Budapest University of Technology and Economics
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Integration of Mathematical and Physical Simulation to Reduce Traffic Hazards by Studying Behavior of Driver

A dissertation submitted by:

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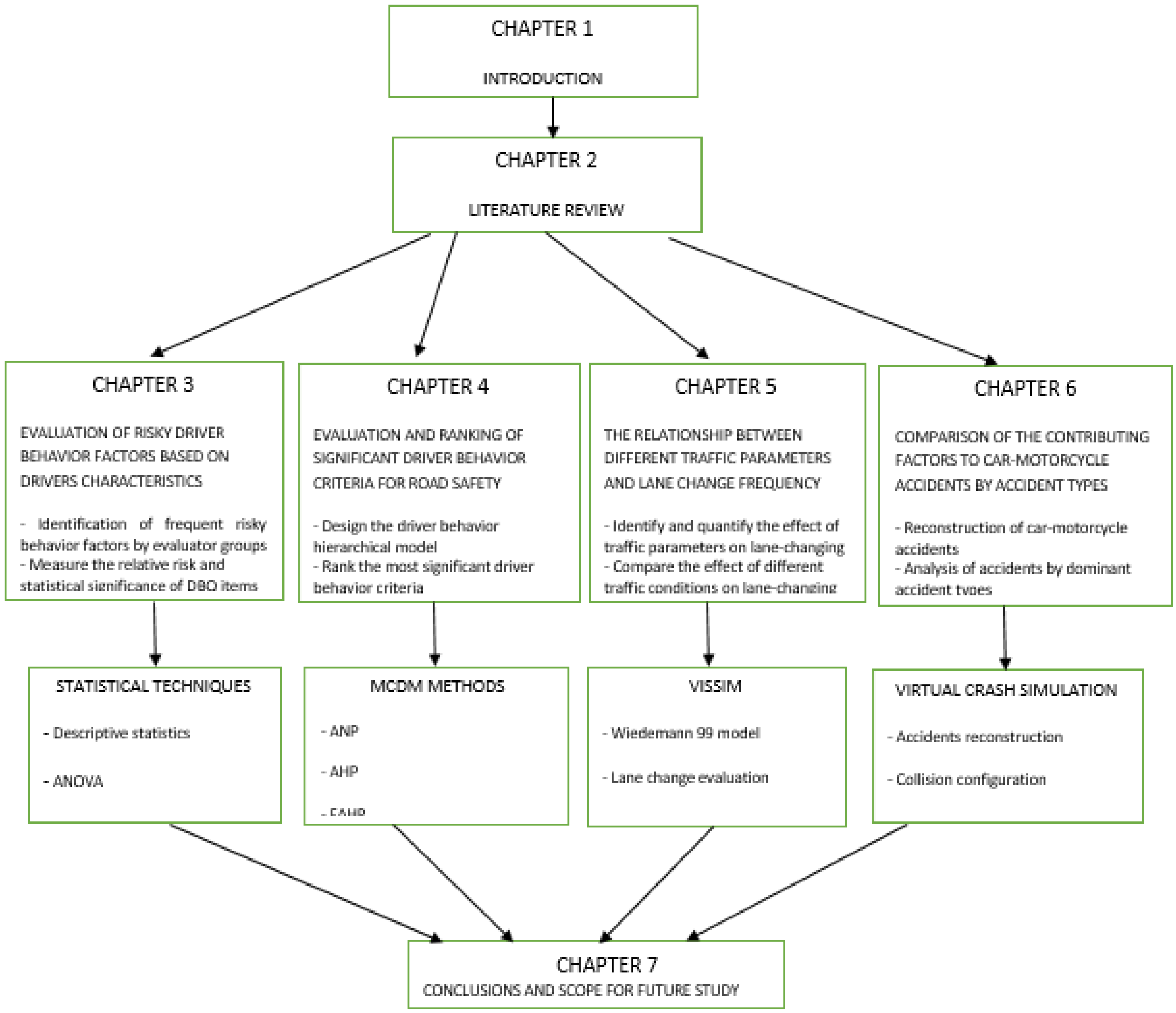
1 Introduction

The Global status report on road safety stated that the number of annual road traffic deaths has reached 1.35 million [1]. The World Health Organization (WHO) estimates that road accidents will be the fifth main cause of death in the year 2030 [2]. Also, the situation analysis of the Road Safety Action Program observes that most of the accidents are caused by human-related factors, thus handling them develops as the most dynamic target of road safety actions.

Driving behavior identification has been studied as a central constraint for traffic studies which give valuable information normally in three major fields such as road safety analysis, microscopic traffic simulation and intelligent transportation systems (ITS) [3]. The profiles and driving aims are unknown in the real-world driving situations; the driver may not behave similarly to the identification models characterize which results in the bias of the models. Consequently, to solve these problems and to make a more reliable model, model adaptation has been introduced and considered as one of the main solutions. Microscopic traffic simulation-based safety analysis provides the fast, safe and cost-effective means of evaluating traffic safety when compared with field implementation and testing [4, 6]. Furthermore, it is generally impractical often dangerous to research with real traffic systems, so traffic researchers must turn to traffic modeling. Traffic simulation models, a category of mathematical models are complex computer formulations usually referred to as traffic micro-simulator. Mathematical models depend on approximation and assumptions about how a traffic system operates. While physical models include traffic conditions, vehicle dynamics and road surface with the help of software to provide realistic scenes and traffic situations [7].

This dissertation aims to integrate the physical and mathematical simulation techniques to investigate the driver behavior and related significant traffic characteristics that influence traffic safety. The main considerations were to identify, categorize and compare the significant driver behavior characteristics for road safety by using statistical methods, Multi-Criteria Decision Making (MCDM) tools and advance simulation techniques. Firstly, the study evaluated and compared the risky driver behavior factors related to road safety based on important drivers' characteristics by utilizing the self-reported DBQ survey. After that, study evaluated and ranked the significant driver behavior criteria which influence the road safety by applying the Multi-Criteria Decision-Making (MCDM) methods for different evaluator groups. Furthermore, the study evaluated and compared the effect of different traffic parameters on lane-changing for road safety. Moreover, the study measured the contributing factors to car-motorcycle accidents by dominant accident types based on simulation model adaptation. The study recommended realistic solutions to different observed risky driver behavior factors related to road safety by comparing the results obtained from simulation studies.

Thesis overview model



Thesis Points

- Thesis 1: Evaluation of risky driver behavior factors related to road safety for different driving cultures.

- Thesis 2: Evaluation and ranking of significant driver behavior criteria for road safety by applying Multiple Criteria Decision Making (MCDM) methods.

- Thesis 3: Theoretical comparison of the effect of different traffic parameters on lane-changing for traffic safety.

- Thesis 4: Theoretical comparison of the contributing factors to car motorcycle accidents by accident types.

2 Research Methodology

2.1 Research methodology related to thesis 1

Statistical tools (Descriptive statistics and ANOVA analysis) were utilized to analyze the risky driver behavior factors related to road safety based on self-reported Driver Behavior Questionnaire (DBQ) data.

Table 1: Driver Behavior Questionnaire survey

How likely did you	**Options**	**Symbols**
Failing to comply with traffic light signal	Often Sometimes Never	Q1
Failing to wear seat belt	Often Sometimes Never	Q2
Disregard speed limit	Often Sometimes Never	Q3
Failing to use personal intelligent assistant	Often Sometimes Never	Q4
Yielding to pedestrian	Often Sometimes Never	Q5

Driving too closely	Often Sometimes Never	Q6
Frequently changing lanes	Often Sometimes Never	Q7
Risk due to encroachments	Often Sometimes Never	Q8
Failing to apply brakes	Often Sometimes Never	Q9
Problems of mixed traffic	Often Sometimes Never	Q10
Sounds horn in annoyance	Often Sometimes Never	Q11

Descriptive Statistics

- Relative risk
- Frequency
- Mean
- Standard deviation

ANOVA Analysis

- F value
- F-critical
- P value

2.2 Research methodology related to thesis 2

Application of MCDM methods to evaluate and rank the significant driver behavior criteria for road safety such as Analytic Network Process (ANP), Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP).

Judgment scale of relative importance for pairwise comparison (Saaty's scale)

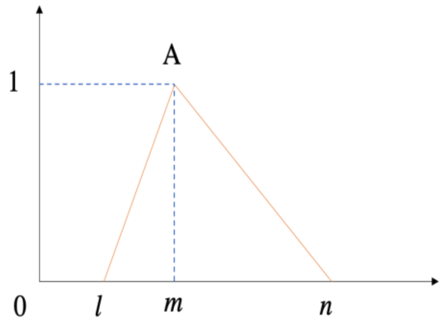
Numerical values	Verbal scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favor one element over another
5	Strong importance of one element over another	An element is strongly favored
7	Very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

Figure 1: Saaty scale [8]

MEMBERSHIP FUNCTION OF LINGUISTIC SCALE

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Weak advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

Figure 2: Fuzzy scale [9]



$$\mu\tilde{A}(x) = \begin{cases} \frac{x-1}{m-1}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & \text{otherwise} \end{cases}$$

Figure 3: Triangular fuzzy number [9]

2.3 Research methodology related to thesis 3

Application of VISSIM model to evaluate and compare the effect of different traffic parameters on lane-changing for driving logic ‘cautious’.

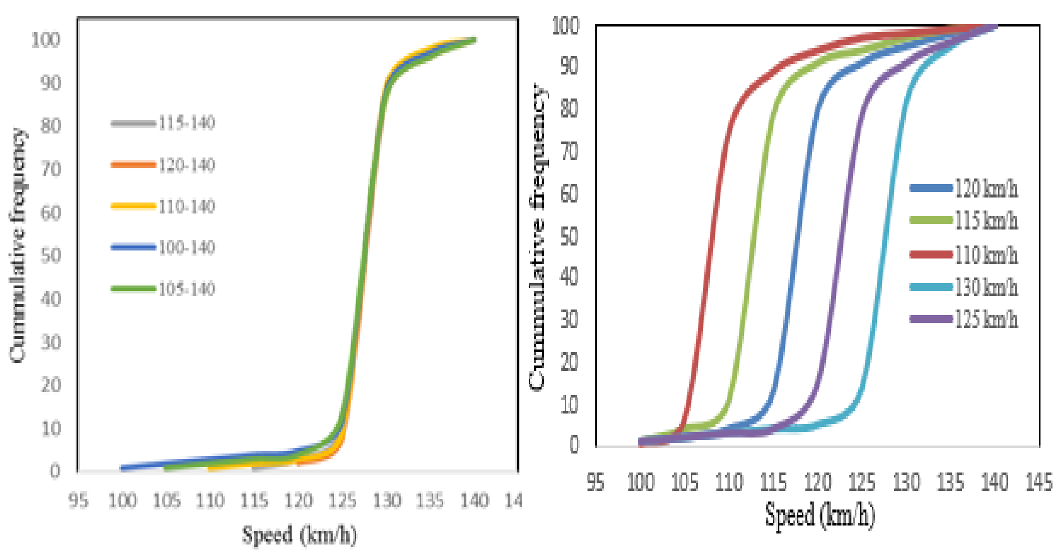


Figure 4: Speed range

Table 2: Wiedemann 99 model [10]

VISSIM code	Description	Default values	Calibrated values (cautious)
CC0	Standstill distance: Desired distance between lead and following vehicle at v = 0 mph	1.5 m	1.5 m
CC1	Headway Time: Desired time in seconds between lead and following vehicle	0.90 sec	1.5 sec
CC2	Following Variation: Additional distance over safety distance that a vehicle requires	4 m	0 m
CC3	Threshold for Entering ‘Following’ State: Time in seconds before a vehicle starts to decelerate to reach safety distance (negative)	-8 sec	-10 sec
CC4	Negative ‘Following’ Threshold: Specifies variation in speed between lead and following vehicle	-0.35	-0.1
CC5	Positive ‘Following Threshold’: Specifies variation in speed between lead and following vehicle	0.35	0.1
CC6	Speed Dependency of Oscillation: Influence of distance on speed oscillation	11.44	0
CC7	Oscillation Acceleration: Acceleration during the oscillation process	0.25 m/s^2	0.1 m/s^2
CC8	Standstill Acceleration: Desired acceleration starting from standstill	3.5 m/s^2	3.5 m/s^2
CC9	Acceleration at 80 mph: Desired acceleration at 80 mph	1.5 m/s^2	1.5 m/s^2

Table 3: Lane change parameters [10]

Parameters	Default values		Calibrated values (cautious)	
	own	Trailing vehicle	own	Trailing vehicle
Maximum deceleration	-4	-3	-3.5	-2.5
-1 m/s^2 per distance	100	100	80	80
Accepted deceleration	-1	-1	-1	-1

2.4 Research methodology related to thesis 4

Reconstruction of car-motorcycle accidents using Virtual Crash software to investigate the contributing factors based on police reported crash data and simulation models.

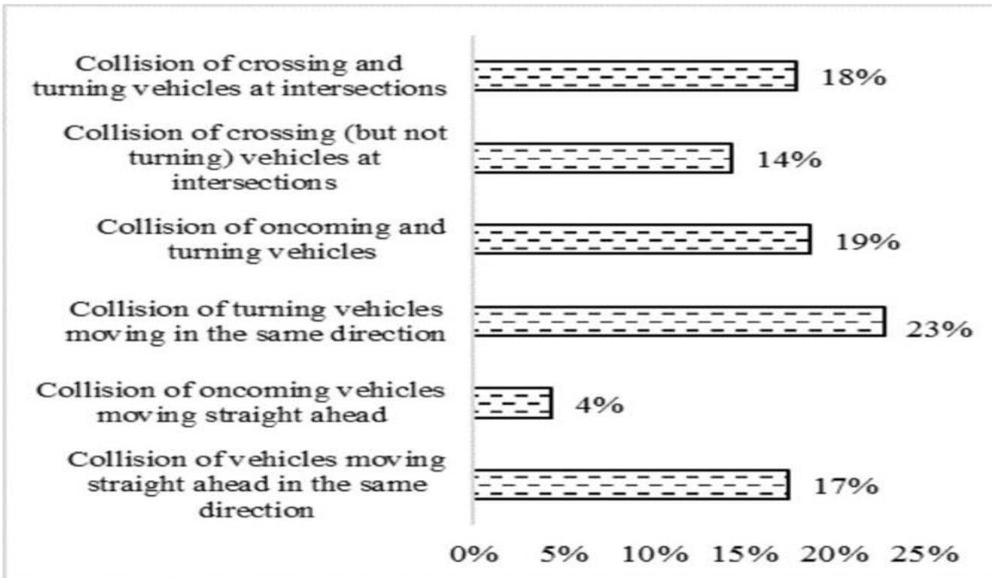


Figure 5: Dominant accident types

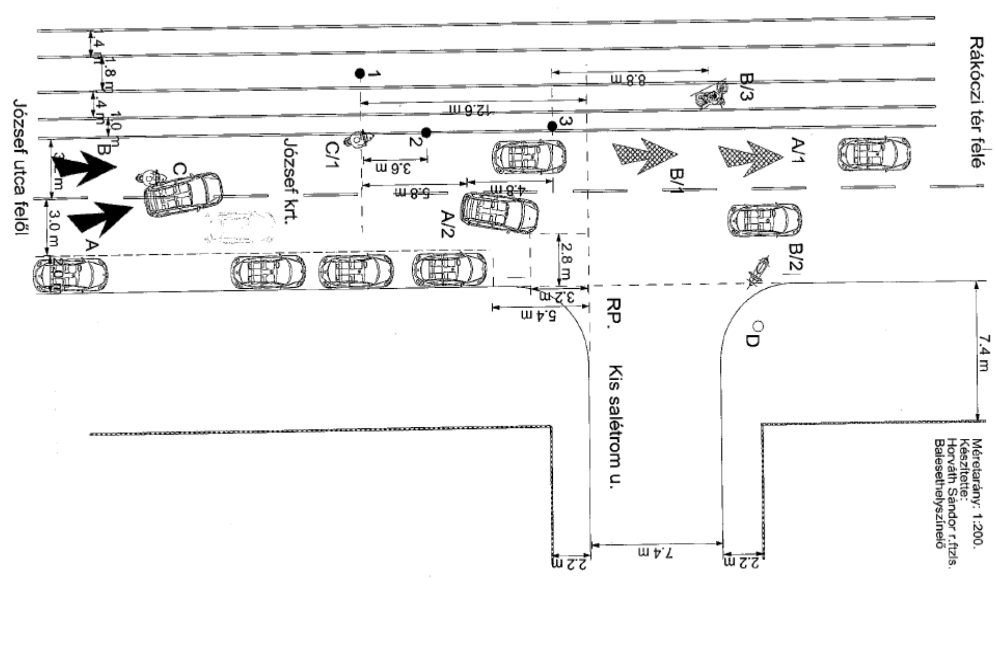


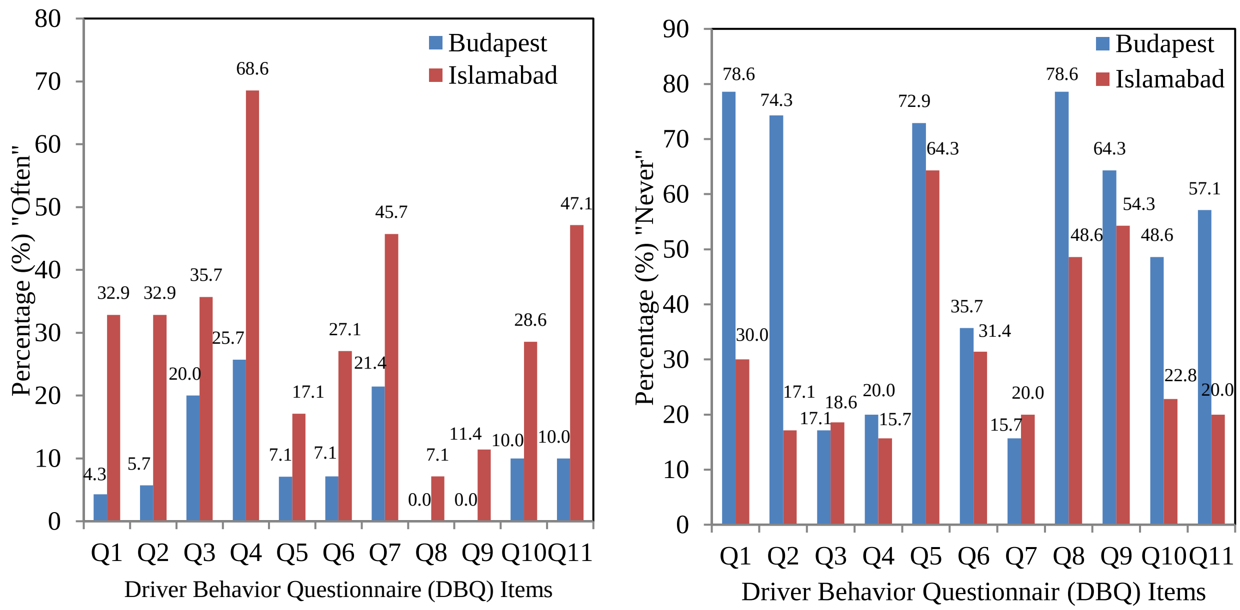
Figure 6: Simulation model

3 New scientific results

3.1 Thesis 1

I evaluated and compared the risky driver behavior factors related to road safety based on important drivers' characteristics by utilizing the self-reported DBQ survey for Budapest and Islamabad. I computed the relative risk which shows the likelihood risk of one driver group for observed driver behavior factors as compared to the other specified group in the sample. I applied the well-designed ANOVA analysis to measure the statistical significance of DBQ items for different driving cultures by considering different drivers characteristics.

The comparison charts were developed to show the differences in drivers' responses on DBQ between observed groups. Firstly, the comparison chart was developed to compare the percentage of drivers who responded the option 'often' on DBQ between two groups (Budapest and Islamabad) as shown in Figure 7(a). It is noticed that the percentage values of option "often" are high for Islamabad drivers as compared to Budapest drivers. Secondly, the comparison chart was developed to show the percentage of drivers who responded the option 'never' on DBQ between two groups (Budapest and Islamabad) as shown in Figure 7(b). It is noticed that the percentage values for the option "never" are high for Budapest drivers as compared to Islamabad drivers. The results showed that Budapest drivers are more compliant to traffic safety rules than Islamabad drivers.



(a) Often (b) Never

Figure 7: Comparison for driver's response "Often" and "Never" between two regions

Relative Risk (RR) was measured to show that how much times one drivers' group is more likely to involve in risky driver behavior factors as compared to the other specified group in the sample. The procedure here involves the selection of two contrary responses and number of responses on DBQ from designated driver groups for relative risk evaluation purposes. The RR analysis results showed the designated drivers' groups with relative risk values greater than 1 for DBQ items. Accordingly, the results found that Islamabad drivers groups have the greater number of DBQ items with RR value greater than 1 as shown in Figure 8.

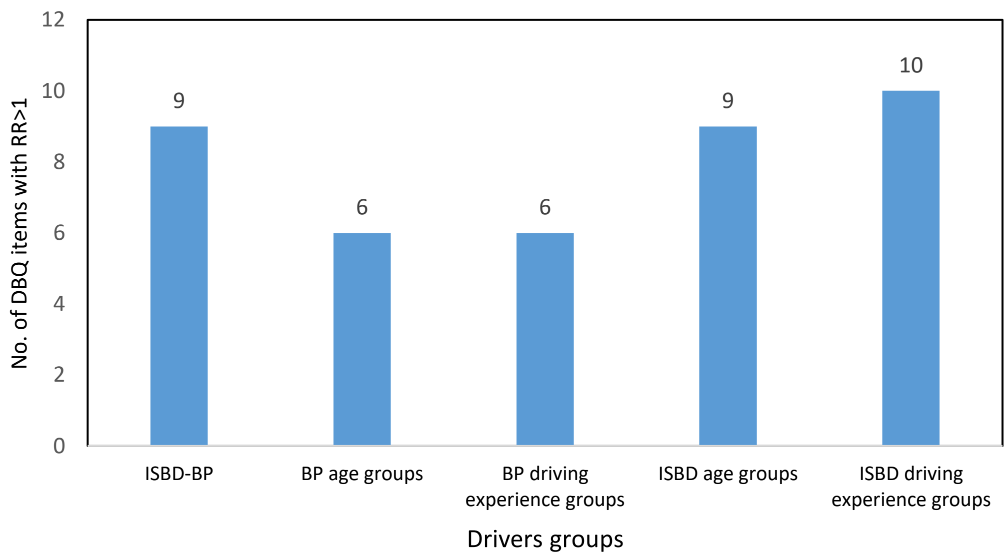


Figure 8: Comparisons of driver's groups with RR value greater than 1

There are two parameters to check the statistically significance of items in sample which are; the F-values should be greater than F-critical, and p-value should be less than significance level (α-value). The significance level was set 0.05. The ANOVA results showed that most terms in the sample were statistically significant due to F-values greater than F-critical and p-value less than 0.05. Only three items were not statistically significant such as 'disregard speed limit' (Q3), 'failing to yield pedestrian' (Q5) and 'frequently changing lanes' (Q7) with F value less than F critical and p-value greater than 0.05 as shown in Table 5.

Table 5: ANOVA analysis results

Questionnaire Items	**DF**	**MS**	**F**	**P-value**	**F-critical**
Failing to comply with traffic light signal	1	20.82857	45.39801	0.000	3.909729
Failing to wear seat belt	1	24.86429	60.88441	0.000	3.909729
Disregard speed limit	1	0.714286	1.592798	0.209056	3.909729
Failing to use personal intelligent assistant	1	7.778571	15.07342	0.000	3.909729
Failing to yield pedestrian	1	1.207143	2.478427	0.117707	3.909729
Driving too closely	1	2.064286	4.372068	0.038366	3.909729

Frequently changing lanes	1	1.4	2.877447	0.092083	3.909729
Risk due to encroachments	1	4.828571	17.18644	0.000	3.909729
Failing to apply brakes	1	1.607143	4.506531	0.035551	3.909729
Problems of mixed traffic	1	6.864286	14.27535	0.000	3.909729
Sounds horn in annoyance	1	19.31429	36.36959	0.000	3.909729

3.2 Thesis 2

I evaluated and ranked the significant driver behavior criteria which influence the road safety by applying the Multi-Criteria Decision-Making (MCDM) methods for different evaluator groups. I developed the driver behavior hierarchical model containing twenty driver behavior criteria in a three-level structure. The study utilized the Saaty scale and fuzzy scale for efficient assessment of complex and uncertain driver behavior based on perceived traffic issues.

For AHP application, the study designed a driver behavior hierarchical model in a three-level structure as shown in Figure 9. The first level included three main driver behavior criteria such as "lapses", "violations" and "errors". The second level considered the distribution of these main driver behavior criteria into related sub-criteria. Subsequently, the third level considered the further distribution of two sub-criteria such as ordinary and aggressive violations into related sub-criteria.

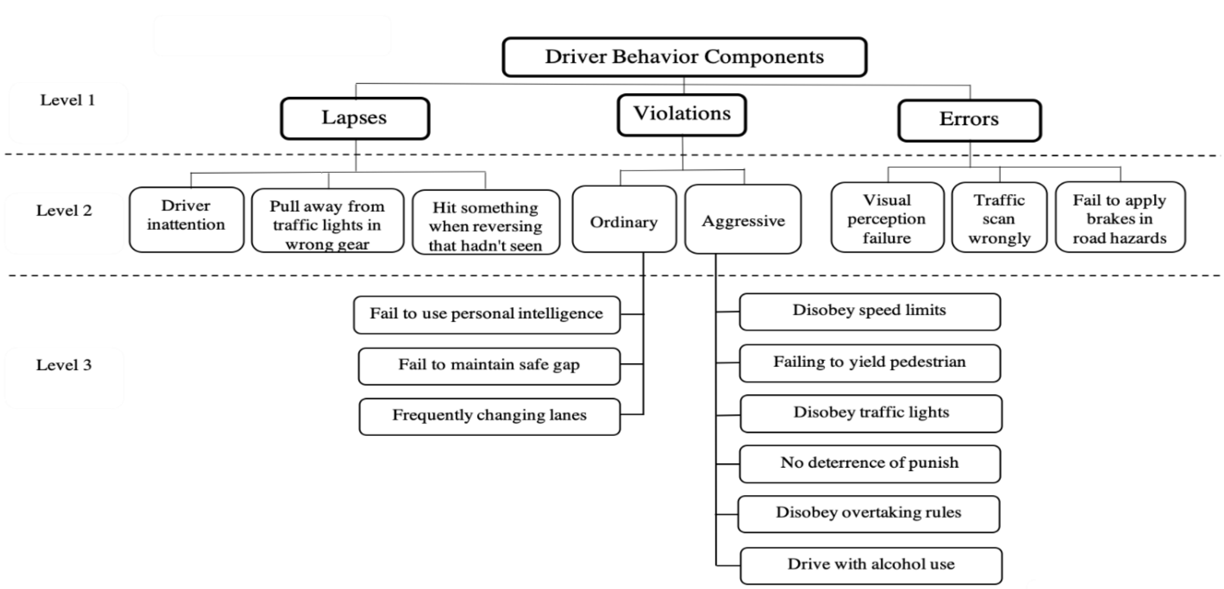
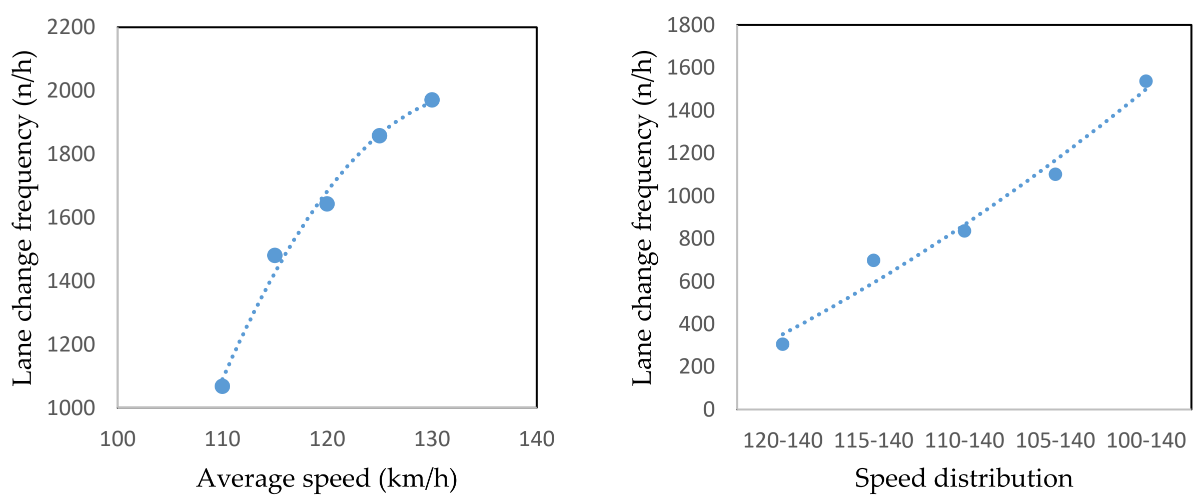


Figure 9: The hierarchical structure of driver behavior criteria related to road safety

3.3 Thesis 3

I estimated and compared the effect of significant traffic parameters on lane-changing for driving logic "cautious" by using VISSIM as a simulation tool. The study explored the significant relationships between observed traffic parameters (average speed, speed distribution, speed exceeding the speed limit and traffic volume) and lane change frequency. The study also developed 3D surface plots to show the integrated effect of specified traffic parameters on lane change frequency. While regression model was developed to quantify the effect of specified traffic parameters on lane change frequency.

The observed simulation data were used to plot the relationships between specified traffic parameters and lane change frequency as shown in Figure 10. Firstly, the effect of the average desired speed on lane change frequency was analyzed for a freeway. The plot results showed the positive relationship between average desired speed and lane change frequency which means that the lane change frequency increase with the increase of average desired speed under predefined speed range. Subsequently, the effect of desired speed distribution on lane change frequency was analyzed. The simulation results showed high lane change frequency when speed dispersion was set large and low lane change frequency when speed distribution was set small. Furthermore, the effect of traffic volume on lane change frequency was analyzed. The plot results showed the positive relationship between traffic volume and lane change frequency which means that lane change frequency increase with the increase in traffic volume. Moreover, the study analyzed the effect of speed rate exceeding the speed limit on lane change frequency for single and mixed traffic. The simulation results found that the lane change frequency generally raise with the vehicles speed variations (positive relation). However, some complex and non-significant relationships are observed due to presence of the HGVs and their speed variations.



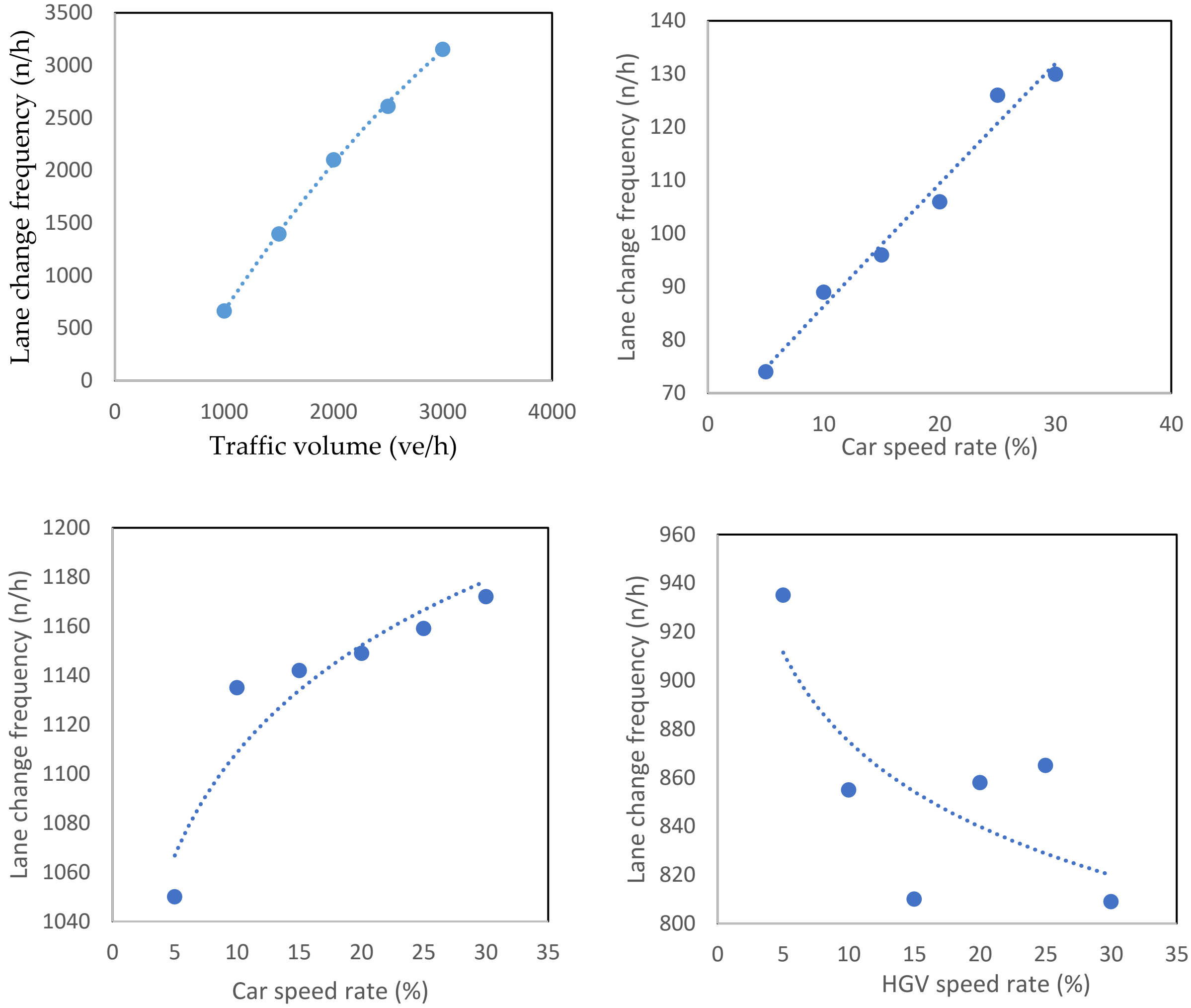
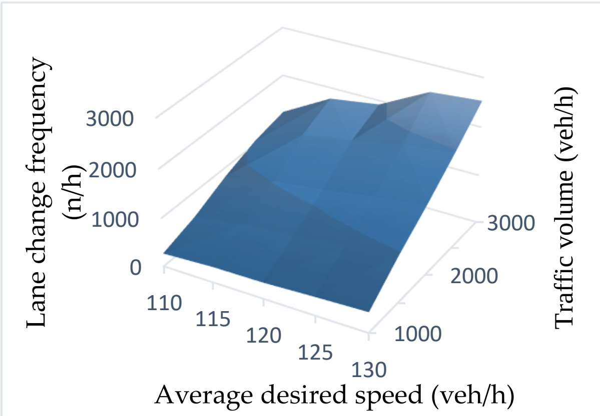
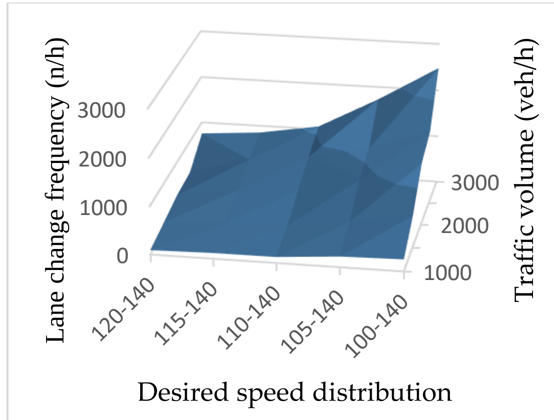


Figure 10: Effect of different traffic parameters on lane change frequency

3D surface plots were developed to analyze the integrated effect of specified traffic parameters (Average desired speed, desired speed distribution and traffic volume) on lane change frequency as shown in Figure 11. Figure 11a presents the 3D surface plot to show the impact of the average desired speed on lane change frequency when associated with traffic volume. While Figure 11b presents the 3D surface plot to show the impact of desired speed distribution on lane change frequency when associated with traffic volume. The plot results noticed the high lane change frequency for both cases due to combined effect of observed parameters.



(a)



(b)

Figure 11: 3D surface plots

The study attempts to develop a regression model between lane change frequency and specified traffic parameters based on observed simulation data. Lane change frequency (LCF) was set as a dependent variable, while the independent variables were average desired speed (ADS) and traffic volume (TV). The regression model was developed based on simulation data and coefficient results were utilized to quantify the effect of traffic parameters on lane change frequency as shown in equation 1. The model results showed that average desired speed has high effect on lane change frequency with high coefficient value as compared to traffic volume with small coefficient value.

$$LCF = (41.38 \times ADS) + (0.68 \times TV) - 5411 \quad (1)$$

3.4 Thesis 4

I evaluated and compared the contributing factors to car-motorcycle accidents by dominant accident types using Virtual Crash software. The study results found the main contributing factors to car-motorcycle accidents such as driver behavior, rider behavior, view obstructions, blind spots and high speed. While simulation plots were developed by measuring relative heading angles to show the contribution of blind spots, stationary view obstructions and mobile view obstructions to car-motorcycle accidents for a specified period.

Simulations were run for each accident on virtual crash software and relative angles were measured for the specified time interval. Results showed that observed accidents occur in different collision configurations as shown in Figure 12. The most frequent observed relative heading angles were between 22.5º and 67.5º degree as well as between 67.5º and 112.5º degree (28% in both cases).

Blind spot in case of car-motorcycle accidents represents an area in which car driver declared that they failed to see the oncoming rider. These blind spots of a car were measured in a field test using one car and one motorcycle. Figure 13 showed the observed blind spots region in terms of relative heading angles at moment of collision for the specified time. The results showed that about 36% of riders were in blind spots area at moment of collision.

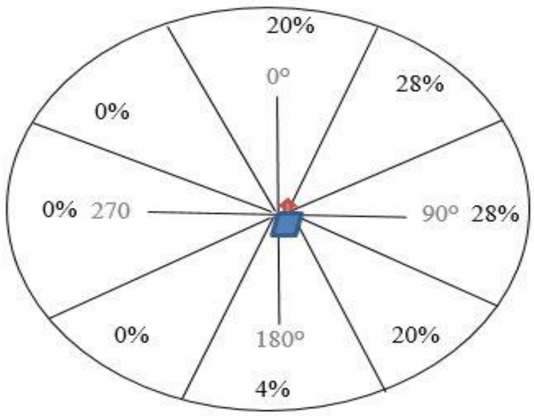


Figure 12: Relative heading angles for motorcycle to car collision

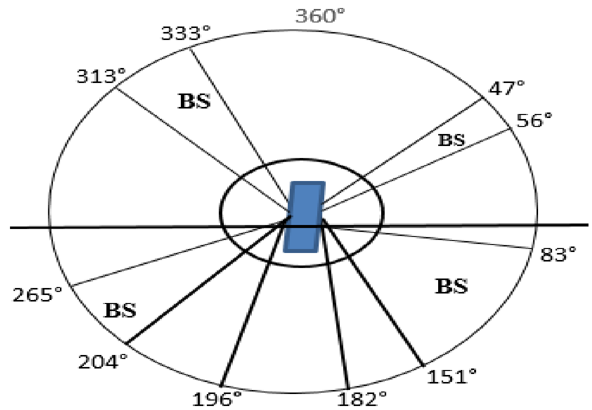
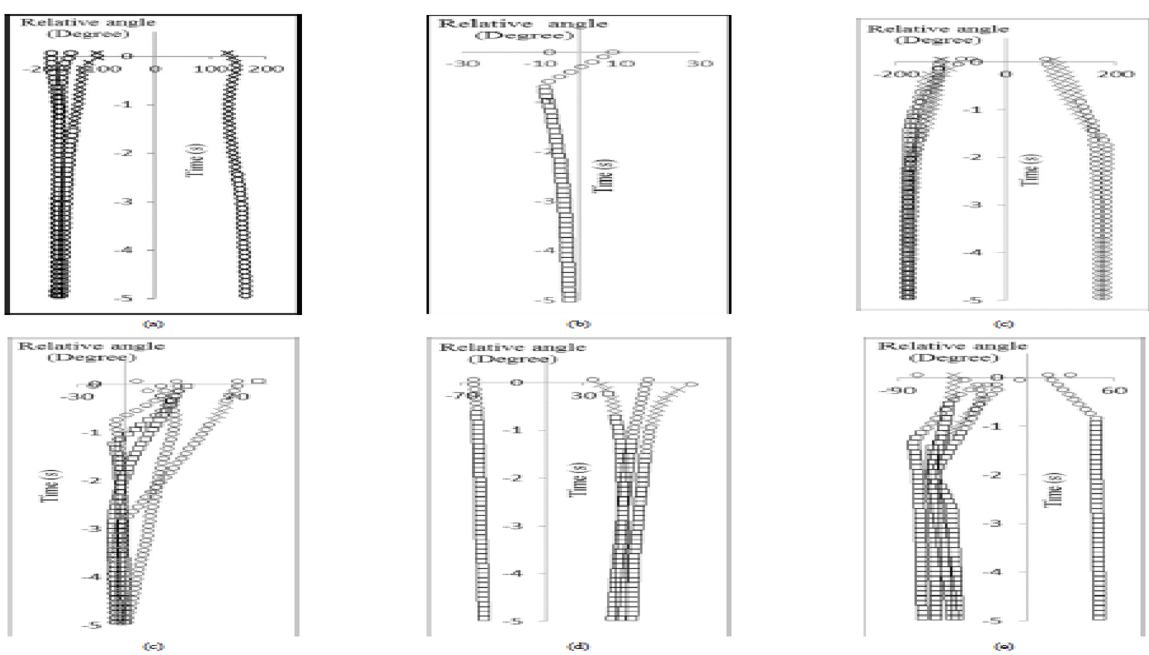


Figure 13: Blind spots area of a car

Figure 14 showed the plots which were developed between relative heading angles and time for all six types of accidents. These simulation plots identified the involvement and variations of contributory factors (view obstructions and blind spots) within the specified period. In these plots, the relative heading angle (degree) was taken along x-axis and time (seconds) was taken along y-axis. Different marks in the plots provided different type of information.



Note: Circular marks (Visible), Cross marks (Blind spot), Rectangular marks (View obstruction)

Figure 14: (a) Same direction and straight-ahead; (b) Opposite direction and straight ahead; (c) Same direction and turning;(d) Opposite direction and turning; (e) Adjacent direction and without turning; (f) Adjacent direction and turning

4 Application of the scientific results

1. The risky driving behaviour factors are the leading cause of traffic crashes which represent a major public safety concern in different countries. Therefore, identification of the frequent risky driving attitudes is of great importance. In thesis 1, a comparative study was designed based on a self-reported questionnaire survey to evaluate and compare the risky driver behavior factors for specified evaluator groups of Hungary and Pakistan. The study utilized the well-designed statistical methods to measure the differences and statistical significance of observed factors among different demographic groups. This study would help local policymakers to focus on highlighted risky driver behaviour factors to solve road safety issues.

2. Having a reliable and comprehensive evaluation of driver behaviour data would be a significant step regarding the decision of the most significant driver behavior criteria affecting road safety. In thesis 2, the MCDM methods were utilized to evaluate and rank the significant driver behaviour criteria for different evaluator groups. The study designed the driver behaviour hierarchical model to analyse and compare the driver behaviour criteria in a three-level structure. Also, the study applied FAHP technique using a fuzzy scale to evaluate the complex driver behaviour by capturing the ambiguity of drivers thinking style.

3. The relationships between significant traffic parameters and accident risk roughly correspond to the driver's behaviour involvement under varying traffic conditions which would be the basis of understanding the traffic safety dynamics. In thesis 3, the micro-simulation approach was applied to identify and compare the effect of different traffic parameters on lane changing related to road safety. The effect of different traffic conditions on lane-changing has also been investigated which can be further considered as the basis of highways traffic state recognition. The study recommends that traffic parameters which influence most on lane-changing should be more focused by policymakers to enhance traffic safety.

4. The recent growth of motorcycles on urban roads has resulted in fatal and seriously injured car-motorcycle accidents. In thesis 4, car-motorcycle accidents were reconstructed using Virtual Crash software to evaluate and compare the contributing factors by dominant accident types. The study also investigated the collision avoidance manueuvres performed by car drivers and motorcycle riders before the collision. The study proposed safety measures from car driver and motorcyclist perspectives to avoid car-motorcycle accidents in future.

5. Rider visibility has been considered as a critical issue in car-motorcycle accidents due to frequency of unperceptive and negligent driving behavior. Most of car drivers on road indicated that they didn't see the rider before the collision. In thesis 5, the study utilized the simulation tool to evaluate the contributing factors that reduce rider visibility for car-motorcycle accidents. The study developed the simulation plots to quantify and compare

the contributing factors to rider visibility issues by measuring relative heading angles for a specified period.

5 Scope for the future study

1. The scope for future research regarding Thesis 1, is to investigate the risky driver behaviour factors under various traffic scenarios for different demographic groups using driving simulators or other advance naturalistic tools.

2. The scope for the future research regarding the Thesis 2, is to analyse dynamically all other contributing factors and their sub-factors affecting road safety such as road infrastructure, vehicles, traffic operators and environment using MCDM methods.

3. The scope for the future research regarding the Thesis 3, is to calibrate a driver behaviour model regarding lane change frequency for speed control sections by measuring real traffic data.

4. The scope for future research regarding Thesis 4, is to investigate the behaviour of participants in different traffic scenarios with the help of driving simulator using police reported simulation models for observed car-motorcycle accidents.

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List of Publications

Farooq, D., Juhasz. J. Simulation-Based Analysis of the Effect of Significant Traffic Parameters on Lane Changing for Driving Logic “Cautious” on a Freeway. Sustainability, 11, 5976, 2019.

Farooq, D., Moslem, S. Evaluation of driver behavior criteria for evolution of sustainable traffic safety. Sustainability, 11, 5976, 2019.

Moslem, S., **Farooq, D.,** Ghorbanzadeh, O., Blaschke, T. Application of AHP-BWM Model for Evaluating Driver Behaviour Factors Related to Road Safety: A Case Study for Budapest City. Symmetry 2020, 12(2), 243.

Farooq, D., Moslem, S. Evaluation and ranking of Driver Behavior Factors Related to Road Safety by Applying Analytic Network Process. Periodica Polytechnica Transportation Engineering, 2019.

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Farooq, D., Juhasz. J.Simulation analysis of contributing factors to rider visibility issues for car-motorcycle Accidents. Periodica Polytechnica Transportation Engineering, 2019.

Farooq, D., Juhasz. J. Analysis of Young Driver Behaviour related to Road Safety Issues in Pakistan and Hungary. International Journal of Civil Infrastructure (IJCI). Volume 1, Year 2018.

Farooq, D., Akram, T. Traffic Flow Analysis and Solutions to Ease Traffic Flow at Unsignalized Taxila Intersection. Periodica Polytechnica Transportation Engineering, 2018.

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Farooq, D., Juhasz. J. In-Depth investigation of contributing Factors to Car-Motorcycle Accidents in Budapest City. (Accepted, Romanian journal of transport infrastructure, 2019).

Farooq, D., Juhasz. J. Statistical Analysis of Risky Driver Behavior Factors that Affect Road Safety based on Age and Driving experience in Budapest and Islamabad (Submitted, European Transport journal, 2019).

Farooq, D., Juhasz. J. An Investigation of Speed Variance effect on Lane Change Frequency by Vehicle Types and Road Environment (Submitted, Advances in Transportation studies (ATS), 2019).

Moslem, S., Gul, M., **Farooq, D**., Çelik, E., Ghorbanzadeh, O., Blaschke T. An Integrated Approach of Best-Worst Method (BWM) and Triangular Fuzzy Sets for Evaluating Driver Behavior Factors Related to Road Safety. Mathematics (submitted).