

# Assessment of risk factors in forest road design and construction activities with fuzzy analytic hierarchy process approach in Turkey

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Received: 29 March 2018 / Accepted: 22 August 2018 / Published online: 31 August 2018  
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**Abstract** Forest road design and construction are time-consuming and complicated because various risk factors can be encountered during the process. The aim of this study is to comprehensively assess the risk factors in forest road design and construction using the fuzzy analytic hierarchy process (AHP) method in Turkey, thus contributing to the proper performance of these activities. Within the scope of the study, six main risk factors and 22 sub-risk factors were identified based on literature review. In order to determine the weights of the relevant risk factors, the opinions of three different groups [(group 1: academicians), (group 2: forest engineers (private sector employees + public sector employees)), (group 3: group 1 + group 2)] about the risk factors were obtained. Relevant risk factor weights were determined using the fuzzy AHP method. According to group 3, the most important main risk factors are technical risks and environmental risks. In addition, the most important sub-risk factors for each relevant main risk factor were incorrect road alignment, inadequate work safety in the field, insufficient capital, legal problems on the road alignment, landslide risk during road construction, and illegal logging. Differences were observed between groups 1 and 2 in the weight rankings of relevant risk factor. The results demonstrate that the

fuzzy AHP method can be used effectively to assess the risks of forest road design and construction.

**Keywords** Multi criteria decision-making · Fuzzy logic · Forest road · Risk assessment

## Introduction

Forest roads are complex, time-consuming, and costly elements of forest operations (Akgul et al. 2016) because the design, construction, and maintenance require complex engineering processes (Sessions 2007). Consequently, technical, economic, social, and environmental conditions should be considered during forest road construction (Akay and Sessions 2005).

Various risk factors (technical risks, environmental risks, commercial risks, etc.) may be encountered in the design and construction of forest roads. Forest managers have more factors to consider than they did in the past, depending on the environmental impact, cost of construction, and design of forest roads (Dutton et al. 2005; Lugo and Gucinski 2000). Therefore, it is very important to identify and assess risks that may be encountered to ensure proper forest road design and construction. The process of risk management consists of defined risks, which are assessed and prioritized (Sum 2013). In this context, it is also important to assess the relevant risks accurately.

Different approaches to risk assessment have been suggested, from classical simple approaches to fuzzy approaches (Aminbakhsh et al. 2013). Existing risk

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assessment studies related to forest roads include studies carried out using the classical AHP method (Dragoi et al. 2015) and the impact probability matrix method (Slinicu et al. 2012; Slinicu et al. 2013). As stated in these studies, risk assessment methods do not appear to have a sufficiently comprehensive framework. Siluncu et al. (2012) and Siluncu et al. (2013) mostly focused on the technical risk factors of forest road construction while another study evaluated a limited number of risk factors (five risk factors) (Dragoi et al. 2015). The impact probability matrix used in previous studies falls under the category of qualitative risk assessment. The results of this risk assessment method are generally descriptive, and risk is not a precise calculation feature (Iacob 2014). Classical AHP is one of the risk assessment methods most commonly used by decision-makers and researchers (Vaidya and Kumar 2006). AHP's decision-making approach is used to solve complex multi-decision problems involving qualitative judgments (Saaty 1980). However, the use of unbalanced scale judgments and the inability to adequately provide ambiguity in the pairwise comparisons phase often cause the AHP method to be criticized (Deng 1999). On the other hand, since human judgments are expressed in exact values in the AHP method, decision-makers remain incompetent in dealing adequately with indefinite and imprecise judgments (Javanbarg et al. 2012). In order to effectively address subjective perception and thinking, the integration of fuzzy numbers into the AHP is given the proper expression of linguistic evaluation (Mardani et al. 2015). The fuzzy AHP obtained by combining the fuzzy set theory and the AHP method provides a more accurate description of the decision-making process (Huang et al. 2008). The fuzzy AHP method has been used in risk assessment studies in different disciplines (Tian and Yan 2013; Zhang et al. 2018).

The aim of this study is to comprehensively assess the risk factors in forest road design and construction using the fuzzy AHP method, thus contributing to the proper performance of these activities. For this purpose, six main risk factors and 22 sub-risk factors were assessed.

## Materials and methods

Within the scope of the study, relevant risk factors were evaluated with three different groups. Group 1 consisted of academicians who were experts in forest engineering departments in Turkey. They

also had PhDs and/or masters degrees on forest road construction and transportation. Group 2 consisted of private sector and public sector employees (Republic of Turkey General Directorate of Forestry Employees). Group 3 consisted of group 1 + group 2 (Fig. 1). The demographic characteristics for the three different groups are shown in Table 1.

Relevant risks were determined based on a literature review. These risks were classified as six main risk factors and 22 sub-risk factors. The determined risks and their definitions are shown in Table 2.

## Fuzzy AHP method

The fuzzy AHP method is based on the fuzzy set theory presented by Zadeh (1965). A fuzzy number  $M$  on  $R$  ( $M$  ( $R$ )) is described as a triangular fuzzy number (TFN) if its membership functions  $\mu_M^{(x)}: R \rightarrow [0, 1]$  equal a condition where  $l \leq m \leq u$  (Eq. (1)). Additionally,  $l$  and  $u$  are the lower and upper support values for  $M$ , and  $m$  is the modal value.

$$\mu_{M \sim}^{(x)} = \begin{cases} \frac{x-l}{m-l} & l \leq x \leq m \\ \frac{u-x}{u-m} & m \leq x \leq u \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The literature includes several fuzzy AHP methods based on different methods (Buckley 1985; Chang 1996; Mikhailov and Tsvetinov 2004; Van Laarhoven and Pedrycz 1983). In the present study, the extent of the fuzzy AHP method used was that presented by Chang (1996). The necessary calculations for the Chang method (1996) were performed with Microsoft Office Excel 2016 software. Matlab R2013a software was also used to calculate the maximal eigenvalues needed to calculate the consistency ratio for the generated pairwise comparison matrices.

## Chang (1996) fuzzy extent analysis method

Let  $X = (x_1, x_2, x_3, \dots, x_n)$  be an object set and  $G = (g_1, g_2, g_3, \dots, g_n)$  be the goal set.

$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m, i = 1, 2, \dots, n$ , where all the  $M_{gi}^j$  ( $j = 1, 2, \dots, m$ ) are triangular fuzzy numbers.

Chang's extended analysis consists of the following steps.

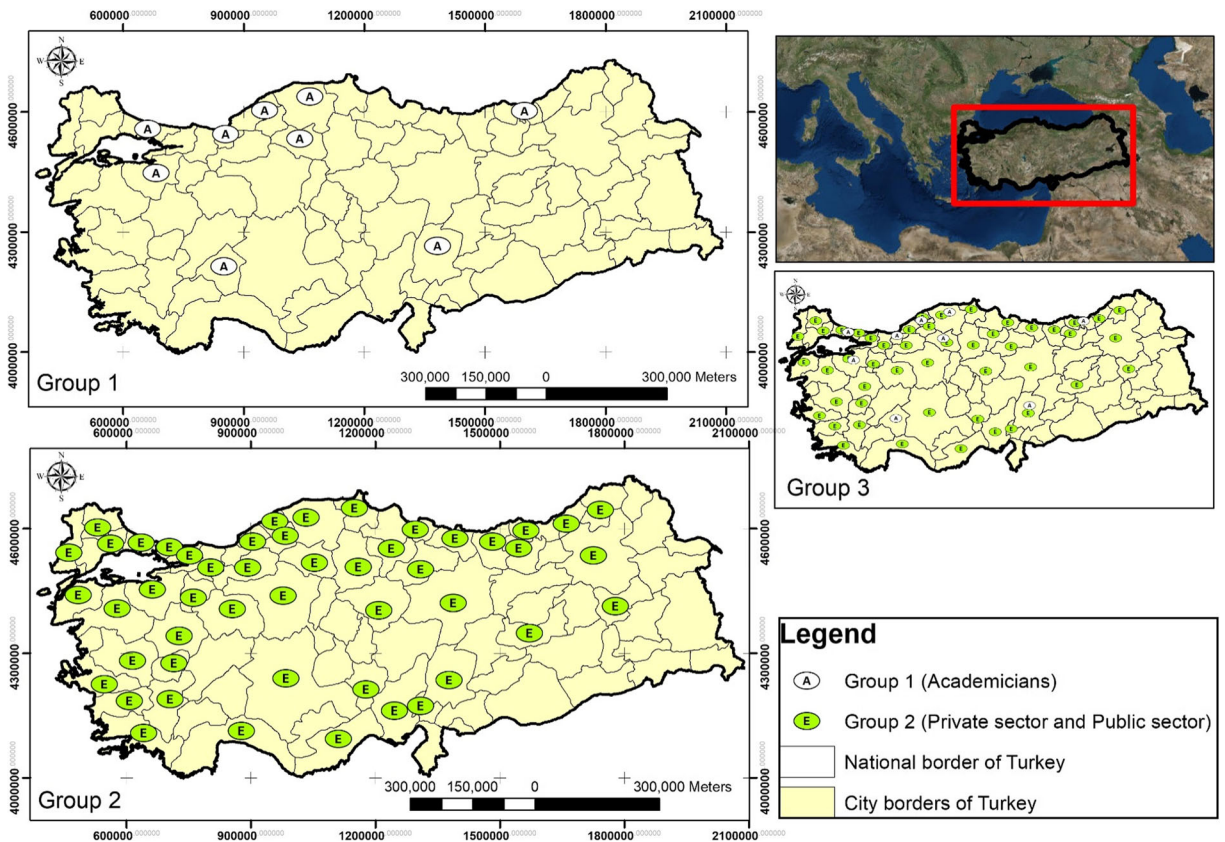


Fig. 1 Distribution of participants

Table 1 Demographic characteristics for groups participating in risk assessment

		Group 1		Group 2		Group 3	
		Academics		Forest engineers (private sector employees + public employees*)		Group 1+ group 2	
		<i>N</i>	%	<i>N</i>	%	<i>N</i>	%
Gender	Male	28	93.33	62	82.67	90	85.71
	Female	2	6.67	13	17.33	15	14.29
Age	23–30	3	10.00	18	24.00	21	20.00
	30–39	8	26.67	29	38.67	37	35.24
	40–49	13	43.33	17	22.67	30	28.57
	50–59	3	10.00	7	9.33	10	9.52
	59+	3	10.00	4	5.33	7	6.67
Experience (year)	1–5	4	13.33	24	32.00	28	26.67
	5–10	8	26.67	17	22.67	25	23.81
	10–20	8	26.67	19	25.33	27	25.71
	20–30	5	16.67	10	13.33	15	14.29
	30+	5	16.67	5	6.67	10	9.52

\*Republic of Turkey General Directorate of Forestry employees

**Table 2** Main risk factors and sub-risk factors and their descriptions

Main risk factors	Sub-risk factors	Description	References
Technical risks (road planning risks)	Incorrect selection of road alignment	The risk of not selecting forest road alignment in accordance with the stated objectives	Acar 2016; Bayoglu 1997; Epstein et al. 2006; Erdas 1997; Gumus et al. 2008; Ozturk et al. 2010; Silincu et al. 2012; Silincu et al. 2013
	Incorrect selection of road type and standardization	The risk of not selecting the forest road type and standard according to the determined objectives	
	Incorrect earthwork method application	The risk of selecting incompatible earthwork method with excavation and topography	
	Incorrect selection of road structures' type and place	The risk of wrongly selecting the type and location of road structure required for forest road construction	
	Incorrect selection of construction machine	The risk of wrongly selecting construction machine in the forest road construction activities such as earthwork and pavement construction	
Topographic risks	Unforeseen geological and topographic conditions	Difficult conditions in the ground and topography during forest road construction	Acar 2016; Eker and Ada 2011; Epstein et al. 2006; Erdas 1997; Fannin and Lorbach 2007; Meignan et al. 2012
	Historical and archeological findings risks in area	Risks of encountering historical and archeological findings in road construction field	
	Inadequate work safety in the field	Inadequate work safety in forest road construction field	
	Incompatibility between road planning and topography	Risks arising from poor topography analysis or poor road planning	
Commercial risks	Insufficient capital	Lack of fund to build forest road	Dragoi et al. 2015; Eker and Ada 2011; Erdas 1997; Meignan et al. 2012; Turk and Gumus 2017
	Delay in payment of progress	The risk of delay in forest road construction activities due to the late payment of progress	
	Incorrect cost calculation	The risk of mistake in the calculation of forest road construction cost	
Administrative and political risks	Changes in relevant legislation	Possible effects of legislative changes related to forest road construction and design activities	Erdas 1997; Fannin and Lorbach 2007; Gorcelioglu 2004; Meignan et al. 2012
	Legal problems on the road alignment	Owned land etc. legal problems on the forest road alignment	
	Political attitudes in road planning	Impact of political approaches on planning forest roads	
	Insufficient of inspection road construction site	Inadequate control of forest road construction activities	
Environmental risks	Unforeseen weather conditions and natural disasters	The risk of natural disasters and weather conditions such as floods, earthquakes, storms during forest road construction	Hayati et al. 2013; Ozturk et al. 2010; Wise et al. 2004
	Landslide risk during road construction		

**Table 2** (continued)

Main risk factors	Sub-risk factors	Description	References
		The risk of landslides associated with topography during forest road construction	
	Stand damage during road construction	The risk of damage to tree in the stand during forest road construction	
Socio-economic risks	Social attitude toward road construction	Public opinion against the environmental effects of forest road construction	Ali et al. 2005; Cole and Landres 1996; Dragoi et al. 2015; Gorcelioglu 2004; Wilkie et al. 2000
	Causing illegal logging	The risk of increasing illegal logging due to access provided by forest roads	
	Causing illegal hunting	The risk of increasing illegal hunting due to access provided by forest roads	

Step 1: The value of the fuzzy synthetic extent with respect to the *i*th object is defined as equation

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \tag{2}$$

$$\sum_{j=1}^m M_{gi}^j = \left( \sum_{j=1}^m l_i, \sum_{j=1}^m m_i, \sum_{j=1}^m u_i \right) \tag{3}$$

$$\left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left( \frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i} \right) \tag{4}$$

Step 2: The degree of possibility of  $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$  is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{5}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \text{otherwise} & \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \end{cases} \tag{6}$$

Step 3: The degree of possibility for a convex fuzzy number greater than *k* convex fuzzy numbers  $M_i (i = 1, 2, \dots, k)$  can be defined as

$$V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \dots \text{ and } (M \geq M_k)] = \min_{i=1, 2, \dots, k} V(M \geq M_i), \tag{7}$$

$$\text{Let } d'(A_i) = \min V(S_i \geq S_k), \text{ for } k = 1, 2, \dots, n; k \neq i, \tag{8}$$

then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \tag{9}$$

where  $A_i (i = 1, 2, 3, \dots, n)$  are elements.

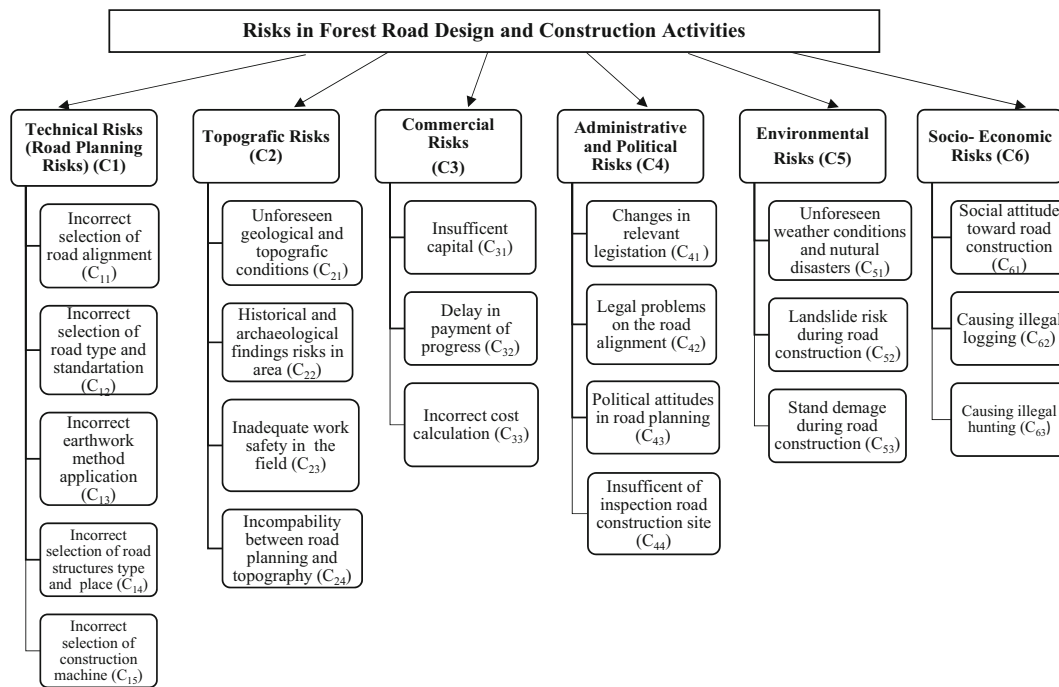
Step 4: Via normalization, the normalized weight vector is

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \tag{10}$$

where *w* is a non-fuzzy vector.

Establishing hierarchical structure for relevant risk factors

Risks in forest road construction and design activities were determined based on the literature review. Descriptions are given in Table 2 for relevant risk factors. These can be listed as follows: technical risks and their sub-risks (Acar 2016; Bayoglu 1997; Epstein et al. 2006; Erdas 1997; Gumus et al. 2008; Ozturk et al. 2010;



**Fig. 2** Risks in forest road design and construction activities

Slinco et al. 2012; Slinco et al. 2013), topographic risks and their sub-risks (Acar 2016; Eker and Ada 2011; Epstein et al. 2006; Erdas 1997; Fannin and Lorbach 2007; Meignan et al. 2012), commercial risks and their sub-risks (Dragoi et al. 2015; Eker and Ada 2011; Erdas 1997; Meignan et al. 2012; Turk and Gumus 2017), administrative and political risks and their sub-risks (Erdas 1997; Fannin and Lorbach 2007; Gorcelioglu 2004; Meignan et al. 2012), environmental risks and their sub-risks (Hayati et al. 2013; Ozturk et al. 2010; Wise et al. 2004), and socio-economic risks and their sub-risks (Ali et al. 2005; Cole and Landres 1996;

Dragoi et al. 2015; Gorcelioglu 2004; Wilkie et al. 2000). The hierarchical structure for the identified risks is given in Fig. 2.

Establishing the pairwise comparison matrix

A questionnaire was prepared for the creation of pairwise comparison matrices for the main risk factors and the corresponding sub-risk factors. The main risk factors in the questionnaire were compared with each other and the sub-risk factors under each main criterion were also compared with each other. The prepared questionnaire was sent via e-mail to the participants in groups 1 and 2 to obtain their opinions about the relevant risks. The linguistic variables were expressed as triangular fuzzy numbers to determine the opinions of the participants (Table 3). The geometric mean method was used to combine the opinions of each group. The obtained average values were transformed to the nearest fuzzy numbers. In this study, a total of 21 pairwise comparison matrices were created, with 7 pairwise comparison matrices for each group. The pairwise comparison matrices for the main risk factors (C1, C2, C3, C4, C5, C6), which were the pairwise comparison matrices used for group 3, are shown in Table 4.

**Table 3** Linguistic variables (Chang 1996)

Linguistic variables	Triangular fuzzy numbers	Reciprocal triangular fuzzy numbers
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

**Table 4** Fuzzy pairwise comparison matrix for the main risk factors

	C1	C2	C3	C4	C5	C6
C1	(1, 1, 1)	(1, 3/2, 2)	(1, 3/2, 2)	(1/2, 1, 3/2)	(1/2, 1, 3/2)	(1, 3/2, 2)
C2	(1/2, 2/3, 1)	(1, 1, 1)	(1, 3/2, 2)	(1, 3/2, 2)	(1/2, 1, 3/2)	(1, 3/2, 2)
C3	(1/2, 2/3, 1)	(1/2, 2/3, 1)	(1, 1, 1)	(1/2, 1, 3/2)	(1/2, 2/3, 1)	(1/2, 1, 3/2)
C4	(2/3, 1, 2)	(1/2, 2/3, 1)	(2/3, 1, 2)	(1, 1, 1)	(1/2, 2/3, 1)	(1/2, 1, 3/2)
C5	(2/3, 1, 2)	(2/3, 1, 2)	(1, 3/2, 2)	(1, 3/2, 2)	(1, 1, 1)	(1, 3/2, 2)
C6	(1/2, 2/3, 1)	(1/2, 2/3, 1)	(2/3, 1, 2)	(2/3, 1, 2)	(1/2, 2/3, 1)	(1, 1, 1)

Calculation of consistency ratio

The consistency ratio (CR) was used to check the consistency of the generated fuzzy pairwise comparison matrices. For the calculation of the CR, the triangular fuzzy numbers in the pairwise comparison matrices were converted to crisp values using Eq. (13) based on a graded mean integration approach (Chen and Hsieh 2000). Then, the CR of the pairwise comparison matrix for the main criteria was calculated by means of Eqs. (11) and (12). The random consistency index (CI) value was obtained from Table 5. Similarly, the CR was calculated for the other pairwise comparison matrices. The CR of the pairwise comparison matrix can be expected to be less than 0.1 (Saaty 1980). All generated pairwise comparison matrices were found to be consistent (CR < 0.1) as a result of the calculations.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{11}$$

$$CR = \frac{CI}{RI} \tag{12}$$

- $\lambda_{max}$  maximal eigenvalue of the pairwise comparison matrix
- $n$  size of pairwise comparison matrix
- $RI$  random consistency index
- $CI$  consistency index

**Table 5** Values of random consistency index (Saaty 1980)

$n$	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

For example, the consistency calculation for the pairwise comparison matrix created by group 3 for the main risk factors was as follows.

$n$ : 6;  $RI$ : 1.24.

$$CI = \frac{6.2196 - 6}{6 - 1} = 0.0439$$

$$CR = \frac{0.0439}{1.24} = 0.03 < 0.1 \tag{13}$$

$$P(\tilde{M}) = M = \frac{l + 4m + u}{6}$$

**Results and discussion**

Weight calculation for risk factors

The calculation of weight values for the main risk factors is given below for group 3. In the first step, fuzzy synthetic extent values for the main risk factors were calculated using Eqs. (2), (3), and (4) (Table 6).

After calculating the fuzzy synthetic extent values for the main risk factors, the degree of possibility values was calculated from Eqs. (5) and (6) (Table 7). Priority weights were calculated with Eqs. (8) and (9) in the next stage (Table 8).

In the last step, priority weights were normalized with Eq. (10). Thus, the weight values were calculated for the main risk factors (Table 9). Similar processing steps were applied to other pairwise comparison matrices. Finally, the weight values for the main risk factors and sub-risk factors were calculated. The weight values for all risk factors (main risk factors and sub-risk factors) are given in Tables 10 and 11.

**Table 6** Fuzzy synthetic extent values for the main risk factors

Main risk factors	Fuzzy synthetic extent values
C1	(5.00, 7.50, 10.00) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.09, 0.20, 0.37)
C2	(5.00, 7.17, 9.50) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.09, 0.19, 0.35)
C3	(3.50, 5.00, 7.00) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.06, 0.13, 0.26)
C4	(3.83, 5.33, 8.50) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.07, 0.14, 0.32)
C5	(5.33, 7.50, 11.00) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.09, 0.20 0.41)
C6	(3.83, 5.00, 8.00) ⊗ (1/54.00, 1/37.50, 1/26.50) = (0.07, 0.13 0.30)

Comparison of groups 1 and 2 in terms of relevant risk factor weight rankings

When the values of the risk weight for groups 1 and 2 are examined in terms of the main risk factors, the risk weight rankings for technical risks, environmental risks, and commercial risks in groups 1 and 2 are equal. However, the risk weight rankings of the other main risk factors vary between the groups. Among these, the most obvious differences are the administrative and political risks. As shown in Table 10, the administrative and political risk weight is in fifth place in group 1 and third place in group 2.

When assessing the technical risk factors for the sub-risk factors according to the risk weight ranking, the top risk factor is incorrect selection of road alignment for groups 1 and 2. Technical risk factors related to other sub-risk factors vary in weight rankings between the groups (Table 11).

Topographic risks show obvious differences between groups 1 and 2. When the commercial risks related to

**Table 7** Degree of possibilities values for main risk factors

Degree of possibilities				
$V(S1 \geq S2) = 1$	$V(S1 \geq S3) = 1$	$V(S1 \geq S4) = 1$	$V(S1 \geq S5) = 1$	$V(S1 \geq S6) = 1$
$V(S2 \geq S1) = 0.96$	$V(S2 \geq S3) = 1$	$V(S2 \geq S4) = 1$	$V(S2 \geq S5) = 0.96$	$V(S2 \geq S6) = 1$
$V(S3 \geq S1) = 0.72$	$V(S3 \geq S2) = 0.74$	$V(S3 \geq S4) = 0.95$	$V(S3 \geq S5) = 0.71$	$V(S3 \geq S6) = 1$
$V(S4 \geq S1) = 0.79$	$V(S4 \geq S2) = 0.82$	$V(S4 \geq S3) = 1$	$V(S4 \geq S5) = 0.79$	$V(S4 \geq S6) = 1$
$V(S5 \geq S1) = 1$	$V(S5 \geq S2) = 1$	$V(S5 \geq S3) = 1$	$V(S5 \geq S4) = 1$	$V(S5 \geq S6) = 1$
$V(S6 \geq S1) = 0.75$	$V(S6 \geq S2) = 0.78$	$V(S6 \geq S3) = 1$	$V(S6 \geq S4) = 0.96$	$V(S6 \geq S5) = 0.75$

**Table 8** Priority weights for the main risk factors

Main risk factors	Priority weights
C1	$\min(1, 1, 1, 1, 1) = 1$
C2	$\min(0.96, 1, 1, 0.96, 1) = 0.96$
C3	$\min(0.72, 0.74, 0.95, 0.71, 1) = 0.71$
C4	$\min(0.79, 0.82, 1, 0.79, 1) = 0.79$
C5	$\min(1, 1, 1, 1, 1) = 1$
C6	$\min(0.75, 0.78, 1, 0.96, 0.75) = 0.75$

sub-risk factors are evaluated, the most important risk factor in groups 1 and 2 is insufficient capital (Table 11).

The most important administrative and political risk factors related to sub-risk factor are legal problems on the road alignment in both groups. Others related to sub-risk factor weight rankings vary between the groups. However, the most obvious difference is found in political attitudes in road planning risk in the two groups (Table 11).

As for the environmental risks related to sub-risk factors, where landslide risk is found during road construction weight rankings, groups 1 and 2 are equal with first place. Others related to sub-risk factor weight rankings vary between the groups. Lastly, when socio-economic risks related to the sub-risk factors are examined, risk weight rankings for causing illegal hunting in groups 1 and 2 are equal with third place while other relevant sub-risk factors vary between the two groups (Table 11).

Results of risk weight for group 3 (group 1 + group 2)

The most important main risk factors are technical risks and environmental risks in group 3. The other main risk factors are topographic risks, administrative and political risks, socio-economic



**Table 9** Weight values and normalized weight values for main risk factors

Main risk factors	Weight vector ( <i>W</i> )	Normalized weight vector ( <i>W</i> )
C1	1	0.19
C2	0.96	0.18
C3	0.71	0.13
C4	0.79	0.15
C5	1	0.19
C6	0.75	0.14

risks, and commercial risks respectively according to the risk weight rankings (Table 10). In a similar study presented by Gumus (2009) using the classical AHP method to identify and rank effective factors for evaluating forest roads, the importance ratings were 30.5% for technical factors, 3.94% for economic factors, 56.46% for environmental factors, and 9.46% for social factors. Our study results are partially similar to those of Gumus (2009). The results of a study by Hayati et al. (2013) demonstrated that the environmental impact should be assessed before beginning road construction to reduce the effects.

Assessment of the sub-risk factors with respect to the main risk factors showed that incorrect selection of road alignment is the most important sub-risk factor under technical risk factors (Table 11). Consistent with this finding, Acar (2016) emphasized that the most important risk factor in forest road planning cannot be determined correctly for the road alignment. In this context, in the related literature, various studies have been published by the many authors to minimize this risk (Meignan et al. 2012; Naghdi et al. 2008; Parsakhoo 2016).

**Table 10** Risk weight values for main risk factors

Main risk factors	Group 1 Weights	Rank	Group 2 Weights	Rank	Group 3 Weights	Rank
Technical risks (planning risks) (C1)	0.20234	1	0.19087	1	0.19135	1
Topographic risks (C2)	0.18596	3	0.16753	4	0.18501	2
Commercial risks (C3)	0.13453	6	0.12946	6	0.13637	5
Administrative and political risks (C4)	0.13946	5	0.16798	3	0.15183	3
Environmental risks (C5)	0.19395	2	0.18350	2	0.19135	1
Socio-economic risks (C6)	0.14372	4	0.16062	5	0.14406	4

The most important topographic sub-risk is inadequate work safety in the field (Table 11). Fannin and Lorbach (2007) stated that in forest road construction and design activities, the safety of forest workers and the general public should be ensured. The other risk factor is incompatibility between road planning and topography in third place while unforeseen geological and topographic conditions and historical and archeological finding risk in area are in second place with equal weights.

Insufficient capital is the most important commercial sub-risk factor according to group 3 (Table 11). Heralt (2002) stated that in road design, cost and other factors such as the distribution of local roads should be considered. Other relevant sub-risk factors are incorrect cost calculation and delays in payment according to the risk weight ranking.

As shown in Table 11, legal problems on the forest road alignment are the most important sub-risk factors under administrative and political risk factors. In this regard, Meignan et al. (2012) reported that land use planning and environmental protection regulations can restrict road construction. Erdas (1997) also emphasized that one of the main factors that influences the planning of forest roads is ownership.

According to group 3, landslide risk during road construction is the most important environmental risk factor (Table 11). Road construction and timber production in unsuitable slopes are known to cause landslides (Larsen and Parks 1997). The most important criteria in the established model for planning and evaluating forest roads in the study presented by Hayati et al. (2013) were slope, soil texture, and landslide sensitivity. Another study by Allison et al. (2004) reported that roads increase landslide risk.

**Table 11** Risk weights values for sub-risk factors

	Sub-risk factors	Group 1 Weights	Rank	Group 2 Weights	Rank	Group 3 Weights	Rank
Technical risks (road planning risks) (C1)	Incorrect selection of road alignment (C <sub>11</sub> )	0.31833	1	0.27026	1	0.26172	1
	Incorrect selection of road type and standartation (C <sub>12</sub> )	0.22312	2	0.19599	3	0.21750	2
	Incorrect earthwork method application (C <sub>13</sub> )	0.14430	4	0.19599	3	0.18470	4
	Incorrec selection of road structure type and place (C <sub>14</sub> )	0.20842	3	0.21298	2	0.20883	3
	Incorrect selection of construction machine (C <sub>15</sub> )	0.10580	5	0.12477	4	0.12722	5
Topographic risks (C2)	Unforeseen geological and topographic conditions (C <sub>21</sub> )	0.28491	1	0.24629	3	0.24773	2
	Historical and archeological findings risks in area (C <sub>22</sub> )	0.22482	2	0.24856	2	0.24773	2
	Inadequate work safety in the field (C <sub>23</sub> )	0.20534	3	0.2681	1	0.27657	1
	Incompability between road planning and topography (C <sub>24</sub> )	0.28491	1	0.23704	4	0.22795	3
Commercial risks (C3)	Insufficient capital (C <sub>31</sub> )	0.38145	1	0.39924	1	0.37218	1
	Delay in payment of progress (C <sub>32</sub> )	0.23708	2	0.26219	3	0.28981	3
	Incorrect cost calculation (C <sub>33</sub> )	0.38145	1	0.33856	2	0.33800	2
Administrative and political risks (C4)	Changes in relevant legistation (C <sub>41</sub> )	0.24309	2	0.24316	3	0.24561	2
	Legal problems on the road alignment (C <sub>42</sub> )	0.28979	1	0.29191	1	0.29920	1
	Political attitudes in road planning (C <sub>43</sub> )	0.23069	4	0.25454	2	0.23177	3
	Insufficient of inspection road construction site (C <sub>44</sub> )	0.23641	3	0.21038	4	0.22340	4
Environmental risks (C5)	Unforeseen weather conditions and natural disasters (C <sub>51</sub> )	0.27305	3	0.32612	2	0.30987	2
	Landslide risk during road construction (C <sub>52</sub> )	0.43011	1	0.37291	1	0.39626	1
	Stand damage during road construction (C <sub>53</sub> )	0.29682	2	0.30095	3	0.29385	3
Socio-economic risks (C6)	Social attitude toward road construction (C <sub>61</sub> )	0.36935	1	0.30987	2	0.32612	2
	Causing illegal logging (C <sub>62</sub> )	0.33066	2	0.39626	1	0.37291	1
	Causing illegal hunting (C <sub>63</sub> )	0.29997	3	0.29385	3	0.30095	3

Illegal logging is the most important socio-economic sub-risk factor (Table 11). Shivakoti et al. (2016) stated that roads increase the risk of illegal logging in forest areas. Other sub-risk factors are social attitudes against road construction and illegal hunting respectively according to their weight rankings. In recent years, public awareness has increased regarding the environmental impacts of forest road construction (Gumus et al. 2008). Gorcelioglu (2004) also stated that forest road construction and timber production remain constant sources of tension between the forestry industry and the public.

## Conclusion

In this study, the risks that may be encountered in forest road design and construction activities were evaluated using fuzzy AHP. A total of six main risk factors and 22 sub-risk factors were identified. The fuzzy AHP method could be used successfully for assessing risk during forest road design and construction. In further studies, the results obtained using different fuzzy multi-criteria decision-making methods can be compared with the results of this study. The results are expected to

contribute to the proper implementation of forest road construction and design activities by ensuring necessary precautions are taken against the risks that may be encountered during forest road construction. The study results will also enable forest road managers and designers (forest engineers) to compare the weight rankings of relevant risk factors.

**Acknowledgements** We would like to thank the expert academicians at the Department of Forest Engineering as well as the employees (forest engineers) at the Republic of Turkey General Directorate of Forestry and in the private sector for contributing to this study by responding to the questionnaire prepared to assess the relevant risk factors. Also, authors thank the editor and anonymous reviewers for their constructive comments, which helped us to improve the manuscript.

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