Prioritization of Suburban Accident Factors Based on Analytical Network Process

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Abstract

The safety management of transportation system leads to decrease in a number of traffic accidents. Identification of the primary reasons in accident incidence is the initial step in controlling the crashes. The source of accidents is divided into 3 groups; namely, human, environment and traffic. Due to the complex nature of traffic accidents, Multi-Criteria Decision-Making (MCDM) methods can be considered as an efficient approach. The main objective of the paper was to use analytical network process (ANP) to evaluate the interaction of human, traffic and road related parameters in occurrence of accidents. ANP is the extended form of analytical hierarchy process (AHP). AHP simulates a decision problem into a hierarchy consists of a goal, decision criteria, and alternatives, while the ANP structures that as a network. Next step is to use pair wise comparisons to calculate the weights of the components of the structure, and to rank the alternatives in the decision. The power of the ANP lies in its use of ratio scales to capture all kinds of interactions and make accurate predictions. In this paper, using ANP structure, instead of pair wise comparison made by experts' opinion in calculation of the weight of components; statistic analysis as well as frequency of effective parameters in accident occurrence, were utilized where statistics was available. This was resulted in more accurate outcomes. Sub-urban accidents data in the length of 945 km of Hamedan province in three-year period was considered as a case study. As a result, although most of the researchers are of the idea that the human plays a crucial role in crash occurrence, road factors had higher priority. Factors such as curvature and grade were more effective than human characteristics. Furthermore, it was concluded that, Condition curvature (0-100) degree per kilometer and grade (0-3%) had higher risk of accidents.

Keywords: Traffic accidents, accident parameters, human factors, multi-criteria decision-making, Analytical Hierarchy Process

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1. Introduction

Each year, traffic accidents result in the death of about 1.25 million people across the world. Between 20 and 50 million more people suffer from non-fatal injuries, results in their diability imposing huge economic costs on the society (between 1% and 3% of gross domestic product (GDP) in most of the countries). Furthermore, death and injuries yield great emotional and financial problems for the millions of families who lost their loved ones. There are a few global estimation regarding the costs of injury. However, research carried out in 2010 suggests that road traffic accidents cost includes approximately 3% of countries' gross national product. This rises to 5% in a number of low and middle-income countries. Considering the high number of road casualties and the corresponding socio-economic costs, new provisions are urgently required to decline a number of accidents and improve road safety [WHO, 2016]. It is necessary to examine and measure the factors contributing to the accidents to improve safety of roads to prevent above-mentioned problems from happening, and make the roads somewhere safer. Investigation regarding accident analysis and prevention tools on roads concern the role of geometric characteristic of roads, drivers, traffic, climate and in accident occurrence [Boroujerdian, et al. 2015]. Traffic accidents as the random and multi-reason phenomena root in the lack of equilibrium between the system's components. Research showed that human, environmental and traffic factors play the most important roles in accident incidence in which drivers' behavior has an important part in traffic safety. A relevant aspect of traffic accident analysis is to distinguish the key factors affecting driver behavior and attitudes [Oña et al. 2014]. It has been argued that accident severity particularly depends on driving experience (license status, years that driver has been driving, accident involvement in the last few years, distance in mile/km driven), drivers' socio-economic characteristics (as gender, age, personal or family income, commuter status, educational level, current marital status), and driving behavior (traffic offence in the last few years, driver physical condition, use of alcohol and drugs, use of seat-belt, driving in excess of posted speed limit, failure to keep in proper lane, passing where prohibited by posted signs, using cell phone, etc) [Wang et al. 2002, Dissanayake, 2004; Yannis et al. 2005, Clarke et al. 2006, Lambert-Bélanger et al. 2012 and Tractinsky, Soffer Ram and Shinar, 2013].

However, still a large number of accidents are happened when drivers are in their normal condition and have enough experience. Further improvement in road physical environment and vehicles' condition has resulted in increasing the road safety. Some of the conducted research showed that the most important parameter affecting the crash occurrence is geometric parameters (environment) [Wang et al. 2015; Boroujerdian et al. 2014]. Therefore, there is a need to take more comprehensive research on the topic by developed and advanced methodologies so as to reach a conclusion on the effective parameters in accident occurrence, as well as their level of priority. This would result in improvement of traffic safety at highways, and help decision makers and engineers to concentrate on the most effective parameters to take them into further consideration.

The main point of the paper is to consider all three factors (Human, Environment and traffic) known important in accident occurrence by their interdependence relationships to reach a conclusion on their level of priority in accident incidence. In doing so, an extended form of multi-criteria decision making method entitled analytical network approach (ANP) was used. The ANP is a generalization of analytical hierarchy process (AHP), and can be used to treat more sophisticated decision problems. AHP is a special form of ANP. That is to say, the ANP method consists of the go and feedback [Saaty, 1980; Saaty, 1990]. In comparison with other decision making models, ANP is able to consider the entire criteria by a similar unit, and like most of the Multi Attribute Decision-making (MADM) techniques, it is able to analyze both quantitative and qualitative situations. Although, the ANP has the advantages of AHP, it is not considered as the framework of AHP. The ANP is more powerful than AHP due to its being able to considered network relationships in the modeling process

[Saaty, 2001]. The ANP is a mathematical theory that makes it possible for one to deal systematically with all kinds of dependence and feedback. The method takes into account the pair wise comparison of the effective parameters by getting experts' opinion on the relationship between parameters to weight them for its calculation. The personal opinion has always been coupled with errors and personal feelings which yield to inaccurate outcomes. Here in this paper where statistics was available, instead of experts' opinion, statistical analysis and frequency of effective parameters in accident occurrence, were utilized to weight the parameters. Also, ANP paves the way to apply both qualitative and qualitative parameters in accident occurrence in one structure, leads to considering interaction of different parameters by making a network [Saaty, 2001].

2. Literature Review

Najib et al. (2012), proposed weights and ranks of five selected reasons associated with road accidents using decision making approach entitled AHP. The judgment data was collected from three experts in road accident analysis. The results showed that "driving faster than the posted speed limit" was ranked as the first cause with the weight of 0.3242 and obstructions (i.e., animals or weather)" were ranked as the last cause among the five road accident reasons. A comprehensive research conducted by Treat et al. (1979), revealed that almost 93% of road accidents were caused by human factors including lack of concentration, improper clearance distance, excessive speed and carelessness. Moreover, both environmental and vehicles' condition were related to road accident problems each with of 34% and 13%, respectively.
Abdullah and Nurnadiah (2010) used correlation analysis, and Fuzzy TOPSIS to rank the effectual factors of road accidents. Correlation analysis used statistical data to measure the variables, and Fuzzy TOPSIS used the types of data collected from the experts as part of multi-criteria decision making. Hence, the decision making by Fuzzy approach could be used to decide the main factors of the road accident issue. Also, risk was modeled by logit concept to estimate willingness-to-pay (WTP) for reduction in road accident [Cardamone, Eboli and Mazzulla, 2014]. Similar Stated Preference (SP) experiments were carried out as well [Rizzi, and de Dios Ortúzar 2003 and Iragüen and de Dios Ortúzar 2004]. Furthermore, a logistic regression was proposed to identify driver behavioral parameters influencing user's choices in order to reduce the accident risk followed by usage of an SP experiment to develop the explanatory model [Yannis et al. 2005]. As for considering the road safety, Jamson et al. (2008) developed a driving safety index using a Delphy SP experiment in which drivers' behavior (either safe or unsafe) were distinguished. In order to identified high risk segments and recognize homogenous segments MCDM methods has been used widely [Horrace and Keane, 2004; Coll et al. 2013, Boroujerdian et al. 2014; and Sadeghi et al. 2012].

3. Methodology

The objective of this study is to prioritize the effective factors in sub-urban accidents using their interactions by network analysis process. Furthermore, the paper aims to propose weights and ranks of selected reasons associated with road accidents using decision-making approach named ANP. Sub-urban accidents data in the length of 945 km of Hamedan province road network in three-year period from 2011 to 2013 was considered as a case study. The selected case study is the arterial highways to Hamedan province wiht industrial and agricultural land use. Also, the case study is the tow lane separated highways and the shoulder length is 1.85 meter along the path.
Screening the data bank, it reduced to 1143 accidents. Considering inspection forms, the available data consists of the geometric characteristics of locations where accidents occurred as well as human and environmental parameters. The quantitative data was categorized in a number of groups based on their meaneangful differences. Then the data bank (both quantative and qualative data) was comapered based on their frequency. The proposed work is to investigate the relationship among road accident severity,

driver characteristics, driving behavior, road surface conditions, and rank of the factors related to road accident problems. The aforementioned process is described in figure 1. Having the experts' opinion and their combination in the model, the final result would be announced after the sensitivity analysis and presentation of incompatibility numbers. With regard to the modeling of the relations, the super matrix is presented as follows.

$$\boldsymbol{W_n} = \begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{W_{21}} & \boldsymbol{W_{22}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{W_{32}} & \boldsymbol{W_{33}} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{W_{43}} & \boldsymbol{W_{44}} \end{pmatrix}$$

Where, w_{21} is the relationship between the goal and criteria, w_{22} is the interrelation between criteria, w_{32} relationship between sub-criteria with respect to criteria, w_{33} is interrelation between sub-criteria, w_{43} is the relationship between the sub-criteria with respect to alternatives, w_{44} is interrelation between alternatives. Therefore, in this study w_{22}=0, w_{32}=0, w_{33}=0.

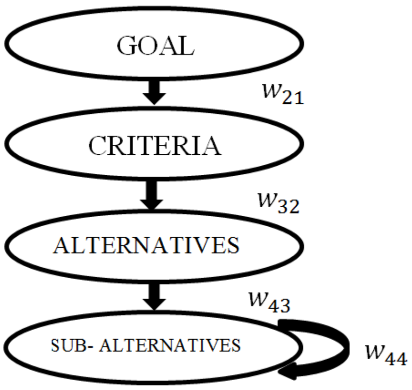

Figure 1. Network form for this study

3.1 Analytic Network Process (ANP)

ANP is an extension of AHP. AHP models are a decision-making framework where it is assumed that there is a unidirectional hierarchical relationship among decision levels. Although, AHP is helpful in resolving complex MCDM problems, it is less successful when applied to problems involving multi-criteria or hierarchy dependence relationships [Saaty, 1980]. ANP includes two parts. The first one consists of a control hierarchy (or network) of criteria and sub-criteria that control the feedback networks. The second part includes the networks of influence containing the factors of the problem and the logical groupings of these factors into clusters. Each control criterion (or sub-criterion) has a feedback network. A super matrix of limiting influence that gives the priorities of the factors in the network is computed for each network. In this study ANP served as the decision analysis tool and Super Decisions was used for implementation of ANP. As it was mentioned earlier, AHP assumes the system elements are uncorrelated and are unidirectional influenced by a hierarchical relationship. ANP or systems-with-feedback approach may be used to assess a dynamic multidirectional relationship among decision attributes due to its complex relationships and lack of exemplary model applications, ANP's application has been very limited special in the traffic safety approach [Saaty, 2001].

Among all the multi-criteria decision making technique, ANP is the only method being able to include all the relevant criteria to arrive at the appropriate decision [saaty, 1996]. As a consequence, Saaty proposed a new theory, which maintains the spirit of AHP and continued developing the ANP method, raising the analytical ability of ANP. In many cases, there is interdependence among criteria and alternatives. ANP provides users with an effective tool, in which interactions among the elements of a system form a network structure and can be calculated by a super matrix approach [Saaty, 1996].

The ANP includes four steps:

Step 1: Modeling and problem structure

The problem must be clearly stated, and decomposed into a rational system such as a network. The framework can be determined based on decision maker opinion via brainstorming or other appropriate methods [Saaty 1996, Meade and sparkis 1998 (a,b)]. In this study, model structure is presented in figure 1.

Step 2: Pair-wise comparison matrices and priority vectors

The ANP decision elements for each component are compared pair-wise with respect to their control criteria. The components themselves are also compared pair-wise with regard to their contribution to the goal. Decision makers are asked to respond to a series of pair-wise comparison where two elements or components at a time will be compared in terms of how they contribute to their particular upper level criterion. A reciprocal value is assigned to the inverse comparison (that is, a_{ij} =1 / a_{ji}). Where, (a_{ij}) denotes the importance of the (i_{th}) element compared to the (j_{th}) element. Similar to AHP, pair-wise comparison in ANP is made in the matrix framework, and a local priority vector can be obtained for estimating the relative importance associated with the elements (or components) being compared by solving the equation (1):

$$A.w = \gamma_{max}.w \qquad (1)$$

Where, (A) denotes the pair-wise comparison matrix, (w) represents the Eigen vector, and (λ_{max}) is the largest Eigen value of (A). Provided (A) denotes a consistency matrix, then Eigen vector (X) can be determined using,

$$(A - \gamma_{max}I)X = 0 \qquad (2)$$

Saaty (1980) proposed adopting the consistency index (CI) and consistency ratio (CR) to verify the consistency of the comparison matrix. The CI and RI are defined by equations (3) and (4), respectively.

$$CI = (\lambda_{max} - n)/(n-1) \qquad (3)$$

$$CR = CI / RI \qquad (4)$$

Where, (RI) denotes the network analysis process. If CR≤ 0.1, then the estimation is accepted; otherwise, a new comparison matrix would be repeated until CR≤ 0.1.

Step 3: Super matrix formation

Considering the components of a decision system as(C_K; k =1… n), where each component (k) has (m_k) elements denoted by (e_{k1}, e_{k2}… $e_k m_k$). The local priority vectors derived from step 2 are grouped and located in appropriate positions in a super matrix. The categorization is based on the influence flow from one component to another, or from a component to itself, as in the loop [Saaty, 2001]. For example, as shown in figure 1, if the criteria are interrelated, the (2, 2) entry of (W_n) given by W_{22} indicates the interdependency, and the super matrix will have a value [Saaty, 1996]. Notably, zero in the super matrix could be replaced by a matrix if there is an interrelationship among the elements in a component or between two components. Firstly, the super matrix must be transformed to be stochastic; that is to say, sum of each matrix columns must be the unit value. Saaty recommended determining the relative importance of the clusters in the super matrix with the column cluster (block) as the controlling component [Meade and sparkis 1998 (a) and Saaty, 2001]. It means that, the row components with nonzero entries for their blocks in that column block are compared according to their impact on the component of that column block [Saaty, 1996]. An Eigen vector of each column block can be obtained through a pair-wise comparison matrix of the row components considering column component.

For each column block, the first entry of the respective Eigen vector is multiplied by all the elements in the first block of that column, the second entry is multiplied by all the elements in the second block of that column, and so on. The block in each column of the super matrix is thus weighed, and the result is termed as the weighed super matrix, which is stochastic [Hsu and Kuo 2011].

To achieve convergence of the important weights, the weighed super matrix is raised to the power of (2k + 1); where k is an arbitrary large number, and this new matrix is called the limit super matrix [Saaty, 1996]. The limit super matrix has the same form as the weighted super matrix, but all the columns are identical. Normalization of each of the blocks related this super matrix results in the final prioritization of the entire elements in the matrix [Saaty, 2001].

$$W = \lim_{X\to\infty} (W_{weighted})^{2k+1} \qquad (5)$$

Step 4: The best alternatives Selection

If the super matrix formed in Step 3 covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized super matrix. On the other hand, if a super matrix was only comprised of interrelated components; additional calculations must be performed to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be selected. In this study factors affecting the suburban accident occurrence were selected by overall priority [Saaty, 2001].

4. Modeling and Results

Step 1: Construct model and identifying relationships

Based on three major criteria, modeling the factors affecting road accidents includes criteria and sub-criteria that have been used in previous studies (refer to figure 2).

Table 2, represents the cluster and sub-cluster relationships between the main criteria, sub-criteria and alternatives, and Figure 3, demonstrates the results obtained from the Super Decision software which is the a sophisticated and user friendly software that implements ANP.

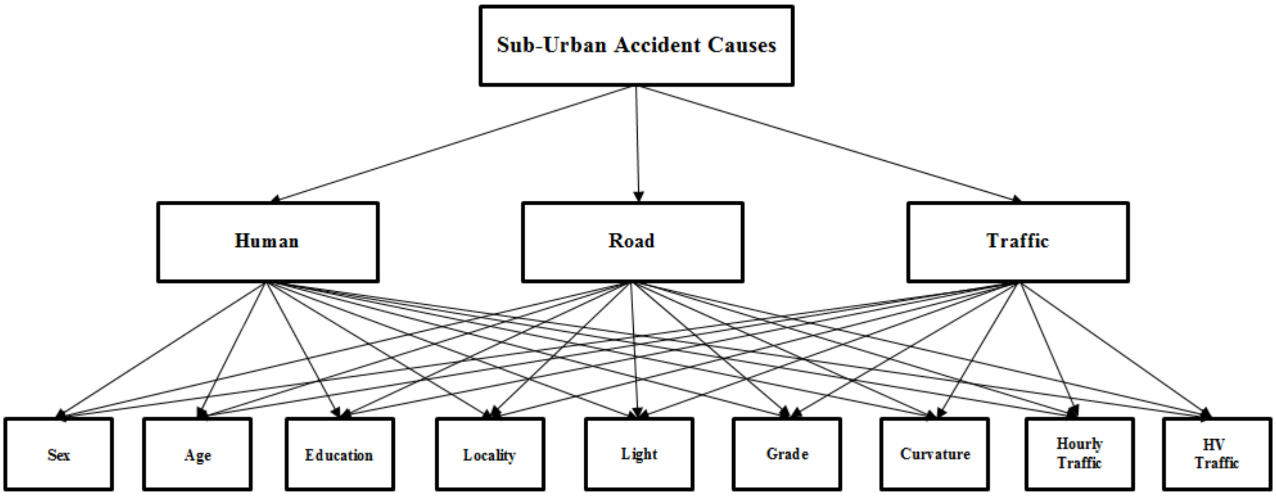

Figure 2. Hierarchy of model - from the goal until alternatives

Table 2. Relations between the components of decision

		Education	Age	Sex	Locality	Grade	Curvature	Light	Hourly Traffic	Hv-traffic
H	**Education**									
	Age									
	Sex	*								
	Locality					*				
R	**Grade**						*			
	Curvature								*	
	Light		*				*			
T	**Hourly Traffic**									
	Hv-traffic									

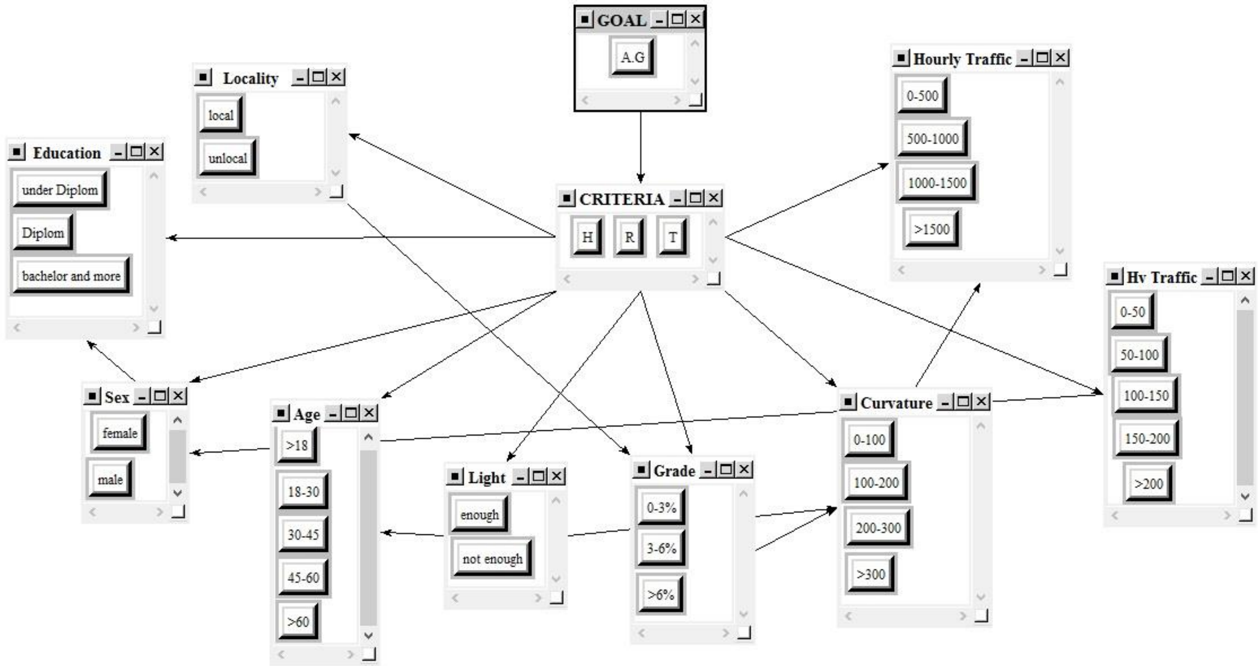

Figure 3. Schematic diagram of relations between alternatives in super decision

Step 2: Pair-wise comparisons criteria

In this section, Pair-wise comparison table were completed based on the opinion of the experts who had enough experience in the accident analysis. Then, the incompatibility (CR≤ 0.1) was taken into account. If there were any incompatibility with the results, the comparisons were revised and the opinions combined (refer to table 3).

Table3. Pair comparison of criteria with respect to goal

	human	road	traffic	priority
human	1.00	1.36	1.57	0.42
road	0.74	1.00	1.15	0.31
traffic	0.64	0.87	1.00	0.26

Step 3: Super matrix formation from clusters priority

Conform Super matrix (Equation 1) was achieved by pair-wise comparison according the modeling of relationships.

Step 4: Priority alternatives and sub-alternatives

Prioritization of each cluster was carried out by direct frequency entry. In this method CR=0 because there was no inconsistency in decision-making. The prioritization among criteria, sub-criteria and alternatives in the accidents is presented as follows:

Table 4. Education prioritization based on frequency

education	frequency	priority
<DIPLOMA	445.00	0.38
DIPLOMA	574.00	0.51
BS and MORE	124.00	0.11

Table 5. Age prioritization based on frequency

age	frequency	priority
<18	1.00	0.01
18-30	340.00	0.29
30-45	541.00	0.47
45-60	205.00	0.17
>60	57.00	0.05

Table 6. Sex prioritization based on frequency

sex	frequency	priority
male	1055.00	0.92
female	88.00	0.07

Table 7. Locality prioritization based on frequency

locality	frequency	priority
local	486.00	0.42
Unlocal	654.00	0.57

Table 8. Grade levels prioritization based on frequency

grade	frequency	priority
0-3%	1050.00	0.91
3-6%	46.00	0.04
>6%	47.00	0.04

Table 9. Curvature levels prioritization based on frequency

curvature	frequency	priority
0-100	1073.00	0.93
100-200	39.00	0.03
200-300	22.00	0.02
>300	9.00	0.01

Table 10. Light conditions prioritization based on frequency

light	frequency	priority
enough	453.00	0.39
not enough	690.00	0.60

Table 11. Hourly traffic levels prioritization based on frequency

hourly traffic	frequency	priority
0-500	863.00	0.75
500-1000	258.00	0.22
1000-1500	20.00	0.02
>1500	2.00	0.00

Table 12. Heavy Vehicle (hv) hourly traffic levels prioritization based on frequency

hv hourly traffic	frequency	priority
0-50	287.00	0.43
50-100	226.00	0.34
100-150	111.00	0.16
150-200	26.00	0.03
>200	4.00	0.01

Table 13. Light condition prioritization based on frequency

not enough light	frequency	priority
<18	0.00	0.00
18-30	151.00	0.33
30-45	202.00	0.44
45-60	82.00	0.18
>60	18.00	0.03

Table 14. hourly traffic levels prioritization with respect curvatures level more than 300 based on frequency

hourly traffic	frequency	priority
0-500	9.00	0.75
500-1000	1.00	0.08
1000-1500	1.00	0.08
>1500	1.00	0.08

Table 15. Sex prioritization with respect hourly traffic level more than 200 based on frequency

sex	frequency	priority
male	7.00	0.88
female	1.00	0.13

Table 16. Curvature levels prioritization with respect grades range (0-3%) based on frequency

curvature	frequency	priority
0-100	1045.00	0.99
100-200	5.00	0.01
200-300	1.00	0.00
>300	1.00	0.00

Table 17. Curvature levels prioritization with respect grades range (3-6%) based on frequency

curvature	frequency	priority
0-100	20.00	0.80
100-200	1.00	0.04
200-300	3.00	0.12
>300	1.00	0.04

Table 18. Curvature levels prioritization with respect grades range (more than 6%) based on frequency

curvature	frequency	priority
0-100	2.00	0.04
100-200	20.00	0.42
200-300	16.00	0.34
>300	9.00	0.19

Table 19. Curvature levels prioritization with respect not enough light

curvature	frequency	priority
0-100	418.00	0.92
100-200	21.00	0.05
200-300	11.00	0.02
>300	4.00	0.01

Table 20. Female education prioritization based on frequency

education	frequency	priority
<DIPLOMA	26.00	0.29
DIPLOMA	45.00	0.51
BS and MORE	17.00	0.19

Table 21. Male education prioritization based on frequency

education	frequency	priority
<DIPLOMA	419.00	0.39
DIPLOMA	526.00	0.50
BS and MORE	107.00	0.10

Table 22. Grade levels prioritization with respect local based on frequency

grade	frequency	priority
0-3%	433.00	0.89
3-6%	22.00	0.05
>6%	31.00	0.06

Table 23. Grade levels prioritization with respect unlocal based on frequency

grade	frequency	priority
0-3%	615.00	0.94
3-6%	24.00	0.03
>6%	15.00	0.02

5. Discussion

It was observed that even when the shape of the curve was flat and nearly horizontal the priorities of the entire alternatives in sensitivity diagram did not intersect. The proposed model calculated the impact of any node by internal and external relations. Also, in every section, the normal rate and its percentage were ranked in every cluster. The degree of influence of each factor placed in each level can be seen in Figure 4. Final prioritization of the model was obtained by each selected sub-alternative factors and their upper-level factors. A case in point, the priority of the sub-alternative titled un-local is measured by 0.67, 0.117 and 0.42 which are selected sub-alternative, selected alternative and criteria, respectively. The entire selected sub-alternatives in each level were compared with each other.

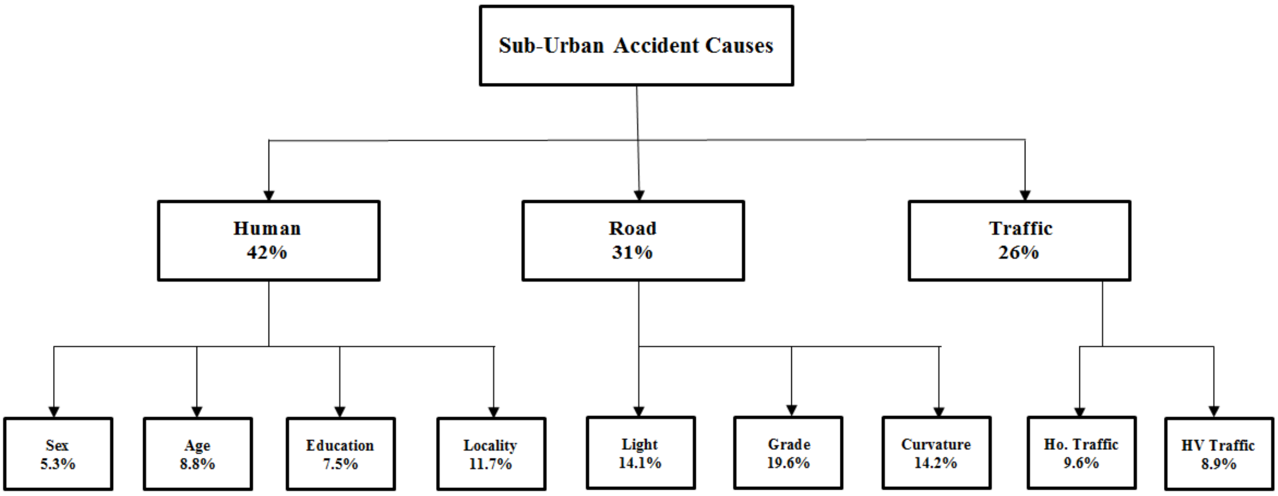

Figure 4. Network structure, accident's factor prioritization

Table 24. Prioritization of alternatives and sub-alternatives

alternatives	Priority	Sub-alternatives	Priority
age	0.088	<18	0.00106
		18-30	0.015
		30-45	0.023
		45-60	0.009
		>60	0.002
locality	0.117	local	0.024
		unlocal	0.033
sex	0.053	female	0.002
		male	0.024
education	0.075	b.s and more	0.006
		Diplom	0.032
		under Diplom	0.024
light	0.141	enough	0.014
		not enough	0.021
grade	0.196	0-3%	0.098
		3-6%	0.0042
		>6%	0.0043
curvature	0.142	0-100	0.148
		100-200	0.004
		200-300	0.003
		>300	0.001
hourly traffic	0.096	0-500	0.042
		500-1000	0.012
		1000-1500	0.001

		>1500	0.0002
hv traffic	0.089	0-50	0.022
		50-100	0.017
		100-150	0.008
		150-200	0.002
		>200	0.0003

6. Conclusions

According to the methodology used in this paper and usage of ANP, by the help of experts opinion and recorded accident data, prioritization of alternatives and sub-alternatives shown in table 24 is sorted from maximum to minimum, it can be seen, compared to sub-alternatives related to human factor, sub-alternatives related to the road and traffic criteria were more effective in the occurrence of accident which is the main outcome of this paper. It can be argued that, regarding road geometric design conditions, condition curvature (0-100) degree per kilometer and grade (0-3%) yields to higher risk of accidents.

The reason for the outcome can be attributed to the nature of ANP, and its ability to consider interaction of different parameters in accident incidence by making a network of parameters. Also, both quantities and qualities parameters were taken into account in ANP leading to its being more successful in solving multi criteria decision making process. In addition, usage of recorded accident data in the analysis resulted in more accurate outcomes. Different research has showed different results regarding the effective parameters in accident occurrence. It has been argued that humans play a key role in occurrence of accident because they are the one who makes the final decision in every situation. Identification of the main reason leading to traffic accident occurrence has always been a controversial topic since the traffic safety science and accident analysis have appeared in road and transportation engineering. Accidents cannot be attributed solely on one parameter and it is suggested to consider the entire relevant factors is in accident analysis to improve the safety standard of roads. Not only traffic parameters must be investigated in an efficient way, but also driver training and road geometric design must be scrutinized effectively. Considering effective actions based on the road and traffic factors with lower cost and higher speed; it would be possible for the managers to take the required measures into account to reduce accidents. Based on the results, it can be said that the geometry modification of the road and imposing traffic restrictions will reduce a number of accidents as well. Research must be continued considering vehicles characteristics in the modeling procedure. Also, human related characteristics such as usage of drug and emotional mood are important in crash occurrence and its severity which must be taken into account. Last but not least, consideration of the pavement condition in the modeling procedure and its level of priority in accident incidence can be taken into account in the future research.

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