ESTIMATION OF DRIVERS' BEHAVIOR CRITERIA AFFECTING ROAD SAFETY BY THE ANALYTIC HIERARCHY PROCESS APPLICATIONS

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Abstract: Driver behavior has been found one of the most influential factors on road safety. Driver behavior identification is key to solve road safety issues related to driver behavior. This study aims to identify and quantify the significant driver behavior factors affecting road safety by using Analytic Network Process applications. The driver behavior dataset is collected from a self-reported questionnaire survey from novice and experienced drivers. The ANP pairwise comparison results are utilized to rank the driver behavior factors based on normalized weights. The ANP results showed that "driving without alcohol use" was the most significant driver behavior criteria for both groups. For experienced drivers, the lowest rank observed driver behavior criteria is "maintain safe gap between vehicles". While for novice drivers the lowest rank observed driver behavior criteria is "use personal intelligent assistant". Furthermore, the Analytic network process (ANP) model found that most of driver behavior factors are interrelated based on driver groups responses. Finally, the Kendall's rank correlation is applied to estimate the concordant degree between evaluator groups. The results evaluated that there is a medium correlation between the driver groups but not a perfect agreement. The study results can help traffic safety authorities to focus on significant driver behavior criteria to solve road issues.

1. Introduction

Human factors have been estimated to be a sole or leading causal factor in approximately 90% of road traffic accidents (NHTSA, 2008; Evans, 2004; Lewin, 1982; Rumar, 1985). According to Hungarian Central Statistical office data there were 625 road fatalities in 2017, a 2.9% increase when compared to 2016 (KSH, 2017). The situation analysis of the Road Safety Action Program observes that most of the accidents are caused by human factors, therefore influencing them becomes the most important target of road safety actions (OECD/ITF, 2016). The basic driver behavior factors which directly influence on road safety were such as driving behavior, driving experience and driver's perception

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of traffic risks (De Oña *et al*., 2014). Mostly drivers involve in behaviors that cause safety issues to both themselves and to other road users also. Many of these driver behavior factors are dynamic, conscious rule violations, while others are the types of errors due to less driving experience, momentary mistakes, failure to perform function or inattention, the latter often related to age (Stanton and Salmon, 2009; Wierwille *et al*., 2002).

The Driver Behavior Questionnaire (DBQ) is one of the most widely used instruments for measuring driving style. To assess deviant driving behavior, the Driver Behavior Questionnaire (DBQ) was first developed as a tool in the related studies 1990s (Parker *et al*., 1995; Reason *et al*., 1990). The findings of the previous studies have shown that self-reported driving behaviors are associated with both active and passive traffic accidents (Bener *et al*., 2007; Bener and Crundall, 2008).

There are several studies which evaluated driver behavior criteria affecting road safety. However, some of these studies applied multi-criteria decision making (MCDM) methods for road safety analysis (Farooq et al., 2019; Chen *et al*., 2015; Kanuganti *et al*., 2017; Fancello *et al*., 2018; Haghighat, 2011). The ANP approach was proposed by Saaty as a generalization approach to dependence and feedback of the well-known Analytic Hierarchy Process (AHP). ANP provides a deeper insight into complex decisions based on PCs than simple statistical survey (Saaty, 1996; Saaty, 2005). The ANP approach can measure all possible interrelations among observed factors by utilizing the pairwise comparison (PC) survey based on Saaty scale (Duleba and Moslem, 2019). While the Kendall's rank correlation is a non-

parametric statistic test used in previous studies to measure the concordance degree between rater groups (Ahmad *et al*., 2015; Duleba and Moslem, 2018; Couso *et al*., 2018).

The study was undertaken to investigate the most significant driver behavior factors affecting road safety by using Analytic Network Process (ANP) Applications. The study highlighted the significant driver behavior criteria for two evaluator groups and measured the interrelations between the observed criteria. Furthermore, Kendall's coefficient of concordance is used to estimate the concordance degree among evaluator groups. The study suggests that the most significant driver behavior factors should be focused to solve road safety issues related to driver behavior.

2. Methodology

2.1. Sample Characteristics

The study utilized the driver behavior questionnaire (DBQ) as a tool to identify and quantify risky driver behavior factors affecting road safety in Budapest city. DBQ can be a useful tool for predicting drivers' involvement in traffic accidents based on their self-reported driving behavior. The results were used to verify the correlation between driver behavior and involvement in traffic accidents (Af Wåhlberg *et al*., 2015).

The Driver Behavior Questionnaire (DBQ) is designed on Saaty's scale which includes thirteen driver behaviour items affecting road safety for the convenience of pairwise comparisons (PCs). The questionnaire survey involved two groups of transportation engineering experts having the driving experience listed here ((Group

A: Experienced drivers who have more than twenty years driving experience) + (Group B: Novice drivers who have less than two years driving experience)). These drivers have sound knowledge about transport safety due to their relevant profession (Department of Transport Technology and Economics). For DBQ data collection, the participants were approached and interviewed to fill the questionnaire on perceived road safety issues in Budapest University of Technology and Economics. The evaluator number of the questionnaire survey is not evidently statistically representative. However, the ANP and the AHP methods provide a deeper insight based on the PCs than the simple statistical surveys (Duleba and Moslem, 2019). Solomon (2006) highlighted in his phenomenon "Wisdom of crowds" that 20 evaluators can provide an extreme opinion. Some important characteristics of participants related to age, gender and driving experience are mentioned below in Table 1.

Table 1

Sample Characteristics

Variables	Group A	Group B
N	40	40
Age Mean SD	43.274 4.672	21.635 2.037
Gender (1=male,0=female) Mean SD	0.873 0.253	0.815 0.317
Driving Experience Mean SD	21.326 3.714	1.852 1.341

2.2. Driver Behavior Criteria Affecting Road Safety

Driver behavior has been found complex and uncertain to study road safety issues. Driving behavior identification was considered as the most important part of traffic studies which provides useful information generally in three main fields such as road safety analysis, microscopic traffic simulation and intelligent transportation systems (ITS) (Bifulco et al., 2014). Thirteen driver behavior factors which directly influence on road safety are considered for the study. These factors are important for safe movements of drivers themselves and for other road users also as discussed in previous studies (De Oña *et al.*, 2014; Farooq and Juhasz, 2018; ACEM, 2004; Pradhan *et al.*, 2014; Bener *et al.*, 2007; Watson, 2004). These factors are symbolized from F1 to F13 for the convenience of analysis. The driver behavior factors along with symbols were listed here. F1: Driver attention, F2: Driver visual perception, F3: Obeying speed limits, F4: Use personal intelligent assistant, F5: Respect yielding rules, F6: Maintain safe gap between vehicles, F7: Avoid frequently changing lanes, F8: Comply traffic lights, F9: Applying brakes at hazardous situations, F10: Deterrence of punish for traffic violations, F11: Traffic scan accurately, F12: Obeying overtaking rules, F13: Driving without alcohol use.

2.3. Analytic Network Process (ANP)

ANP is a dynamic process that reflects the real situation of the complex problems in which factors act in a non-hierarchical way. The analytic network process (ANP) was developed by Saaty which can examine the complex interrelationships among factors and decision levels (Saaty, 1996; Saaty, 2005; Farooq and Sarbast, 2019).

In this study, the ANP approach is utilized to identify and quantify the most significant driver behavior factors affecting road safety. Super decision software is used to analyze the questionnaire data for evaluator groups such as novice drivers and experienced drivers. According to ANP approach, the first step of the analysis is to fill the pairwise comparison matrices (PCM) to set the factors level of the PCs. Saaty suggested the fundamental scale of 1-9 to compare between factors (Saaty, 1996). The fundamental ratio scale consists of numerical values which provide different sorts of information is shown in Table 2. For example, digit one represents equal importance of both factors and digit nine represents extreme importance of one factor over another.

Table 2
Judgment Scale of Relative Importance for Pairwise Comparison

Numerical values	Verbal scale	Explanation
1	Equal importance of both factors	Two factors contribute equally
3	Moderate importance of one factor over another	Experience and judgment slightly favor one factor over another
5	Strong importance of one factor over another	Experience and judgment strongly favor one factor over another
7	Very strong importance of one factor over another	One factor is very strongly dominant
9	Extreme importance of one factor over another	One factor is favored by at least an order of magnitude
2,4,6,8	Intermediate values	Used to compromise between two judgments

Source: (Saaty, 1996)

The consistency analysis of selected factors in super matrix was examined by applying Saaty's Consistency Index (CI). Consistency Ratio (CR) < 0.1 (Saaty, 2005) was determined as follow Eq. (1).

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

where CI is the consistency index, λ_{max} is the maximum eigenvalue and n is the number of rows in the matrix. CR can be determined by Eq. (2).

$$CR = \frac{CI}{RI} \qquad (2)$$

where RI is the random consistency index. If A is a consistency matrix in relation with vector W depicted as $A.W = \lambda_{max}.W$. Then eigenvector W can be calculated as $(A - \lambda_{max}).W = 0$, where λ_{max} is the maximum eigenvalue of the matrix A. λ_{max} is also known as principal eigenvalue of the matrix A. The threshold was also determined by Saaty, the PCM can be considered as acceptable from inconsistency point of view if CR < 0.1.

Pairwise evaluations have been aggregated in the case of multiple evaluators. For aggregating collected data, the geometric mean aggregation method was applied, because it is the most common group preference aggregation method in AHP and ANP approaches (Aczél and Saaty, 1983; Saaty, 1989).

If "h" evaluators exist in the procedure, then Eq. (3):

$$f(x_1, x_2, \ldots, x_h) = \sqrt[h]{\prod_{k=1}^{h} x_{a_{ijk}}} \qquad (3)$$

Where a_{ijk} denotes the aij element of the evaluator "k".

After generating the aggregated matrices, the driving weight vector scores was further determined in the procedure. For measuring the eigenvectors of the aggregate matrices, the following method was applied as Eq. (4):

$$w_{Ai} = \frac{w_j}{w} \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}} = \left(\frac{w_j}{w} \frac{1}{\sum_{k=1}^{n} w_{ik}} \right) w_{ij} \qquad (4)$$

where $j = 1, \ldots, m$ and $w_j > 0$ represents the related weight coordinate from the previous level; $w_{ij} > 0$ is the eigenvector computed from the matrix in the current level, w_{Ai} is the calculated weight score of current level's elements ($i = 1, \ldots, n$). The consistency ratio (CR) was acceptable to complete ANP analysis.

The main eigenvector of each PCM represented the synthesis of the numerical judgments established at each level of the network (Saaty, 1989).

2.4. Kendall's Concordance Test

Kendall's coefficient of concordance (W), was proposed by Kendall and Smith (1939). W is a normalization of the statistic of the Friedman test, which is considered as a non-parametric statistic technique and can be used for a set of criteria to highlight the agreement level among different raters (Gibbons and Kendall, 1990; McLeod, 2005; Abdi, 2007). To estimate the agreement degree or concordant degree between group A and group B, the Kendall's coefficient of concordance is measured using Eq. (5).

$$R_i = \sum_{j=1}^{m} r_{ij}, \qquad (5)$$

Where R_i is the aggregated ranking of the factor i, r_{ij} is the rank given to factor i by the evaluator group j, m is the number of rater groups rating the n factors.

$$R = \frac{m(n+1)}{2}, \qquad (6)$$

R (Eq. 6) is the mean of the Ri values.

$$S = \sum_{i=1}^{n} (R_i - R)^2, \qquad (7)$$

Where S is a sum of squares statistic (Eq. 7) deviations over the row sums of ranking R_i.

Following that, Kendall's "W" statistic can be obtained from the following formula Eq. (8):

$$W = \frac{12\,S}{m^2\,(n^3 - n)} \qquad (8)$$

After applying the formula, the result will be a number that determines the agreement degree among the different groups. The Kendall's agreement degree value occurs between zero and one (Duleba and Moslem, 2018; Couso *et al.*, 2018) as shown in Table 3.

Table 3

Kendall's Agreement Degree (W) Scale

Correlation Coefficient	Interpretation
1	Perfect agreement
0.9 - 1	very high agreement
0.7 - 0.9	High agreement
0.4 - 0.7	Medium agreement
0.2 - 0.4	Low agreement
0 - 0.2	very low agreement
0	No agreement

Source: (Kendall and Smith, 1939)

3. Results and Discussion

The study estimated the driver behavior criteria affecting road safety and measured the correlation between evaluator groups by using Analytic Network Process (ANP) applications. Firstly, ANP was utilized to quantify the significant driver behavior factors based on drivers' responses. Accordingly, pairwise comparison method was utilized to assign each criteria a quantitative weight. In the pairwise comparison method, the criteria were arranged in square matrix. Based on the measured parameter such as normalized weight, the driver behavior factors were ranked from one to thirteen for both evaluator groups as shown in Table 4. The ANP analysis results showed that "driving without alcohol use" was the most important factor based on driver's response data for both rater groups. Also, the results

can be justified according to Hungarian driving laws that there is zero tolerance policy towards drinking and driving (WHO, 2015). Furthermore, for experienced drivers the second most significant observed factor was "obeying overtaking rules". It was analyzed that dangerous overtaking accounted for 41% of all drivers who died in traffic in 2006 (Walker, 2007). While the lowest rank observed factor for experienced drivers was "maintain safe gap between vehicles". Moreover, for novice drivers the second most observed significant factor was "comply traffic lights". One of the possible causes for the high number of crashes and injuries is due to beating traffic lights (Subramaniam *et al.,* 2007). While the lowest rank observed factor for novice drivers was "use personal intelligent assistant". These preferences make decisions more flexible to solve the variety of road safety problems.

Table 4
Final Normalized Weights for Driver Behavior Factors Related to Road Safety

Factors	Group A		Group B	
	Normalized weight	Ranking	Normalized weight	Ranking
F1	0.059	8	0.047	9
F2	0.047	11	0.043	11
F3	0.041	12	0.053	8
F4	0.06	7	0.041	13
F5	0.066	6	0.042	12
F6	0.038	13	0.065	4
F7	0.048	10	0.08	3
F8	0.081	5	0.165	2
F9	0.05	9	0.06	6
F10	0.094	3	0.058	7
F11	0.083	4	0.063	5
F12	0.101	2	0.046	10
F13	0.232	1	0.237	1

Secondly, Analytic Network Process (ANP) was further utilized to describe the structure of the driver behavior model by measuring the interrelations between specified factors for evaluator groups as shown in Figures 1(a) and 1(b). These connections indicated the flow of influence between the factors based on driver responses on perceived road safety issues. The analysis results showed that most factors were interrelated for both groups and few factors were not interrelated. Figures 1(a) and 1(b) were observed slightly different from each other, where Figure 1(a) has four interrelations more than Figure 1(b) which are presented in dotted lines. In the applied survey, seventy-eight comparisons were observed between the factors. Results showed that sixty-three (78-15 = 63) factors are interrelated in case of group (A) and fifty-nine (78-19 = 59) factors are interrelated in case of group (B). The four higher in numbers observed interrelations between observed factors for experienced drivers are listed here; (i) driver visual perception and applying brakes at hazardous situation (ii) driver visual perception and driving without alcohol use (iii) obeying the speed limit and use personal intelligent assistant (iv) use personal intelligent assistant and deterrence of punish for traffic violation.
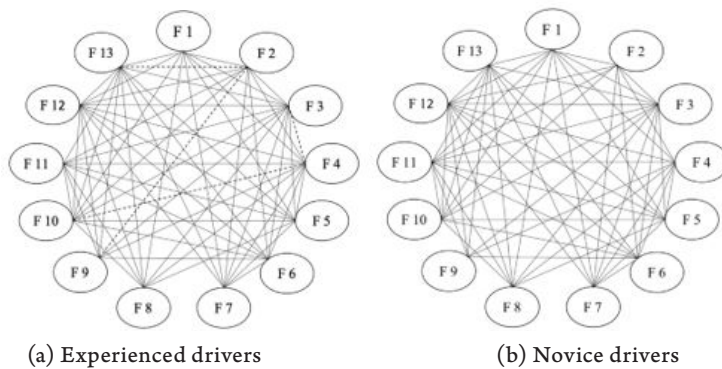

(a) Experienced drivers   (b) Novice drivers

Fig. 1.
The Interdependent Relationships Between Driver Behavior Criteria for Evaluator Groups

Finally, Kendall's rank correlation was applied to estimate the agreement degree or concordant degree between evaluator driver groups based on driver behavior criteria affecting road safety. Kendall's coefficient of concordance (W) was measured for assessing agreement among rater groups. Kendall's correlation value (W)

ranges from 0 (no agreement) to 1 (complete agreement). According to Kendall's coefficient of concordance (W), the value observed is 0.5632 as shown in Table 5. This value evaluated that there is a medium agreement between the rater groups but not a perfect aggreement.

Table 5
ANP Results for Estimation of Kendall's Coefficient of Concordance (W)

Factor	Rank of Group A	Rank of Group B	R_i	$(R_i - R)^2$
F1	8	9	17	9
F2	11	11	22	64
F3	12	8	20	36
F4	7	13	20	36
F5	6	12	18	16
F6	13	4	17	9
F7	10	3	13	1
F8	5	2	7	49
F9	9	6	15	1
F10	3	7	10	16
F11	4	5	9	25
F12	2	10	12	4
F13	1	1	2	144
n=13	m=2	S=410	R=14	W=0.5632

3. Conclusion

The study was designed to use Analytic Network Process (ANP) applications for evaluation and ranking of the driver behavior's factors affecting road safety. The self-reported questionnaire survey based on Saaty's scale was used as a tool for evaluator groups evaluation by considering thirteen important driving attitudes. The pairwise comparison method was used to assign each criteria a quantitative weight in such a way to satisfy the rank quantitatively. For this purpose, the normalized weight values were calculated for each factor. The ANP results showed that "driving without alcohol use" was the most significant driver behavior factor based on driver response data for

both groups. The results also evaluated that "maintain safe gap between vehicles" was the lowest observed factor for experienced drivers. While for novice drivers, the lowest rank observed factor was "use personal intelligent assistant". These results help to understand which driver behavior factors are more significant from experienced and novice drivers' point of view. Furthermore, ANP model results found that most of driver behaviour factors are interrelated to each other based on drivers' responses by evaluator groups in DBQ. However, experienced drivers selected four extra interrelations between specified factors as compared to novice drivers. ANP results were further used to measure Kendall's rank correlation for the estimation of the agreement degree or

concordant degree between evaluator groups. The results showed that there was a medium agreement between evaluator groups but not perfect agreement.

The overall study results can help to identify the significant driver's behavior criteria affecting road safety for experienced and novice drivers. ANP applications enable the decision-makers to better understand the complex and uncertain individual driver behavior in the decision-making and subsequently improves the reliability of the decision. However, a large amount of driver behavior data with advance multi-criteria decision-making technique can help to evaluate the driver behaviour criteria more comprehensively.

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