Integrated fuzzy analytic hierarchy process and VIKOR method in the prioritization of pavement maintenance activities

Peyman Babashamsi a,∗, Amin Golzadfar a, Nur Izzi Md Yusoff a, Halil Ceylan b, Nor Ghani Md Nor c

a Department of Civil & Structural Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
b Department of Civil, Construction and Environmental Engineering, Iowa State University, Ames, IA 50011, USA
c Department of Economics and Management, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

Received 25 June 2015; received in revised form 21 March 2016
Available online 26 March 2016

Abstract

Maintenance activities and pavement rehabilitation require the allocation of massive finances. Yet due to budget shortfalls, stakeholders and decision-makers must prioritize projects in maintenance and rehabilitation. This article addresses the prioritization of pavement maintenance alternatives by integrating the fuzzy analytic hierarchy process (AHP) with the VIKOR method (which stands for ‘VlseKriterjumska Optimizacija I Kompromisno Resenje,’ meaning multi-criteria optimization and compromise solution) for the process of multi-criteria decision analysis (MCDA) by considering various pavement network indices. The indices selected include the pavement condition index (PCI), traffic congestion, pavement width, improvement and maintenance costs, and the time required to operate. In order to determine the weights of the indices, the fuzzy AHP is used. Subsequently, the alternatives’ priorities are ranked according to the indices weighted with the VIKOR model. The choice of these two independent methods was motivated by the fact that integrating fuzzy AHP with the VIKOR model can assist decision makers with solving MCDA problems. The case study was conducted on a pavement network within the same particular region in Tehran; three main streets were chosen that have an empirically higher maintenance demand. The most significant factors were evaluated and the project with the highest priority was selected for urgent maintenance. By comparing the index values of the alternative priorities, Delavaran Blvd. was revealed to have higher priority over the other streets in terms of maintenance and rehabilitation activities.

Keywords: Maintenance and rehabilitation prioritization; Fuzzy analysis hierarchy process; VIKOR model; Pavement condition index; Multi-criteria decision analysis

1. Introduction

Pavement management systems require concurrent consideration of new road construction as well as pavement network maintenance and rehabilitation during the life-cycle of pavements. Several major maintenance and rehabilitation projects are normally considered when assessing pavement life-cycle [1]. Pavement managers can evaluate options like applying surface layer covering or adopting preventive strategies more confidently if they
have the ability to foresee the general function of a pavement’s life-cycle based on its future maintenance and improvement programs. Beria et al. defined multi-criteria decision analysis (MCDA) as a tool for choosing between various projects with a range of social, economic and environmental impacts [2]. The method significantly rests upon the various evaluation criteria and stakeholders’ decisions. For this reason, many authors recommend MCDA as the most suitable tool to assist with the decision-making process [3–5]. Hence, the multi-attribute decision-making tool is considered the most suitable option for sustainable pavement management. Major concerns with employing multi-attribute decisions relate to multiple objectives, criteria limitations and value weighting to evaluate various criteria.

In considering annual maintenance and rehabilitation budget shortfalls, selecting projects with higher priority is not only preferred but mandatory. This will ensure optimized maintenance costs for any given pavement network [6]. Recently, some scholars have asserted that assimilating multi-criteria and cost-benefit techniques may help attain absolute sustainability [2,7,8]. Additionally, many researchers have attempted to utilize various life-cycle optimization methods and soft computing techniques, such as genetic algorithms, fuzzy logic, neural networks and many other different systems to optimize pavement management systems [9,10] and to model pavement damage [11,12].

The aim of this study is to contribute to the decision-making process of urban managers and road authorities while organizing maintenance projects. The aim is also to work toward sustainable decisions that can prevent probable critical damage by practically prioritizing roads that need maintenance and rehabilitation by using the fuzzy analytical hierarchy process (AHP) integrated with the VIKOR method. For this purpose, five indices are first weighted using AHP, after which fuzzy logic is employed to convert human judgment into mathematical scales, and finally the VIKOR model is used to classify the prioritization of the different alternatives. The research case study was conducted in District 4 of Tehran Municipality, specifically on Hengam St., Farjam Ave. and Delavaran Blvd. It should be noted that the indices (criteria) were selected by considering various factors, such as traffic congestion, pavement condition, construction history, type of road, and pavement structure [13]. In this research, the presented alternatives are prioritized by weighting five indices (criteria) according to pavement expert opinions. The evaluation process in this study includes the steps shown in Fig. 1.

First, the important criteria are identified by experts. After evaluating the criteria hierarchy by AHP, the weight of each criterion is calculated based on the fuzzy sets theory. Finally, the VIKOR model is used to obtain the final classification results.

2. Priority criteria by analytical hierarchy process

Because pavement deterioration occurs non-linearly, prioritization is a multi-decision making process [12]. The analytical hierarchy process (AHP) is a simple decision-making method for life-cycle optimization that prioritizes and allocates a budget to be used in rail and infrastructure construction [14,15] as well as for roads and pavements [16,17].

According to Saaty and Vargas [18], AHP is a systematic method that is widely used for decision-making problems with numerous criteria and options. Saaty defined AHP as splitting a problem into smaller problems, finding a solution for each problem, and finally collecting the solutions to all the smaller problems in order to reach an acceptable result [19]. The hierarchy consists of three levels (purposes, criteria and options/alternatives). Saaty stated that this method has an organized framework for prioritizing each hierarchy level using pair comparison. It provides a methodology for synchronizing the numerical scale for assessing quantitative as well as qualitative performance. It entails decomposing a multi-decision into a hierarchy with goals at each level and sublevel of the hierarchy. Therefore, AHP can be considered both a descriptive and prescriptive decision-making model. One of the main advantages of AHP is group decision-making, i.e., collecting the opinions of a group to present ideas and judgments in order to carry out the pair comparisons.

In this section, the indices are explained in detail in order to achieve more precise prioritization. These indices include pavement condition index (PCI), pavement width, traffic congestion, operation costs and operation time. The AHP for the criteria in this research is depicted in Fig. 2.

Among these criteria, only PCI needs to be explained. There are two common methods for determining the riding quality of pavement surfaces. Several researchers have used the international roughness index (IRI) [20–23], while the pavement condition index (PCI) has been presented in some literature by other researchers [17,24–26]. PCI is widely accepted as a suitable standard for airport, road and parking lot pavements. This index has additional functions for intercity roads and is a numerical scale with values ranging from 0 (for an unusable pavement) to 100 (for an intact and well-designed pavement) as shown in Fig. 3. PCI is employed by decision makers to select maintenance
and improvement strategies. Therefore, all decisions and policies are intended to maintain the PCI value above a critical point. The critical PCI point is that after which the pavement begins to deteriorate rapidly. The PCI index is used in this study, where PCI of 100 is high, 55 is medium and 0 is low [27,28].

Relative scale assessment is used to perform pair comparisons in order to determine the relative importance of each criterion among the aforementioned criteria. Thus, comparison is done three times to provide a clear expression of the results. Therefore, the obtained relative importance of the pair comparisons is accepted based on a certain degree of inconsistency. To find the relative weight among the criteria, Saaty used a particular vector for the pair comparison matrix that was created by scale relativity [29]. The same approach is utilized in the present research.

AHP has the ability to precisely measure the differences between the criteria of different options and this approach outperforms others. Thus, the AHP method is used in this research to evaluate the quality criteria for pavement components and Fuzzy is used to prioritize them from an expert’s point of view.

3. Fuzzy sets theory

Every day people face a wide variety of issues that require decision-making. The results of these decisions are measurable based on the fuzzy state of human decisions. The fuzzy sets theory was first proposed by Professor Zadeh in 1965. Afterward, Bellman and Zadeh described a decision-making method in a fuzzy environment, which led to a large number of studies on uncertainty conditions [30]. A fuzzy system is based on knowledge and rules [31]. The system converts human knowledge into arithmetical form with the help of linguistic variables, if–then rules and a mapping system (fuzzy engine) [17]. The application of the fuzzy theory has been described in various studies [32–34]. The important theoretical aspect of fuzzy systems is that they prepare a systematic process for converting a knowledge resource into non-linear mapping [35].

3.1. Linguistic variables

It is very difficult to offer a well-justified definition that expresses the complexity of common problems. Thus, linguistic variables are useful for collecting opinions in many cases. Linguistic variables can accept words from natural language as their own values, which are then defined by a fuzzy set in the range suggested by the variables. A linguistic variable differs from a numerical variable in that its value is shown as phrases and expressions rather than numbers. An example of a linguistic variable is the prioritization of a network’s pavement components and the possible values for this variable include five points on the
Linguistic variables are in fact an expansion of numerical variables. It should be mentioned that various membership functions can be used to depict linguistic variables. Ordinarily, there are two methods for clarifying a membership function. First is expert knowledge, which means that experts are asked to model a suitable function in their own professional field, and second is using collected data to define a membership function [12].

3.2. General evaluation of fuzzy interval numbers

Fuzzy numbers are subsets of real numbers, and they symbolize the extent of the confidence interval concept. According to the definition suggested by Dubois and Prade, these numbers require three features to be called fuzzy [36]. The features are related to the calculation of triangular fuzzy numbers (TFNs). This study includes the fuzzy decision-making theory, which considers possible fuzzy judgments with evaluators in relation to pavement component prioritization.

An evaluator always comprehends the weight of a hierarchy subjectively. Therefore, in order to consider uncertainty, i.e., the interactive effects of other criteria when computing the weight of a specified criterion, the fuzzy weights of criteria are used.

The general evaluation of fuzzy judgment is defined as considering all experts’ opinions on any of the criteria concurrently (see Eq. (1)). Obviously, the ideas and opinions of experts may differ and each parameter is a fuzzy number that can be presented with a triangular membership function. Sayadi et al. [25] stated that in determining lower and higher (ultimate) points of a fuzzy triangle it is possible to use fuzzy judgment, which comprises Eqs. (2) and (3):

$$E_{ij} = [LE_{ij}, UE_{ij}]$$  \( (1) \)

$$LE_{ij} = \left( \sum_{k=1}^{m} LE_{ijk} \right) / m$$  \( (2) \)

$$UE_{ij} = \left( \sum_{k=1}^{m} UE_{ijk} \right) / m$$  \( (3) \)

where \( L \) and \( U \) are the lower and ultimate points, respectively, and \( LE_{ij} \) and \( UE_{ij} \) are the interval points of the general performance valuation of \( i \) pavement alternatives under \( j \) criteria for \( m \) number of experts. Subsequently, the decision matrix is built based on the interval numbers with the following design, where \( A_1, A_2, \ldots, A_i \) are possible alternatives among which decision makers must choose; \( C_1, C_2, \ldots, C_j \) are criteria used to measure the alternatives’ performance; and \( w_1, w_2, \ldots, w_j \) are the weights of each criterion.

\[
\begin{array}{cccccc}
& C_1 & C_2 & \cdots & C_j \\
A_1 & [LE_{i1}, UE_{i1}] & [LE_{i2}, UE_{i2}] & \cdots & [LE_{ij}, UE_{ij}] \\
A_2 & [LE_{i1}, UE_{i1}] & [LE_{i2}, UE_{i2}] & \cdots & [LE_{ij}, UE_{ij}] \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
A_i & [LE_{i1}, UE_{i1}] & [LE_{i2}, UE_{i2}] & \cdots & [LE_{ij}, UE_{ij}] \\
\end{array}
\]

\( W = [w_1, w_2, \ldots, w_j] \)

4. VIKOR technique

In 1998, Opricovic developed the VIKOR method, which stands for ‘ViseKriterijumska Optimizacija I Kompromisno Resenje,’ meaning multi-criteria optimization and compromise solution [37]. Wu and Liu stated that the basis of VIKOR is to determine the positive-ideal solution (the best alternative value) as well as the negative-ideal solution (the worst alternative value) in the first step [38]. Finally, the superiority of the plans is arranged based on the closeness of the alternatives’ assessed values to the ideal scheme. Thereby, the VIKOR method is popularly known as multi-criteria decision-making method based on the ideal point technique (multi-criteria optimization) [39].

Multi-criteria optimization is a methodology to determine the most effective possible answer in keeping with the established criteria. Practical problems are often characterized by various non-commensurable and conflicting criteria and there could also be an acceptable solution to satisfy all criteria at one time. Therefore, the answer might be a set of non-inferior solutions, or a compromise solution in line with the decision maker’s preferences. The compromise solution may be a possible answer that is the nearest to the ideal, and compromise means an agreement established by mutual concessions [40]. As shown in Fig. 5, \( E^* \) is a feasible answer for a compatible solution and shows the closest value to the ideal as \( E^* \).

There are several methods to evaluate MCDA such as simple additive weighting (SAW), elimination and choice translating reality (ELECTRE), analytic network process (ANP), simple multi-attribute rating technique (SMART), the technique for order of preference by similarity to the ideal solution (TOPSIS), and multi-criteria optimization and compromise solution (VIKOR). Generally, the
VIKOR and TOPSIS methods are used to optimize complicated multi-criteria decision analysis (MCDA) systems. A comparison of the VIKOR and TOPSIS methods reveals that each employs different aggregation functions and normalization methods. The TOPSIS method is based on the principle that the optimal point should be the closest to the positive ideal solution (PIS) and the furthest from the negative ideal solution (NIS). Therefore, this method is suitable for situations in which the decision maker wants maximum profit and the risk of the decision is less important. Assuming that each alternative (A1, A2, ..., An) is evaluated according to the various criterion functions (C1, C2, ..., Cn), the ranking can be performed by comparing the closest alternative to the ideal solution [41].

In the VIKOR method that is chosen for this study, a compatible ranking list, compatible solutions and weight stability intervals for priority stabilization are determined in compromise solutions. This method focuses on ranking and selecting from the available choices [40]. In classical MCDA methods, the criteria rankings are known precisely, whereas in the real world, e.g., in uncertain environments, it is unrealistic to assume that the knowledge and representation of a decision maker or expert is very precise. In such situations, determining the exact attribute values is difficult or even impossible. Therefore, to describe and treat imprecise and uncertain elements present in a decision problem, fuzzy and stochastic approaches are frequently used [42].

In research works on fuzzy decision-making, fuzzy parameters are assumed to be with known membership functions and in stochastic decision-making, parameters are assumed to have known probability distributions. Integrating fuzzy AHP with the VIKOR model leads to determining the best solution and providing precise results in multi-criteria optimization.

In order to obtain a compatible index ranking in MCDA, the Lp-metric, which is a collective function, is used with a compatible programing technique [40,43]. $E_{ij}$ is the value of the jth criterion function for alternative Ai; and J is the number of criteria. Only $E_{ij} \in [LE_{ij}, UE_{ij}]$ is known, while $E_{ij}^* \approx$ shows the PIS and $E_{ij}^*$ shows NIS values of criterion functions.

$$L_{pi} = \left\{ \sum_{i=1}^{n} \left[ (E_{ij}^+ - E_{ij})/(E_{ij}^+ - E_{ij}^-) \right]^p \right\}^{1/p}$$

$$1 \leq p \leq \infty; \quad j = 1, 2, \ldots, J.$$  \hspace{1cm} (4)

In the VIKOR technique, $I_{1i}$ (as $S_i$) and $I_{\infty i}$ (as $R_i$) are used to formulate ranking rates. The solutions obtained from max $S_i$ show the “maximum group majority” and the solutions obtained from min $R_i$ demonstrate the “minimum individual regret” of the alternative.

The VIKOR ranking algorithm includes the following steps:

1 – Determining the best $E_{ij}^+$ (PIS) and worst $E_{ij}^-$ (NIS) values of the criterion functions ($j = 1, 2, \ldots, n$), which are described as follows:

$$E_{ij}^+ = \{ (\max \ UE_{ij} | j \in I) \text{ or } (\min \ LE_{ij} | j \not\in J) \}$$ \hspace{1cm} (5)

$$E_{ij}^- = \{ (\min \ LE_{ij} | j \in I) \text{ or } (\max \ UE_{ij} | j \not\in J) \}$$ \hspace{1cm} (6)

where I is associated with benefit criteria, and J is associated with cost criteria.

2 – Calculating $[LS_i, US_i]$ and $[LR_i, UR_i]$, with the equations below:

$$LS_i = \sum_{j \in I} w_j (E_{ij}^+ - UE_{ij})/(E_{ij}^+ - E_{ij}^-)$$

$$+ \sum_{j \not\in J} w_j (LE_{ij} - E_{ij}^-)/(E_{ij}^+ - E_{ij}^-)$$ \hspace{1cm} (7)

$$US_i = \sum_{j \in I} w_j (E_{ij}^+ - LE_{ij})/(E_{ij}^+ - E_{ij}^-)$$

$$+ \sum_{j \not\in J} w_j (UE_{ij} - E_{ij}^-)/(E_{ij}^+ - E_{ij}^-)$$

$$LR_i = \max \{ w_j (E_{ij}^+ - UE_{ij})/(E_{ij}^+ - E_{ij}^-) | j \in I, \ w_j (LE_{ij} - E_{ij}^-)/(E_{ij}^+ - E_{ij}^-) | j \not\in J \}$$ \hspace{1cm} (9)

$$UR_i = \max \{ w_j (E_{ij}^+ - LE_{ij})/(E_{ij}^+ - E_{ij}^-) | j \in I, \ w_j (UE_{ij} - E_{ij}^-)/(E_{ij}^+ - E_{ij}^-) | j \not\in J \}$$ \hspace{1cm} (10)

where $w_j$ represents the weight of the criteria and shows the relative importance.

3 – Calculating $Q_i = [LQ_i, UQ_i]$ with following equation:

$$LQ_i = v(\max \ LS_i - S^-)/(S^- - S^+) + (1 - v)(LR_i - R^+)/R^- - R^+$$ \hspace{1cm} (11)

$$UQ_i = v(\max \ US_i - S^-)/(S^- - S^+) + (1 - v)(UR_i - R^+)/R^- - R^+$$ \hspace{1cm} (12)

where:

$$S^- = \max \ US_i, \ S^+ = \min \ LS_i$$ \hspace{1cm} (13)

$$R^- = \max \ UR_i, \ R^+ = \min \ LR_i$$ \hspace{1cm} (14)
and ε represents the strategy of “the majority of criteria”.

Suppose that \([LQ_1, UQ_1]\) and \([LQ_2, UQ_2]\) are two interval numbers and we want to choose a minimum interval number between them. These two interval numbers can have four statuses:

1. If the two interval numbers are the same, both have the same priority.
2. If these interval numbers have no intersection, the minimum interval number is the one with the lowest value. In other words, if \(UQ_1 \leq LQ_2\) then \([LQ_1, UQ_1]\) is selected as the minimum interval number.
3. In situations where \(LQ_1 \leq LQ_2 < UQ_2 \leq UQ_1\), the minimum interval number is selected as follows: if \(a \left(\frac{LQ_2 - LQ_1}{C_0}\right) \geq (1 - a) \left(\frac{UQ_1 - UQ_2}{C_0}\right)\) then \([LQ_1, UQ_1]\) is the minimum interval number, otherwise \([LQ_2, UQ_2]\) is the minimum interval number.
4. In situations where \(LQ_1 < LQ_2 < UQ_1 < UQ_2\), if \(a \left(\frac{LQ_2 - LQ_1}{C_0}\right) \geq (1 - a) \left(\frac{UQ_2 - UQ_1}{C_0}\right)\) then \([LQ_1, UQ_1]\) is the minimum interval number, otherwise \([LQ_2, UQ_2]\) is the minimum interval number.

Here, \(a\) is introduced as the optimism level of the decision maker \(0 < a \leq 1\). If \(a\) is closer to 1, the decision maker is more optimistic. For a rational decision maker \(a = 0.5\), in which situation the comparison results obtained with the introduced method are similar to the interval number comparison that has been made on the basis of interval number means.

5. Case study

The case study was conducted on a pavement network within the same particular region in the east of Tehran. Farjam Ave. (shown with a blue marker), Delavaran Blvd. (shown with a purple marker) and Hengam St. (shown with a red marker) were chosen, as they have empirically higher maintenance demand (Fig. 6).

For this research, a questionnaire was prepared as a poll to be answered by 25 experts in pavement design and management. AHP was used to determine the relative weights of the criteria, and interval numbers were used to assess the performance of the criteria of each pavement alternative. Moreover, linguistic variables were applied by the participants and scores of 0–100 were attributed to the variables in order to reassess the membership functions.

The five notable criteria chosen by experts for this study are pavement conditional index (PCI), operational time (OP), operational cost (OC), traffic congestion (TC) and pavement width (PW). The weights of the five effective

---

**Fig. 6.** Situation of three alternatives in region 5 east of Tehran.
criteria on pavement component prioritization were obtained from an analytic hierarchy. The weights of the criteria were: PCI \((W_1) = 0.394\), Operation Time \((W_2) = 0.196\), Traffic Congestion \((W_3) = 0.195\), Operation Cost \((W_4) = 0.127\) and Pavement Width \((W_5) = 0.088\). The weights generally indicate that experts were most concerned with PCI followed by OP, and they were least concerned with PW.

### 6. Result and discussion

This section explains how the proposed method can be used. Suppose there are three alternatives \((A_1 = \text{Farjam Ave.}, A_2 = \text{Delavaran Blvd.}, A_3 = \text{Hengam St.})\) and five criteria \((C_1 = \text{PCI}, C_2 = \text{OT}, C_3 = \text{TC}, C_4 = \text{OC}, C_5 = \text{PW})\). The decision matrix values are not precise and the interval numbers serve to describe and treat the uncertainty of the decision problem. The interval decision matrix is shown in Table 1.

After determining the interval decision matrix, the decision maker(s) wishes to choose an alternative with minimum PCI, OT and OC (cost criteria) and maximum TC and PW (benefit criteria). The PIS and NIS are computed with (5) and (6) and presented in Table 2.

In the next step, \([LS_i, US_i]\) and \([LR_i, UR_i]\) are computed using (7)–(10). As mentioned before, the solutions obtained from \(S_i\) represent the maximum group majority and the solutions obtained from \(R_i\) demonstrate the minimum individual regret of the alternative. Then interval \(Q_i = [LQ_i, UQ_i]\) is computed using (11)–(14). \(v\) represents the strategy of “the majority of criteria” and assumes 0.5 here. The results are presented in Table 3.

As mentioned earlier, VIKOR is based on the particular measure of “closeness” to PIS, and the higher the value (maximal interval), the more urgent the need to prioritize maintenance and rehabilitation is. The decision maker claims their optimism level is \(z = 0.5\). By using the four-step comparison of the interval results mentioned in the previous section, Hengam St. is the closest to PIS followed by Farjam Ave. and Delavaran Blvd., respectively. Therefore, Delavaran Blvd., Farjam St. and Hengam St. are ranked from first to last in terms of priority of maintenance. Other significant findings from this research are:

- PCI is the most important criterion for experts, followed by operational time, traffic congestion, operational cost and pavement width.
- Fuzzy performance indicates satisfactory results for the research problem, and the results outperform those of statistical methods.
- These results are suggested for improving administrators’ decision-making process, and pavement network administrators can contribute to enhancing the quality of their management by prioritizing experts’ criteria in their future plans.
- This model can also be considered for evaluating which segment of a specific network is a priority in terms of maintenance, even among a network that is divided into several segments. In the latter case, the indices should be defined carefully among all network segmentations. In airport pavement management, the proposed model can be utilized by dividing a runway into several segmentations to consider which part of the network requires maintenance and rehabilitation. This will help managers to effectively allocate more of their budget to impaired sections based on the conditions.

### 7. Conclusion

Due to shortfalls in annual budgets for pavement maintenance projects, decision makers unavoidably have to select prioritized sections for optimal rehabilitation. In this research, the alternatives were prioritized by considering five important indices (criteria) that were chosen according to experts’ judgment. In the real world, owing to uncertain
environments, it is unrealistic to assume that the knowl-
dge and representation of a decision maker or expert
would be very precise. In such circumstances, determining
the exact attribute values is difficult or impossible, so it
is better to choose an interval for each criterion. The weight
of each index (criterion) was determined using Fuzzy
AHP. After the main indices were weighted, the obtained
weights were placed in the VIKOR model and the prior
alternative was determined. The VIKOR method is popu-
larly known as multi-criteria decision-making method
based on the ideal point technique. It is suitable for situa-
tions in which the decision maker wants to achieve maxi-
mum profit and the risk of the decision is less important.

In this case study, after comparing the index values of
the alternative priorities, Delavaran Blvd. was revealed to
have higher priority over other components in terms of
maintenance and rehabilitation activities on the pavement
network of District 4, Tehran Municipality. After this com-
ponent, Farjam Ave. and Hengam St. were in the next
places, respectively.

References

infrastructure based on condition, safety, optimization, and life-cycle
[2] P. Beria, I. Maltese, I. Mariotti, Comparing Cost Benefit and Multi-
criteria Analysis: The Evaluation of Neighbourhood’s Sustainable
Mobility, University of Mesina, 2011.
of knowledge: the implications of assessing the social distribution of
312–318.
alternative road construction methods on low-volume roads, Transp.
[7] M.B. Barfod, K.B. Salling, S. Leleur, Composite decision support by
combining cost-benefit and multi-criteria decision analysis, Decis.
and multi-criteria analysis to prioritise a national road infrastructure
2960.
[10] S. Terzi, Modeling the pavement serviceability ratio of flexible
highway pavements by artificial neural networks, Constr. Build.
probability matrices for pavement deterioration modeling, in: J.
and maintenance prioritization of urban roads using fuzzy logic,
making methods for assessment of quality in bridges and road
construction: state-of-the-art surveys, Baltic J. Road Bridge Eng. 3 (3)
[16] J. Farhan, T.F. Fwa, Pavement maintenance prioritization using
decision-making applications in pavement rehabilitation prioritiza-
[18] T.L. Saaty, L.G. Vargas, Models, Methods, Concepts & Applications
of the Analytic Hierarchy Process, vol. 175, Springer Science &
[19] T.L. Saaty, How to make a decision: the analytic hierarchy process,
[20] A. Aavik, Estonian road network and road management, Baltic J.
[21] Y. Wang, D. Allen, Staged survival models for overlay performance
[22] D. Cygas, A. Laurinavicius, A. Vaitkus, Z. Pervenekaas, A. Motiejunas,
Research of asphalt pavement structures on Lithuanian roads (I), Baltic
maintenance prioritization model: an integrated approach for high-
426–433.
[24] E. Gallego, M. Moya, M. Piniés, F. Ayuga, Valuation of low volume
roads in Spain, Part 2. Methodology validation, Biosyst. Eng. 101 (1)
the type of pavement repair, The 7th WSEAS International Confer-
ence on Applied Informatics and Communications (AIC’07), Vou-
liagmeni Beach, Athens, Greece, 2007, pp. 1–6.
[26] R.G. Mishalani, L.Y. Gong, Optimal infrastructure condition sam-
ping over space and time for maintenance decision-making under
scheme for the Micro PAVER pavement management system,
comprehensive pavement management system in Tehran, Iran using
[29] T.L. Saaty, A scaling method for priorities in hierarchical structures,
[31] A.C.M. Chang, P.E. Krugler, R.E. Smith, A knowledge approach
oriented to improved strategic decisions in pavement management
practices, The 1st Annual Inter-university Symposium on Infrastruc-
ture Management (AISIM), University of Waterloo, Ontario,
Canada, 2005.
electronic marketplaces using satisfying and fuzzy AHP, Expert Syst.
[33] N.S. Arunraj, J. Maiti, Risk-based maintenance policy selection using
[34] R. Joshi, D.K. Banwet, R. Shankar, A Delphi-AHP-TOPSIS based
benchmarking framework for performance improvement of a cold
[35] A. Turan, A hybrid model of fuzzy and AHP for handling public
assessments on transportation projects, Transportation 36 (1) (2009)
97–112.


