study suggested that "road safety" is the most important criterion in maintenance and "traffic volume" and "pavement quality index (PCI)" have the second and third rank in importance. Moreover, "The width of the street" is the least important criterion in road maintenance. Additionally, the streets' final ranking was obtained using the proposed method.

Research limitations/implications – The proposed method helps managers effectively assign their limited budget and resources to roads with higher maintenance priority and as the result, increase the roads efficiency.

Originality/value – In this research, eight main criteria were collected using previous researches and experts' opinions. Also, a new combination of different MCDM techniques is proposed in this research.

Keywords Road maintenance, Multi-criteria decision-making, ELECTRE, AHP, Copeland

Paper type Research paper

1. Introduction

Roads are among the most important public assets and the main means of transport. Hence, it is essential to use proper planning and timely maintenance operations to help preserve them (Burningham and Stankevich, 2005). If road maintenance operations are carried out on time and by employing the most appropriate maintenance methods, not only their destruction is delayed but also the operating costs of vehicles driving on them are reduced due to increased road surface quality (Robinson *et al.*, 1998). In addition, timely maintenance will result in increased road safety and transportation reliability, providing benefits for users, and increasing optimum usage (Burningham and Stankevich, 2005). If maintenance is not carried out on time, repair (renovation operations) and even rebuilding (re-restoration) may be required, often at a higher cost than simple maintenance (Morgan and Nearing, 2011). Due to budget limitations, it is usually not possible to maintain and repair all the roads at the same time, and their maintenance needs to be prioritized. In this case, managers face a multi-criteria decision-making (MCDM) problem. In an MCDM problem, there are different alternatives that need to be prioritized according to several criteria. In this research, the effective criteria in prioritizing the maintenance of roads are identified and their weights are calculated using the analytic hierarchical process (AHP) method. Then, using the three different versions of the ELemination Et Choice Translating Reality (ELECTRE) method, namely ELECTRE II,

International Journal of Quality & Reliability Management
Vol. 38 No. 8, 2021
pp. 1661-1679

0265-671X
DOI 10.1108/IJQRM-01-2020-0020

ELECTRE III and ELECTRE IV, the roads' maintenance are prioritized. In order to better understand the proposed method, a case study has been conducted on the four major streets in Tehran, Iran in order to prioritize their maintenance. Each MCDM technique has a particular point of view and considers specific aspects in evaluating and ranking alternatives. Therefore, different MCDM techniques may offer different results. To integrate the results, the Copeland method is used to achieve the final ranking.

The main research question of this study is:

What is the maintenance priority of roads that require maintenance, using AHP, ELECTRE II, ELECTRE III, ELECTRE IV and Copeland methods?

Moreover, the research sub-questions are as follows:

(1) Which criteria are the most effective in assessing the priority of road maintenance?

(2) How much is the importance of each criterion?

(3) What is the score of each decision alternative with respect to each criterion?

In the remainder of this research, Section 2 deals with the theoretical foundations and the literature review. The research methodology is described in Section 3 and the results applying the proposed method to the case study are described in Section 4. Finally, Section 5 provides general conclusions and suggestions for future research.

2. Theoretical foundations

As mentioned earlier, each MCDM method has its own perspectives on evaluating and ranking alternatives. The proposed model in this study seeks to integrate these views. A brief description of the techniques is presented in the following.

2.1 MCDM

MCDM is an important part of modern decision-making science that aims to support decision-makers who are faced with different decision-making criteria and alternatives. The development of MCDM methods is because of the fact that different types of real-world problems require considering multiple criteria. Another reason is that researchers have been showing interest to propose different approaches to enhance decision-making enhanced using recent advances in mathematical optimization, scientific computing and computer technology. The impact that the MCDM paradigm has on business, engineering and science is reflected in a large number of articles and studies (Wiecek *et al.*, 2008). MCDM not only is used for simplifying and achieving a clear decision but also allows researchers and managers to achieve a balance between different opposing criteria (Govindan *et al.*, 2015). Among the numerous types of MCDM methods, the four methods of AHP, ELECTRE II, ELECTRE III and ELECTRE IV have been used in this study.

2.1.1 AHP. The AHP method is one of the most famous MCDM techniques, which Saaty (1977) presented in the 1970s. In this method, the elements are compared two by two, and the results are shown in a matrix, called the "Pairwise Comparison Matrix." In each comparison, decision-makers have choices to determine the preferred status of one element over another. Verbal expressions must be converted to numbers in order to calculate the final weights of the elements being compared.

2.1.2 ELECTRE II. ELECTRE II was proposed by Roy and Bertier (1973) in 1973 to address the inability of ELECTRE I in rating alternatives. The inputs to ELECTRE I, are weight vectors (relative importance of the criteria) and decision matrix. This method has difficulties and weaknesses in determining the outranking relationships between the alternatives, however, ELECTRE II can simply find the kernel set and introduce strong and weak outranking ratios. Thus, a constraint is added to ELECTRE I. ELECTRE II was the first method of the ELECTRE family, which was designed for rating purposes only. In this method, two weak and strong levels for the outranking relations between the alternatives are expressed. ELECTRE II was the first method that uses wider relationships. This method uses actual criteria (not pseudo-criteria) and does not have a rejection threshold. Also, the relationships of outranking calculations were changed in a way that can implement separated outranking relationships.

2.1.3 ELECTRE III. This method, similar to ELECTRE I, is one of the ranking-based methods for outranking. Roy (1978) presented the original idea for the creation of ELECTRE III in 1978 and in subsequent studies, its specific concepts and procedures were developed. ELECTRE III is designed to enhance the ELECTRE II method and deals with inaccurate and uncertain data, which have incomplete calculations. ELECTRE III has been used in a wide range of real problems over the past 2 decades. This method uses pseudo-criteria instead of actual metrics and is the most powerful method among the ELECTRE methods because of its sensitivity to the thresholds of preference and considering different modes of communication between the alternatives.

2.1.4 ELECTRE IV. ELECTRE IV is based on the use of multiple non-phase relationships to determine the degree of alternatives outranking. The main difference between ELECTRE III and ELECTRE IV is that in ELECTRE IV, the weight of the criteria has no numerical effect and the importance of the criteria affects other parameters of the algorithm (Roy and Hugonnard, 1982). Because of the differences in the trends and perspectives of these approaches, each of them offers a different rating. This method is used to study real problems that their criteria cannot be numerically weighted. The problem-solving approach in ELECTTRE IV, similar to other ELECTRE editions, is based on a pairwise comparison between the alternatives and the criteria. The inputs to this method are the preference, veto and indifference thresholds along with the decision matrix.

2.1.5 Copeland. This method is a prioritization strategy, used to combine the results of several methods and obtain final prioritization of alternatives. There are sometimes situations where several different methods can be used to solve a problem but these methods with the same preference information evaluate the problem from different points of view. Therefore, they may produce different results. The Copeland method is basically used to calculate the scores and determine the winning alternative. Because of its comprehensibility and popularity, Copeland is often used in prestigious competitions and tournaments and is based on the number of wins, draws and losses.

2.2 Research gap

Many studies have been conducted so far on road maintenance using various combinations of (MCDM). Ramadhan *et al.* (1999) set seven different criteria for evaluating the priority of street pavement maintenance and, using hierarchical analysis (AHP), weighted these criteria to rank a large number of street sections for maintenance. Cafiso *et al.* (2002) described a developed method for providing a multi-criteria analysis framework in HDM-4 with five basic criteria. Khademi and Sheikholeslami (2010) presented a hybrid model of the Delphi conference method, which is a group decision-making method. They used the AHP method with 13 different criteria for ranking low-quality road maintenance. Moazami *et al.* (2011) defined a model for prioritizing urban road maintenance using fuzzy logic. The four criteria were prioritized by the AHP method, and a fuzzy logic modeling was performed using MATLAB software, which is a robust inference engine. Zolfani *et al.* (2011) used six criteria and nine sub-criteria to prioritize the best location for forest road construction. These criteria were first weighted by the AHP method and then ranked using the COPRAS-G method. Abdurrahman *et al.* (2015) proposed a systematic evaluation method for ranking urban road maintenance using the Fuzzy Hierarchical Analysis (FAHP) method with four criteria and five sub-criteria, which allow investigating some technical and non-technical aspects. Ouma *et al.* (2015) ranked road pavement maintenance priority using both FAHP and Fuzzy TOPSIS (FTOPSIS). The two ranking approaches provided approximately the same results. Babashamsi *et al.* (2016) prioritized road maintenance by integrating the two FAHP and VIKOR methods. They former calculated the weight of the five different criteria using, and the latter ranked the priority of the alternatives based on the weighted index. Gunasoma and Pasindu (2016) proposed a method for adopting optimization and prioritization models that help choose appropriate road maintenance. According to this research, five different criteria were presented. The weight of these criteria was determined and ranked using the AHP method. Hendhratmoyo *et al.* (2017) studied the evaluation of the screening process in deciding on the maintenance of urban roads and their reconstruction priorities. The prioritization of the four criteria was carried out using AHP and the street with the highest priority for maintenance was identified. Li *et al.* (2018) proposed a method based on AHP in order to determine the weight of the criteria affecting the decision on the priority of maintenance of asphalt roads. Five criteria were considered that, given the relative importance of each, provided a final ranking for the 26 streets studied. Bhandari and Nalmpantis (2017) used the three MCDM methods of TOPSIS, MOORA and PROMETHEE to rank rural roads. Three main criteria and 12 sub-criteria were identified by experts using a questionnaire and the weighting was done using AHP. Surbakti and Harefa (2017) prioritized the maintenance of roads considering five different criteria, which were ranked using the Analytic Network Process (ANP) method. Singh *et al.* (2018) provided an approach to assess and prioritize pavement status, which can examine different aspects of street performance using different indicators. This paper presents two fuzzy mathematical analysis approaches for alternatives maintenance: FAHP and Fuzzy Weighted Average (FWA). Miyata *et al.* (2018) used an AHP method to select the best type of road construction on Maros-Watampone Road in Indonesia. They identified nine important criteria that contribute to better road construction and determined the weight of each criterion using AHP. In another study, Siswanto *et al.* (2019) prioritized the maintenance of two roads in Indonesia using the AHP method. They considered four criteria, namely: road conditions, traffic, land use and economics. The results showed that the prioritizing of the criteria for each road is different. Table 1 provides a summary of important studies in this area and the criteria used in each research. The distinction of this research with similar studies is described as follows:

(1) Applying a comprehensive set of criteria to prioritize road maintenance;

(2) Introducing a new hybrid model based on AHP and three different ELECTRE methods, including ELECTRE II, ELECTRE III and ELECTRE IV in order to rank road maintenance priorities.

(3) Implementing the proposed model in order to prioritize road maintenance in a real case study in Tehran, Iran.

3. Research method

As mentioned, this article investigates road maintenance priority. For this purpose, first, the effective criteria for road maintenance are identified using the literature review and interviews with experts. Then the criteria are given weights using the AHP technique. Afterward, by combining the ELECTRE II, ELECTRE III and ELECTRE IV techniques, the roads are prioritized and ranked for maintenance. All three ELECTRE methods require the criteria's weights as input, which are determined using the AHP method. In order to integrate

Criteria	Traffic volume	Road safety	Social importance	Economic importance	Road width	Pavement quality index (PCI)	Maintenance cost	Maintenance time
Ramadhan *et al.* (1999)	*	*	*				*	
Cafiso *et al.* (2002)		*					*	
Khademi and Sheikholeslami (2010)	*	*						
Moazami *et al.* (2011)	*				*	*		
Zolfani *et al.* (2011)	*		*	*				
Abdurrahman *et al.* (2015)	*		*	*				
Ouma *et al.* (2015)		*				*		
Babashamsi *et al.* (2016)	*				*	*	*	*
Hendhratmoyo *et al.* (2017)	*		*	*		*		
Li *et al.* (2018)	*					*		
Singh *et al.* (2018)	*	*						
Bhandari and Nalmpantis (2017)			*	*			*	
Surbakti and Harefa (2017)						*		
Miyata *et al.* (2018)		*		*			*	*
Gunasoma and Pasindu (2016)	*	*	*	*		*		
Siswanto *et al.* (2019)	*			*		*		

Table 1. The used criteria in this study

the results, the Copeland method is used to aggregate these different points of view and achieve a comprehensive ranking. The research steps are as follows (Figure 1):

Step 1: Identifying proper criteria

As the first step in this research, it is necessary to identify important criteria in selecting and prioritizing road maintenance. For this purpose, all related research conducted in recent years on the maintenance of roads has been review. Then the best and most effective criteria are chosen with the help of experts, including university professors and people who work in the municipality.

Step 2: Identifying alternatives

After identifying the effective criteria for road maintenance, the appropriate alternatives for ranking the maintenance priority are determined. Alternatives are the streets or roads that we want to prioritize for repair and maintain.

Step 3: Obtaining pairwise comparison and decision matrices

Two questionnaires were used for data collection: the first questionnaire is called the pairwise comparison questionnaire and includes all criteria. The purpose of this questionnaire is to compare the binary combinations of the criteria in pairs in order to identify the weight and importance of the decision criteria using AHP. The AHP method is based on pairwise comparisons. The pairwise comparison matrix between the criteria is obtained from the first questionnaire, in which the decision-maker in each comparison uses the linguistic phrases in the questionnaire to determine the outranking of one criterion over another criterion. Because linguistic variables cannot be directly involved in the mathematical calculations, they should

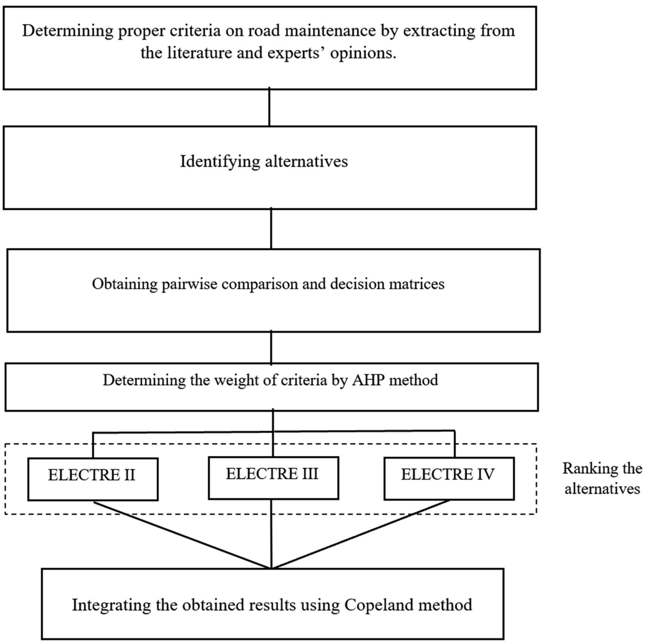

Figure 1.
The used research steps

be converted into numbers. In this paper, Table 2 is used to convert the qualitative options to a number.

The second questionnaire was designed to determine the score of each alternative in each criterion (decision-making matrix). When the criteria are qualitative, a conventional spectrum should be used to convert verbal variables into quantitative ones. In this study, the values in Table 2 were used to convert qualitative values into quantitative ones.

Both questionnaires were completed by a group of eight experts, including people with more than 10 years of experience in the technical and development department of the Tehran Municipality Organization. Both questionnaires are standard and their validity have been confirmed (Torkzad and Beheshtinia, 2019). The reliability of the first and second questionnaires are confirmed according to a 0.08 inconsistency rate, and a 0.81 Cronbach's alpha, respectively.

Step 4: Determining the criteria weights

In this step of the research, the AHP method is used to determine the weight (importance) of the criteria. The steps of the AHP method are as follows:

Step 4-1: The first step in prioritizing the components of a problem is to make pairwise comparisons. During pairwise comparisons, the outranking of a criterion against another one is determined in each comparison and then their corresponding numeric value is extracted from Table 2. Afterward, we can form the evaluation matrix A. The arrays of the matrix, indicated a_{ij}, represent the relative weight of the criteria, as shown in Equation (1 and 2).

$$A = [a_{ij}], \quad i = 1, 2, \ldots, n \tag{1}$$

$$a_{ij} = \frac{1}{a_{ji}}, \quad j = 1, 2, \ldots, m \tag{2}$$

Step 4-2: The normalization is done through the following equation:

$$a^*_{ij} = a_{ij} \Big/ \sum\nolimits_{i=1}^{n} a_{ij}, \quad j = 1, 2, \ldots, m \tag{3}$$

Step 4-3: The weights are calculated as follows:

$$w_i = \sum\nolimits_{i=1}^{n} a^*_{ij} \Big/ n, \quad j = 1, 2, \ldots, m \tag{4}$$

AHP		Decision matrix	
Linguistic term	Quantitative value	Linguistic term	Quantitative value
Much less preferred	1	Very little	1
Low preferred	3	A little	2
preferred	5	Average	3
Much preferred	7	A much	4
Very much preferred	9	Too much	5

Table 2. Linguistic terms and their related quantitative values (Sedady and Beheshtinia, 2019)

Step 5: Ranking of alternatives

ELECTRE II, ELECTRE III and ELECTRE IV methods are used to rank the maintenance of the roads. In all of these methods, the weight of the criteria should be introduced as inputs, which are already calculated from the AHP method.

In each of the above methods, there is a decision matrix X with dimensions $m \times n$, which means it has m alternatives $(A_1, A_2, \ldots, A_m)$ and n criteria $(C_1, C_2, \ldots, C_m)$, then array x_{ij} is the score of alternative A_i in criterion C_j and W_j is the weight of C_j.

Step 5-1: Using ELECTRE II

Step 5-1-1: Normalization of the decision matrix. If $A_1, A_2, \ldots, A_m$ are the alternatives, $C_1, C_2, \ldots, C_m$ are the criteria and x_{ij} is the score of alternative A_i in criterion C_j, then the normalized value of R is obtained from the following formula:

$$R = [r_{ij}]_{m\times n} \quad i = 1, 2, \ldots, \ m \quad j = 1, 2, \ldots, n \tag{5}$$

So that:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{6}$$

Step 5-1-2: Calculation of the Weighted Normal Matrix. To do this, we must multiply the weight of each criterion (calculated in this research by the AHP technique) by the elements of that criterion in the matrix, as shown as follows:

$$V = [v_{ij}]_{m\times n}, v_{ij} = w_j \times r_{ij}, \tag{7}$$

where r_{ij} is the normalized (non-scalable) matrix element obtained from step 2 and w_j is the weight of the criterion j.

Step 5-1-3: Creating Concordance and Discordance sets. Considering the weighted normalized matrix, the concordance set c_{kl} includes the criteria in which alternative k is not worse than alternative l, and discordance set includes the criteria in which alternative k is worse than alternative l. In general, if we assume that the criteria should be maximized:

$$c_{kl} = \{j | v_{kj} \geq v_{lj}\}, \quad j = 1, 2, \ldots, m \tag{8}$$

$$d_{kl} = \{j | v_{kj} < v_{lj}\}, \quad j = 1, 2, \ldots, m \tag{9}$$

If the criteria are negative, then:

$$c_{kl} = \{j | v_{kj} \leq v_{lj}\}, \quad j = 1, 2, \ldots, m \tag{10}$$

$$d_{kl} = \{j | v_{kj} < v_{lj}\}, \quad j = 1, 2, \ldots, m \tag{11}$$

Step 5-1-4: Forming the concordance and discordance matrices. The concordance (discordance) matrix is $m \times m$ and its main diameter has no element and the other elements are derived from the sum of the weight of criteria in the concordance (discordance) set. Assuming that the sum of the criteria weights is 1:

$$C_{kl} = \sum w_j, \ j \in c_{kl} \tag{12}$$

$$D_{kl} = \frac{\max\{|V_{kj} - V_{lj}| \forall j \in d_{kl}\}}{\max\{|V_{kj} - V_{lj}|\}} \tag{13}$$

Step 5-1-5: Forming the Ultimate Dominance Matrix. Using concordance (C_{kl}) and discordance (D_{kl}) matrices, we identify the strong and weak preferences and insert them in the ultimate dominance matrix. For this purpose, four thresholds need to be defined as follows:

(p^*, q^*) and (p^, q^). The pair (p^*, q^*) is defined as the concordance and discordance threshold for the strong outranking relations, and the pair (p^, q^) is defined as the threshold for the weak outranking relations, and p^*>p^ and q^*<q^. Next, outranking relations are built according to the following two rules:

(1) If $C_{ab} \geq p^*$, $D_{ab} \leq q^*$ and $C_{ab} \geq C_{ba}$, then alternative a strongly outranks alternative b. In this case, the SF symbol is inserted in the corresponding array of the pair of alternatives in the ultimate dominance matrix.

(2) If, $D_{ab} \leq q$^, $D_{ab} \leq q$^ and $C_{ab} \geq p$^, then alternative a is weakly outranks alternative b. In this case, the sf symbol is inserted in the corresponding array of the pair of alternatives in the ultimate dominance matrix.

The arrays that do satisfy any of the above-mentioned conditions, their corresponding pair of alternatives in the ultimate matrix are left blank.

Step 5-1-6: Ranking process.

(1) Decreasing mode: In this case, the alternatives are sorted from best to worst, according to the ultimate matrix. In other words, the more SF and Sf symbols in the ultimate dominance matrix rows, the more dominant is the alternative.

(2) Increasing mode: In this case, the alternatives are sorted from worst, according to the ultimate matrix. In other words, the more SF and sf symbols in the ultimate dominance matrix rows, the more inferior is the alternative.

Step 5-2: Using ELECTRE III

After forming the decision matrix as described in the previous method, the following steps are implemented:

Step 5-2-1: Determining the boundaries of preference, veto and indifference thresholds.

In ELECTRE III, three associated thresholds are defined and used to enhance the ability to identify top alternatives and to involve decision-makers' opinions in the selection process. These three thresholds are indifference threshold (p), preference threshold (p), and veto threshold (v), where $v \geq q \geq p$. These thresholds are set all by decision-makers.

Step 5-2-2: Calculating the harmoniousness matrix for each criterion.

In this step, using the decision matrix and the thresholds set in the previous step, and considering the relationship of the alternatives with respect to each criterion, harmoniousness matrix (C_j) is formed for each criterion. Each array of the harmoniousness matrices can be calculated using the following equations:

Positive criterion harmoniousness index:

$$c_j(a,b) = \begin{cases} 0 \rightarrow p_j + r_{aj} < r_{bj} \\ \dfrac{r_{aj} - r_{bj} + p_j}{p_j - q_j} \rightarrow q_j < r_{bj} - r_{bj} \leq p_j \\ 1 \rightarrow q_j + r_{aj} \geq r_{bj} \end{cases} \tag{14}$$

Negative criterion harmoniousness index:

$$c_j(a,b) = \begin{cases} 0 \rightarrow r_{aj} - p_j > r_{bj} \\ 1 \rightarrow r_{aj} - q_j \leq r_{bj} \\ \dfrac{r_{aj} - r_{bj} + p_j}{p_j - q_j} \rightarrow o.w \end{cases} \tag{15}$$

Step 5-2-3: Forming the overall harmoniousness matrix.

In this step, according to the harmoniousness matrix formed for each criterion, the overall harmoniousness matrix (C) is formed by obtaining the average weight according to Equation (16).

$$C\ (a,b) = \frac{\sum_j w_j \cdot c_j(a,b)}{\sum_j w_j} \tag{16}$$

where w_j is the criterion's weight and c_j (a, b) is the outranking level of alternative a over alternative b in criterion j, obtained from Equations (14 and 15).

Step 5-2-4: Calculating the unharmoniousness matrix for each criterion.

In this step, similar to the second step, using the decision matrix and the set thresholds, the unharmoniousness matrices of the alternatives are formed for each of the criteria as follows:

Positive criterion unharmoniousness index:

$$d_j(a,b) = \begin{cases} 1 \rightarrow v_j + r_{aj} < r_{bj} \\ \dfrac{r_{bj} - r_{aj} - p_j}{v_j - p_j} \rightarrow p_j < r_{bj} - r_{aj} \leq v_j \\ 0 \rightarrow p_j + r_{aj} \geq r_{bj} \end{cases} \tag{17}$$

Negative criterion unharmoniousness index:

$$d_j(a,b) = \begin{cases} 1 \rightarrow \ r_{aj} - v_j > r_{bj} \\ 0 \rightarrow \ r_{aj} - v_j \leq r_{bj} \\ \dfrac{r_{aj} - r_{bj} - p_j}{v_j - p_j} \rightarrow o.w \end{cases} \tag{18}$$

Step 5-2-5: Forming the overall unharmoniousness Matrix.

In this step, according to the unharmoniousness Matrix formed for each criterion, the overall unharmoniousness matrix (*D*) is formed by obtaining the average weight according to Equation (19):

$$D \ (a,b) \ = \frac{\sum_j w_j \cdot d_j(a,b)}{\sum_j w_j} \tag{19}$$

Step 5-2-6: Creating the credibility matrix.

After creating the harmoniousness Matrix (*C*) and the unharmoniousness Matrix (*D*), the Credibility matrix (*S*) is formed between the different alternatives based on the two matrices above. The Credibility matrix's elements are calculated using the following mathematical equation:

$$S(a,b) = \begin{cases} C(a,b) \rightarrow J(a,b) = \phi \\ C(a,b). \prod_{j \in J(a,b)} \dfrac{1 - d_j(a,b)}{1 - C(a,b)} \\ 0 \rightarrow \ d_j = 1 \quad \text{At} \quad \text{least} \quad \text{for} \quad \text{one} \quad j \end{cases} \tag{20}$$

Step 5-2-7: Creating the ultimate comparison matrix.

According to matrix *S*, calculated in the previous step, for the ultimate comparison matrix, λ and $S(\lambda)$ are calculated based on Equations (21 and 22), which are given below.

$$\lambda = \max(S) \tag{21}$$

$$S(\lambda) = 0.3 - 0.15 \ \lambda \tag{22}$$

Then, the ultimate comparison matrix (*t*) is formed using the following equation:

$$T(a_1,b_1) \begin{cases} 1 \quad \text{if } S(a_1,b_1)\rangle\lambda - S(\lambda) \\ \quad 0 \ \text{otherwise} \end{cases} \tag{23}$$

Step 5-2-8: Performing the ranking process.

After the ultimate comparison matrix is formed, in order to prioritize the alternatives, the alternatives are ranked from best to worst, and then from worst to best. Finally, by comparing the two decreasing and increasing trends, the final ranking of alternatives is obtained.

Step 5-3: Using ELECTRE IV

In this method, similar to the previous methods, after forming the decision matrix, the following steps are performed:

Step 5-3-1: Determine indicators of the relationship between alternatives.

These indicators are determined by comparing two alternatives and indicate the relationship between the two alternatives. In ELECTRE IV the two alternatives can have relationships in several possible ways. The concepts of strength, weakness and indifference in the outranking of alternatives are defined as follows:

(1) iP_j Strong outranking of alternative i over j in K criterion (in positive): $r_{ik} - r_{jk} > p_k$

(2) iP_j Strong outranking of alternative i over j in K criterion (in negative): $r_{ik} - r_{jk} > -p_k$

(3) iQ_j Weak outranking of alternative i over j in K criterion (in positive): $q_k < r_{ik} - r_{jk} \le p_k$

(4) iQ_j Weak outranking of alternative i over j in K criterion (in negative): $-p_k < r_{ik} - r_{jk} \le -q_k$

(5) iIj Indifference in the outranking of alternative i over j in K criterion (both positive and negative): $\left|r_{ik} - r_{jk}\right| < q_k$

Step 5-3-2: Determine the conditions of the alternatives' dominance.

$n_q(a,b)$: The number of criteria in which iQ_b

$n_p(a,b)$: The number of criteria in which aP_b

$n_q(a,b)$: The number of criteria in which aI_b and $a_{aj} > a_{bj}$

$n_o(a,b)$: The number of criteria in which a and b are equal.

Clearly, if there are n criteria, then Equation (24) applies to the above definitions.

$$n = n_p(a,b) + n_q(a,b) + n_I(a,b) + n_o(a,b) + n_I(b,a) + n_q(b,a) + n_p(b,a) \tag{24}$$

In ELECTRE IV, unlike the third version, the outranking of the alternatives is discrete and is determined in the form of classification (Bashiri *et al.*, 2015):

(1) Q-Type Dominance (Quasi-domination): It is often assigned the value of 1 and applies to the following conditions:

$$S_Q(a,b) \Leftrightarrow n_P(b,a) + n_Q(b,a) = 0\ , n_I(a,b) \le 1 + n_I(a,b) + n_Q(a,b) + n_p(a,b); \tag{25}$$

(2) C-Type Dominance (Canonical domination): Often holds the value of 0.8 and applies to the following conditions:

$$S_C(a,b) \Leftrightarrow n_p(b,a) = 0, n_Q(b,a) \leq n_P(a,b), n_Q(b,a) + n_I(b,a) \leq 1 + n_I(a,b) + n_Q(a,b) + n_P(a,b); \tag{26}$$

(3) *P*-Type Dominance (Pseudo-domination): Often holds the value of 0.6 and applies to the following conditions:

$$S_P(a,b) \Leftrightarrow n_p(b,a) = 0, n_Q(b,a) \leq n_Q(a,b) + n_p(a,b) \tag{27}$$

(4) *S*-Type Dominance (Sub-domination): Often holds the value of 0.4 and applies to the following conditions:

$$S_S(a,b) \Leftrightarrow n_P(b,a) = 0; \tag{28}$$

(5) *V*-Type Dominance (Veto-domination): Often holds the value of 0.2 and applies to the following conditions:

$$S_V(a,b) \Leftrightarrow n_P(b,a) = 0, \{S_P(a,b) - or - n_P(b,a) = 1\}, \forall j\colon (a_{bj} < a_{aj}), n_P(a,b) \geq \frac{n}{2}; \tag{29}$$

Step 5-3-3: Ranking process

After determining the relationship between the alternatives, the results of the second step can be represented as a matrix. This matrix is similar to the final matrix in the ELECTRE III method. In this method, in order to prioritize the alternatives, the alternatives are sorted from best to worst, and then from worst to best. Finally, by comparing the two decreasing and increasing trends, the alternatives' final ranking is obtained.

Step 6: Integrating the obtained results using Copeland method

After ranking the alternatives using the three methods mentioned above, it is time to integrate their results. In other words, there are three different ratings while a unique rating should be announced. There is no clear standard to determine which approach is right. In the Copeland method, a pairwise comparison matrix is used to record the number of wins or losses of an alternative over other alternatives. The steps of this method are described in the following:

Step 6-1: Creating a table whose rows are the rank or the preference of each alternative and its columns are the methods.

Step 6-2: Forming the matrix of pairwise comparisons. This matrix is obtained by comparing the number of wins or losses of one alternative over another in different methods. If the number of preferences of one alternative over another is greater than the number of defeats of that alternative, then *M* (win) is placed in the pairwise comparison matrix, and if there is no majority vote in this comparison or the votes are equal, *X* (lose) will be placed in the pairwise comparison matrix.

Step 6-3: Adding the wins column to the last column and the losses row to the last row of the pairwise comparison matrix.

Step 6-4: Subtracting the number of losses from the number of wins to calculate the score for each alternative.

Step 6-5: Obtain the final rank of each alternative by sorting the numbers derived from the difference of wins and losses in descending order.

4. Empirical case study

4.1 Identifying the proper criteria

After studying the literature and conducting interviews with experts regarding the separation and elimination of overlapping criteria, the 8 main criteria of traffic volume, road safety, road social importance, road economic importance, road width, pavement condition index (PCI), maintenance cost and maintenance time were identified as the main criteria for this study. The criteria, their symbols, and the approach of each criterion in terms of profit (positive) or cost (negative) are depicted in Table 3.

4.2 Identifying alternatives

By checking the roads' status of maintenance and using the experts' opinions, four major streets in Tehran, Iran were considered as alternatives. The alternatives and their symbols are shown in Table 4.

4.3 Obtaining pairwise comparison and decision matrices

Questionnaires 1 and 2 were developed and then completed by experts. The pairwise comparison matrix was obtained using the first questionnaire (Table 5) and the decision matrix containing the scores of each alternative in each criterion was obtained using the second questionnaire (Table 6).

4.4 Determining the criteria weights

It was stated in the previous chapter that by using the AHP method and the pairwise comparison of the criteria, numbers are obtained as pairwise comparative values that form a matrix. Table 5 shows the weight of each criterion using the AHP method implementation.

Symbol	Criteria	Type	Weight (From AHP method)
C_1	Traffic volume	Profit	0.185649
C_2	Road safety	Profit	0.268945
C_3	Road social importance	Profit	0.078110
C_4	Road economic importance	Profit	0.135641
C_5	Road width	Profit	0.047275
C_6	Pavement Condition Index (PCI)	Profit	0.172012
C_7	Maintenance cost	Cost	0.054966
C_8	Maintenance time	Cost	0.057401

Table 3.
Considered criteria

Symbol	Alternatives (Street name)
A_1	Dadman boulevard
A_2	Darya boulevard
A_3	Paknejad boulevard
A_4	Eyvanak boulevard

Table 4.
Considered alternatives

4.5 Ranking of alternatives

4.5.1 Using ELECTRE II. In the previous section, it was stated that a second questionnaire was used to obtain the data required for forming the decision matrix in the ELECTRE method. For this purpose, the quantitative matrix data such as road width and pavement condition index (PCI) are obtained through measurement and calculation and the qualitative data such as traffic volume, road safety, road social importance, road economic importance and maintenance cost and time are obtained using the second questionnaire. According to Table 3, in this decision matrix, qualitative data are converted to numbers. We then scale this matrix and assign a weight to it using the weight calculated by the AHP method. The values used in this study for the concordance and discordance thresholds in ELECTRE II are given in Table 7.

Moreover, the Ultimate Dominance Matrix is shown in Table 8.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Weight
C_1	1	0.656	3.296	0.687	1.792	1.173	6.617	5.036	0.186
C_2	1.525	1	2.813	2.511	3.327	2.082	5.422	4.984	0.269
C_3	0.303	0.356	1	1.586	1.029	0.379	1.314	1.163	0.078
C_4	1.456	0.398	0.63	1	3.091	1.13	3.359	1.969	0.136
C_5	0.558	0.301	0.972	0.324	1	0.222	0.643	0.244	0.047
C_6	0.853	0.48	2.635	0.885	4.5	1	3.005	4.372	0.172
C_7	0.151	0.184	0.761	0.298	1.556	0.333	1	1.877	0.055
C_8	0.199	0.201	0.86	0.508	4.095	0.229	0.533	1	0.057

Table 5. Pairwise comparisons matrix and weight of each criterion using AHP method

	A_1	A_2	A_3	A_4
C_1	3.556	3.889	3.222	3
C_2	3	3	3	3.222
C_3	3.667	4	3.333	3.556
C_4	4.111	3.889	3.556	3
C_5	24	20	28	24
C_6	80	90	84	77
C_7	3.333	3.444	3.444	3.111
C_8	3.111	2.667	3.111	2.667

Table 6. Decision matrix

Symbol	Value	Description
p^*	0.8	concordance threshold for strong dominance
q^*	0.5	discordance threshold for strong dominance
$p^\wedge$	0.6	concordance threshold for weak dominance
$q^\wedge$	0.3	discordance threshold for weak dominance

Table 7. Threshold values of concordance and discordance for strong and weak dominance (Ataei, 2018)

	A_1	A_2	A_3	A_4
A_1	–	0	0	0
A_2	0	–	SF	0
A_3	0	0	–	0
A_4	0	0	0	–

Table 8. Ultimate dominance matrix

Finally, by comparing the two decreasing and increasing trends, the final ranking of alternatives is obtained. The final ranking obtained by the AHP-ELECTRE II method is given in Table 9.

4.5.2 Using ELECTRE III. In this method, the weighted normalized decision matrix should also be formed, which is the same as the matrix of the ELECTRE II method. According to the experts' opinions, the three thresholds of indifference threshold (q), preference threshold (p) and veto threshold (v) are considered, which are presented in Table 10.

The results of the ELECTRE III method are summarized in Table 9.

4.5.3 Using ELECTRE IV. Similar to the two previous methods, the matrix of Table 6 is used as the decision matrix. The results of the ELECTRE IV ranking are summarized in Table 9.

4.6 Integrating the obtained results using Copeland method

Table 11 shows the results of wins and losses, their difference, and the final ranking of each alternative in the Copeland method.

5. Conclusion

Roads are the national asset of any country and managers need to plan carefully to maintain them in order to save budget and costs and reduce casualties and financial losses. The best way to achieve this goal is to rank the roads according to their scores on various criteria. This article discusses a method for ranking streets with eight criteria. The criteria were given weights using the AHP method and the alternatives were ranked by the three different methods of ELECTRE. The roads were prioritized by three combinations of methods of AHP and ELECTRE, which are AHP-ELECTRE II, AHP-ELECTRE III and AHP-ELECTRE IV. Finally, the results were combined with the Copeland method to achieve a final ranking.

Table 9. Final ranking of alternatives

	ELECTRE II				ELECTRE III				ELECTRE IV			
	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
Decreasing ranking	2	1	2	2	1	2	3	4	1	2	2	2
Increasing ranking	1	1	2	1	1	1	1	2	1	1	2	1
Final ranking	$A_2 > A_1 = A_4 > A_3$				$A_1 > A_2 = A_3 > A_4$				$A_1 > A_2 = A_4 > A_3$			

Table 10. Introducing thresholds in ELECTRE III

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
q	0.1	0.1	0.1	0.1	3.0	5.0	0.5	0.5
p	0.2	0.2	0.2	0.2	6.0	10.0	0.7	0.7
v	0.5	0.5	0.5	0.5	7.0	15.0	1.0	1.0

Table 11. Ranking by Copeland

	Win	Lose	Difference	Final ranking
A_1	3	0	3	1
A_2	2	1	1	2
A_3	0	3	–3	3
A_4	1	2	–1	4

5.1 Discussion

In this study, a list of criteria related to road maintenance prioritization was presented. Obviously, some criteria are more important than others. Therefore, organizations should pay more attention to the use of their limited resources in road maintenance and repair. It is not reasonable to allocate a huge amount of resources to unimportant criteria. The results of AHP showed that the most important criteria according to their weight are respectively road safety (0.269), traffic volume (0.186) and pavement condition index (0.172). Subsequently, the economic importance of the road, the social importance of the road, maintenance time, maintenance cost, and the road width are ranked next.

Each of the three methods used to rank the streets produced different results. The results merged by the Copeland method show that Dadman Street gained a better ranking than the other streets, respectively followed by Darya, Eyvank and Pakenjad street. This means Dadman Street has a higher priority for maintenance than the other three streets.

Road safety is the most important criterion, perhaps because of its relevance to human health and lives. Among the consequences of failing to make timely repairs and maintenance, endangering people's lives can be one of the most important consequences. In addition, traffic volume and pavement condition index (PCI), which are in the next degrees of importance after road safety, can somehow be related to road safety. For example, a street with more traffic volume will be depreciated sooner and the pavement will be damaged faster. These factors can be hazardous and threaten safety.

According to the decision matrix obtained in this research, we can conclude that:

Dadman Boulevard was better than the other streets in the "economic importance" criterion and never worse than the other alternatives in any criteria. Darya Boulevard was better than the other alternatives in traffic volume, social importance, and pavement condition index (PCI) criteria and was the worst in road width. Eyvank Boulevard was better than the other alternatives in terms of road width and was worse in terms of social importance. Pankejad Boulevard was better than the other alternatives in terms of road safety and was worse in terms of traffic volume, economic importance, pavement condition index (PCI) and maintenance costs.

The ranking of the alternatives indicates that Dadman Street (A_1) has the highest priority. The reason for this may be that this alternative has been ranked first in two of the methods used to rank the alternatives and ranked second in one method. This means that the important criteria on this street have higher scores in the decision matrix than the unimportant criteria. On the other hand, as mentioned before, Dadman Street was not worse than the other alternatives in any criteria in the decision matrix. Also, the ranking shows that Pakenjad Street (A_4) has the lowest priority, which could be because of the fact that it was ranked last in three methods and was ranked third in one method. This means that the important criteria on this street scored lower in the decision matrix than the unimportant criteria. In the decision matrix, Pankejad Street was worse than the other alternatives in four criteria.

5.2 Research implication

In this study, a comprehensive set of criteria affecting the repair and maintenance of roads was introduced, which can help managers in this field determine what criteria should be considered in prioritizing road maintenance. In addition, the proposed approach in this research may help managers prioritize road maintenance and use the limited resources of organizations to improve road networks.

5.3 Suggestion for future research

Applying the method presented in this study to other streets and even in other cities and countries could be a subject of future research. Also, other MCDM methods, as well as other combinations of these methods may be implemented in future studies.

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