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**Road Geometry and Topographic Formation -
Center of Traffic Crash Attraction and Severity
Level**

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1. Introduction

Road geometry design is strictly related to the level of traffic crashes [1]. Planning, designing and constructing road infrastructure should give priority to safety and comfort for road users [2]. The poor road geometry alignment had a significant impact on crash occurrence [3]. Lane number and pavement condition variables are most significant factors affecting accident rates [4].

Identifying road traffic center of crash attraction and the proper method of assessment is a step towards reducing traffic crashes. A poorly designed road geometry can directly lead to a higher density of traffic crashes [5, 6]. Distance proximity between traffic crashes is also defined by the impacts of road geometry formation. This implied that the number of traffic crashes, center of crash attraction and the severity rate potentially related with the geometry formation of the road.

Analyzing traffic crash, accident, and crash cost distribution is not sufficient to define the severity level of the road unless the combined effects are explored. A severity level depends on a combination of factors including the extent of damage to the road surface, visibility conditions, traffic volume, weather conditions, and the surrounding environment; all of which can contribute to the potential risk of accident [7, 8] s. A higher number of crashes on a road generally indicates a higher road severity level, meaning that crashes occurring on that road are more likely to result in severe injuries or fatalities [9]. A higher road severity level directly correlates to a significantly higher accident cost [10]. As stated, the severity level of road segment depends on the number of traffic crashes, number of traffic accident and cost of crashes.

In road design, minimum radius (R_{min}), the maximum side friction factor (f_{max}) and maximum superelevation (e_{max}) are basic design parameters used to define the design speed at horizontal road curvature. A direct correlation reflected between traffic crashes and speed, meaning that as speed increases, the likelihood of a crash occurring also increases, and the severity of the crash is likely to be greater [11, 12]. For every 10 mph of increased speed, the risk of dying in a crash doubles. In practical terms, increasing driving speed from 60 mph to 80 mph increases the risk of a fatal crash by 4 times [13]. Mostly unmanageable side friction factor that resulted due to roughness of the road surface can causes huge losses of life and physical injuries [14, 15]. Side friction results in increased traveler discomfort, reduced speed behind stopped vehicles and abrupt volume rises on the roadway [16].

Road traffic crashes and their severity level are likely caused by variations in elevation, slope, and terrain formation of the road topographic formation [17, 18]. A significant elevation difference on a road, particularly steep inclines or declines, can considerably increase the risk of traffic crashes due to factors like reduced visibility, difficulty in vehicle control, and increased braking demands [19]. A significant correlation exists between traffic crashes and slope variation on roads, meaning that areas with sudden changes in grade are more likely to experience accidents [19] [20] [21]. Terrain formation can significantly impact the frequency and severity of traffic crashes by influencing factors like road design, visibility, and driver behavior, with features like steep slopes, sharp curves, blind corners, and uneven surfaces often contributing to higher accident rates in areas with complex topography [22, 23].

Like other modes of transport, micromobility is a form of transport with benefits but still liable for accidents. The sleek of micromobility is to make the city more accessible and allowing people to explore their cities [24, 25, 26]. The SDGs report showed that micromobility could play a major role in achieving the SDGs through creating good health and well-being by lowering toxic gas emissions (greenhouse gases). Moreover, it plays a significant role by reducing projected traffic accidents [27]. Micromobility accounts for a higher proportion of injuries [28, 29, 30]. The risk of injury for riders, pedestrians, and other vehicles on the road is a primary concern [31, 32, 33].

2. Research objectives

The key objective of this dissertation is to create awareness about the impact of road geometry and topographic formation on road traffic crash occurrences and their severity level, where the following research objectives are identified.

- Analyzing the impact of road geometry formation on traffic crash occurrences.

This objective attempted to examine the impacts of road geometry formation on traffic crash occurrences and its significance. In addition, used to analysis determinant factor of traffic accident.

- Assessing the pertinence of the density estimation and proximity level of traffic crashes using point and kernel density estimation, and multipoint-to-multipoint approach.

This objective attempted to explore blackspot location based on point and kernel density estimation and its comparative implications. Distance proximity between traffic crashes was also explored and used to define the center of the traffic crash attraction zone.

- Evaluating road severity level based on existing and an alternative combined parameter approach using traffic crash, accident, and crash cost relative percentage share.

This objective attempted to examine the impacts of the relative percentage share of traffic crashes, traffic accidents, and crash costs in analyzing the severity level of road segments based on the geometry formation of the road. In addition to that, the existing and an alternative severity level analysis approach was explored.

- Examining an empirical model for the desired operating speed due to the variation of the side friction factor at horizontal road curvature.

This objective empowered the development of a new empirical model that was used to analysis desired operating speed of vehicles on a bend (horizontally curved) road with a variation in the side friction factor due to a change in the roughness of the pavement surface across the design period of the road.

- Scrutinizing the interaction of topographic formation and traffic crashes using triangular irregular network (TIN).

This objective is designed to examine the impacts of elevation difference, slope variation, and terrain formation between traffic crashes to define the center of the traffic attraction zone of the road network.

- Assessing micromobility factors contributing to accidents, market and service trend, and related mishaps.

This objective is conceived to review the impacts of micromobility vehicles on humans, their market and service trends, factors causing micromobility accidents, and their remedial actions. It also framed to examine the global accessibility and usage of micromobility vehicles.

3. Applied methods

Multinomial Logistic Regression (MNL) was an appealing statistical approach in modeling the severity of road traffic crashes because it allows for more than two categories of the dependent or outcome variable and does not require the assumption of normality, linearity, or homoscedasticity [34, 35]. Multilayer Perceptron Artificial Neural Network (MLPANN) is a type of artificial neural network that is used to analyze and model complex patterns and prediction problems [36, 37]. Pearson Correlation Coefficient used to analysis the relationship between variables.

Pythagorean (Euclidean) distance is a distance calculated from the cartesian coordinates of the points using the Pythagorean theorem [38]. Multipoint-to-multipoint distance proximity is calculating distances between multipoint or distances from each point of an input multipoint feature to each point of the near multipoint, and the smallest of these distances is the distance

between the two multipoint features. Skewness is a measure of the asymmetry of a distribution. A distribution is asymmetrical when its left and right sides are not mirror images [39].

Combined parameters approach is a method that allows severity index to use both severity level indicator and determinant factor as parameters to analysis severity value interdependently. Relative percentage share is the percentage obtained by dividing the aggregate value of the share consideration by the aggregate consideration value [40, 41]. Analysis of variance is the statistical procedure of comparing the mean of a variable across several group of individuals [42, 43]. It is a statistical measurement that is used to determine the spread of numbers in a data set with respect to the average value or the mean [44]. Severity score is a value that indicates the level of severity of injuries, disability or vulnerability.

Point Density Estimation (PDE) tool used to calculates the density of point features around each output raster cell [45]. Whereas the Kernel Density Estimation (KDE) tool is used to calculate the density of features in a neighborhood around those features [46]. Bandwidth Estimation is an algorithm used to determine the default search radius for spatial analysis.

Triangular Irregular Network (TIN) are often generated using the triangulation of a point coordinate (x, y, z). The fact that the points are distributed differently depending on an algorithm that ascertains which points are most essential to produce an accurate representation is one benefit of utilizing a TIN [47]. In addition to resolution, the quality of TIN measured by elevation difference (z-factor) between input TIN surface and interpolated output surface [48]. Z-factor represent the difference between elevation. While the elevation difference between point is zero, that means the z-factor is 1. Figure 1 illustrates scientific method used in each thesis point of the dissertation.

Explanatory review is a research method that explores why something occurs when limited information is available [49]. It is also a technique used to gain a deeper understanding of the underlying reasons for, causes of, and relationships behind a particular issues [50]. Exploratory research design can be defined as research conducted to investigate an undefined/unclear problem. It is carried out to gain a better understanding of the current problem [51, 52].

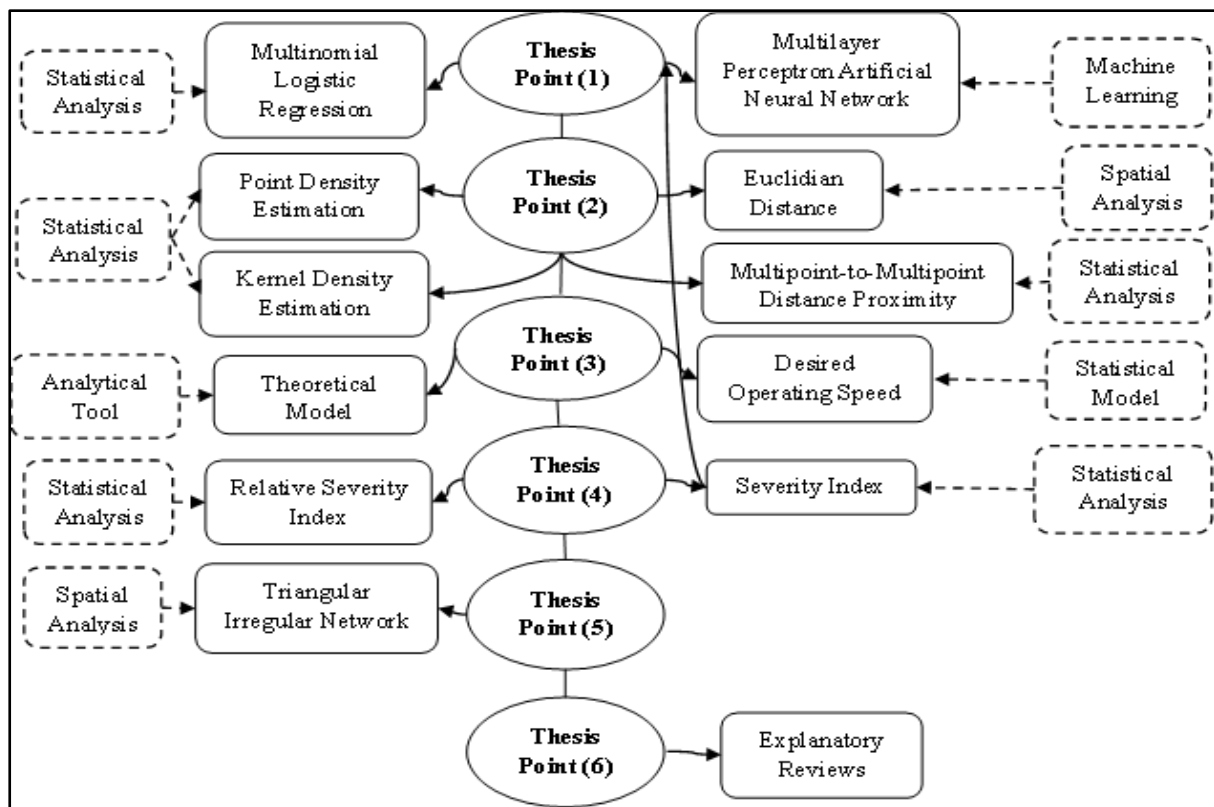


Figure 1. The applied scientific methods

4. Scientific findings

In this chapter, imprints of road geometry formation on traffic crashes, the center of traffic crash attraction and proximity level, road traffic crash severity level analysis approaches and alternatives, bend (horizontal curved) roads and desired operating speed, and road topographic formation impacts on traffic crash occurrence-related findings of each thesis point were described accordingly.

Thesis 1

I developed an accident prediction model utilizing multinomial logistic regression (MNL). Using multilayer perceptron-artificial neural network (MLP-ANN), the relationship between road geometry formation and traffic crash occurrences was analyzed. In addition to that, the impacts of road geometry formation on traffic crash occurrences and other determinant factors were identified.

Based on the geometry formation and the distribution of traffic crashes, a higher frequency of road traffic crashes and their outcomes are observed in straight road that account for around 63.7%. The higher severity level was observed on bend (horizontal curved) road.

The Multinomial Logistic (MNL) Regression Model output indicated that light conditions, collision type, alcohol consumption, speed limit, and road geometry formation have significant impacts on the occurrences of road traffic crashes and their outcomes. In terms of collisions, a high number of road traffic deaths and injuries were registered due to collisions happening between vehicles and vehicles with pedestrians. Vehicle collisions (especially rear-end collisions) play an important role in the occurrence of road traffic crashes at straight and intersection parts of the road network.

Table 1. Determinant factor of road traffic crash and its outcome

Crash Outcome	Parameter Estimates						95% Confidence Interval for Exp(β)		
	β	Std. Error	Wald	df	Sig.	Exp(β)	Lower Bound	Upper Bound	
Fatality	Intercept	-14.340	0.941	232.268	1	0.000			
	WC	0.169	0.076	4.917	1	0.027	1.184	1.020	1.375
	LC	0.505	0.125	16.464	1	0.000	1.657	1.298	2.115
	CT	0.118	0.028	17.357	1	0.000	1.125	1.064	1.189
	RG	-0.038	0.085	0.202	1	0.653	0.963	0.816	1.136
	AC	1.216	0.176	47.942	1	0.000	3.374	2.391	4.760
	R	0.064	0.026	6.006	1	0.014	1.066	1.013	1.122
	PS	0.262	0.139	3.559	1	0.059	1.299	0.990	1.705
	VL	0.727	0.090	65.023	1	0.000	2.069	1.734	2.469
Serious Injuries	Intercept	-2.367	0.187	159.628	1	0.000			
	WC	0.008	0.020	0.147	1	0.701	1.008	0.969	1.048
	LC	0.126	0.038	11.251	1	0.001	1.135	1.054	1.222
	CT	0.039	0.007	35.082	1	0.000	1.039	1.026	1.053
	RG	0.104	0.020	25.784	1	0.000	1.109	1.066	1.155
	AC	0.031	0.027	1.251	1	0.263	1.031	0.977	1.088
	R	0.058	0.006	85.482	1	0.000	1.060	1.047	1.073
	PS	0.152	0.049	9.831	1	0.002	1.164	1.059	1.281
	VL	0.013	0.040	0.098	1	0.754	1.013	0.936	1.096

a. The reference category is: Slight Injuries.

For the study area on the basis of the above findings, the model that helps to determine the significant level of road traffic accidents can be expressed using the following traffic accident (A) predicting equation.

$$A = \beta + \beta_1 WC + \beta_2 LC + \beta_3 CT + \beta_4 RG + \beta_5 AC + \beta_6 R + \beta_7 PS + \beta_8 VL + \varepsilon(\text{error})$$

According to the Multilayer Perceptron Artificial Neural Network (MLP-ANN), bend (horizontal curved) road has a positive and significant relationship with road traffic fatalities. The intersection and horizontal curve had positive interactions and a strong impact on the occurrences of slight injuries. Concomitantly, the one-lane road has positive and strong interaction with road traffic crashes that causes serious and slight injuries. Meanwhile, two-lane roads had positive and strong interaction with road traffic crashes that result slight injuries. One-lane and three-lane roads have a positive impact in the occurrences of fatalities.

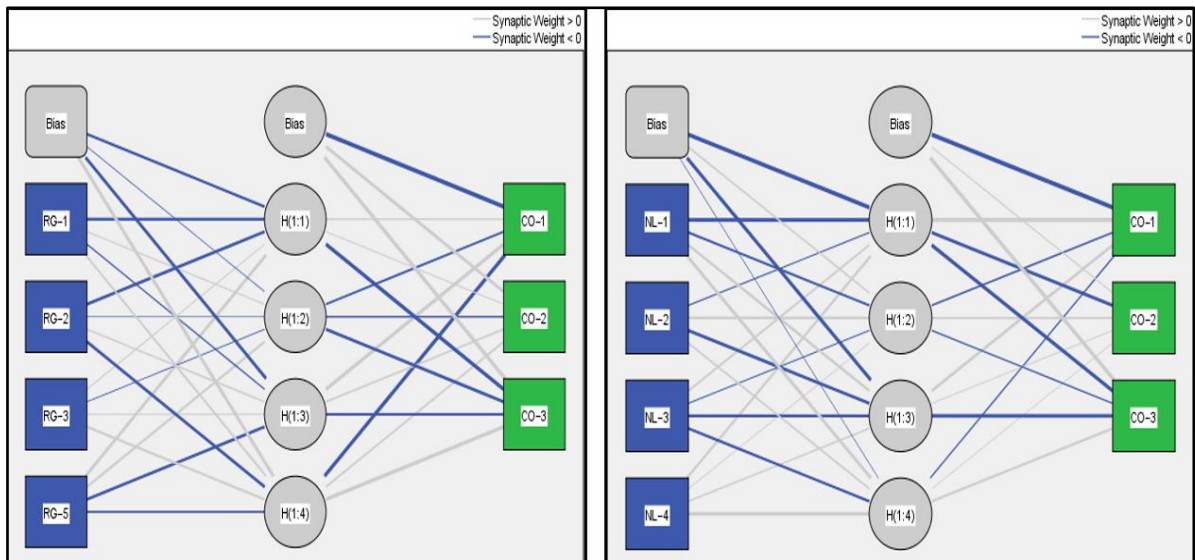


Figure 2. Road geometry formation and number of lane impact on traffic crash outcome

A high number of road traffic crashes were registered due to the improper use of traffic control devices. The primary reasons for the occurrences of a road traffic crash at an intersection, horizontal curve, and straight road geometric formation were the improper use of road traffic signs, road pavement condition, and stopping sight distance problems, respectively. In this study, the driver played a vital role in the occurrences of road traffic crashes, and their outcomes accounted for more than 82.6%.

Relative to other forms of road geometry, intersections (cross roads) have positive and strong impacts on the occurrences of slight injuries, and the maximum number of road traffic accidents registered in the study area was slight injuries.

Thesis 2

I revealed the proper method used to analysis center of traffic crash attraction comparatively using point and kernel density estimation. I proposed a new concept used to define the raster data cell to analysis traffic crashes at the center of attraction based on the minimum spacing between the intersection zone to outline the bandwidth/radius of the raster cell size. To figure it out, the density-based blackspot location of the intersection zone of the road network was analyzed for the study area. Using a multipoint-to-multipoint distance proximity approach as a new tactic that exploited to analysis traffic crashes in the attraction zone using mean, mode, mean-mode variation, and skewness at the macroscopic level of the road network. Based on the distance proximity concept between the traffic crash location/point, a highly severe road geometry formation was analyzed.

Based on point and kernel density estimation common attribute the study identified five blackspot locations at intersection zones of the study area road network as shown in Figure 2 below. The study depicted an intersection zone with a high number of legs concord with a high number of road traffic crashes and their outcomes.

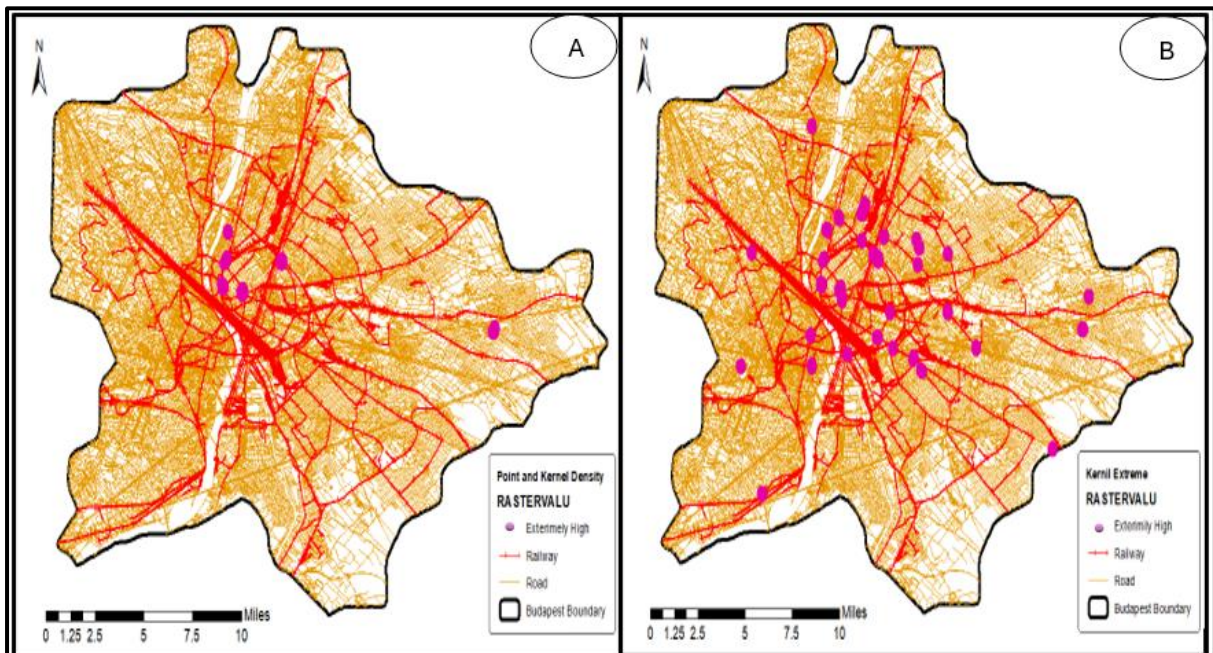


Figure 3. Blackspot location using Point Density Estimation (A) and Kernel Density Estimation (B) at neighborhood radius (r) of 0.002 degree.

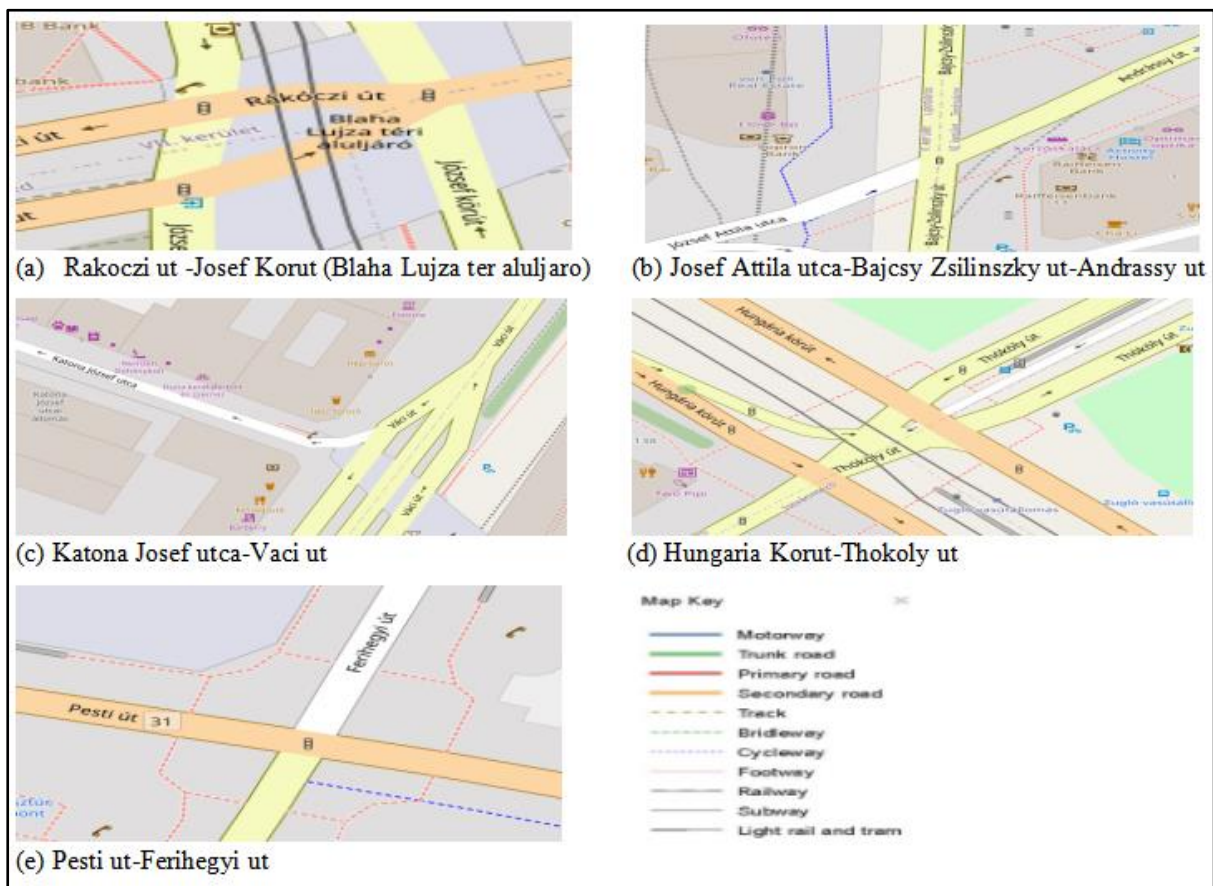


Figure 4. Blackspot intersection zone of Budapest city road (Source: open street map)

From the stated density estimation approach, point density estimation was preferable for identifying highly dense black spot locations in a specified road network. As a result, it is highly recommended that a point density estimation approach be used to identify the location of extremely high road traffic crashes (black spots) for the entire road network of a given study area at a macroscopic level.

Based on multipoint-to-multipoint distance proximity result indicated that the severity level of crossroad, straight road, bend road and cross road was high based on mean, mode, mean-mode variation and skewness respectively.

Table 2: Mean - Mode Variation

Road Segment	Mean (km)	Mode (km)	Mean-Mode Variation (km)
Bend Road	16.584	10	6.589
Cross Road	11.99	9	2.99
Straight Road	13.35	8	5.35

Table 3. Distance Proximity and Severity level.

Variables	Severity Level		
	High	Medium	Low
Mean	Cross Road	Straight Road	Bend Road
Mode	Straight Road	Cross Road	Bend Road
Mean-Mode Variation	Bend Road	Straight Road	Cross Road
Skewness	Cross Road	Straight Road	Bend Road

Thesis 3

I established a newly empirical model that was used to analysis road network severity level based on the traffic crashes, traffic accidents, crash costs, other determinant factors, and their combined effect. The comparative implication of the newly and existing severity level analysis approach was properly examined. Based on the newly and existing approach of the severity value of the road network, its severity level was analyzed based on the geometry formation.

In the study area, most traffic crashes, traffic accidents, and traffic crash costs were recorded on straight segments of the road network. But, based on equations in Table 4 below, the higher severity level registered on the bend (horizontally curved) road. This depicts that having a high number of traffic crashes, accidents, or crash costs doesn't outline the maximum severity level.

Table 4. Severity level analysis approaches and parameter

Source	Equation	Missing Variable
[53, 54]	$SI = \frac{N_A}{N_C}$ Equ. A1	C_C
[55, 56]	$RSI = \frac{\sum_{i=1}^n RC}{TNG}$ Equ. A2	N_A

In the study area, due to traffic crashes in the past 5 years (from 2017-2021), around 1.4 billion dollars were lost. This depicted that Hungary lost on average, around 0.2% of its GDP annually due to traffic crashes registered in the city of Budapest. In terms of geometry formation, the maximum crash cost was registered due to an accident recorded on a straight road segment of the road network. Of the total crash costs, around 0.9 billion dollars were lost due to traffic crashes that happened in straight road segment.

Even though different approaches were used to analyze the severity level, most of the analysis approaches depend on the number of traffic crashes, traffic accidents and crash costs. Based on the overall combined variables assumption equations were proposed as an alternative

to analyze the severity level of the road segments based on relative percentage share as shown in Table 5.

Table 5. Existing and an alternative severity level analysis approaches

Existing Equations	Missing Variable	New/An alternative Equations
$SI = \frac{N_A}{N_C}$	C_C	$SI = \frac{N_A}{N_C} * \frac{S_{CC}(\%)}{S_A(\%)}$
		$SI = \frac{S_A(\%) * S_{CC}(\%)}{(S_C(\%))^2}$
$RSI = \frac{\sum_{i=1}^n RC}{TNG}$	N_A	$RSI = \frac{\sum_{i=1}^n R_C}{TN_C} * \frac{S_{CC}(\%)}{S_A(\%)}$
		$RSI = \frac{(S_{CC}(\%))^2}{S_C(\%) * S_A(\%)}$

Both in the existing and an alternative approach, the severity level of the bend road segment of the study area was higher. In an alternative approach, the combined variables concept creates a significant change in severity value. Even though the severity level of the crossroad was higher than the straight road segment due to the existing approach, an alternative approach for Equation A1 of Table 4 showed that a straight road was more severe than a crossroad. In all, an alternative approach, the severity value, and severity score of crossroads significantly reduced when compared to bend road and straight road segments.

In general, having a higher traffic crash, traffic accident, and traffic crash cost doesn't describe the severity level of the road segment, and vice versa. Therefore, analyzing and considering the combined effects of severity level indicators and other determinant factors had significant implications for defining the severity level of the road segment. The study identified that the consequence of poor pavement quality and over-speeding makes the bend road severe.

Thesis 4

I affirm that a newly empirical model that is used to analysis desired operating speed (Ds) at a bend (horizontal curved) road. The impacts of pavement surface roughness on desired operating speed across the design period of the road were examined. To illustrate the empirical model's applicability, the desired operating speed at a constant minimum radius, constant maximum superelevation, and variation in the maximum side friction factor (coefficient of side friction) was analyzed.

Among the severity level of road segment pavement quality and design speed define the occurrences of traffic crashes. Road surface roughness, type, block, and condition of tire as a basis in defining the side friction factor that determines the comfort of road users and vehicular movement. Equation 1 below showed that vehicular speed (V_D) has a direct relation to the side friction factor. This empirical model consider constant speed across the design period. The speed of vehicular maneuver is affected by the variation in side friction factor resulted due to change in roughness of pavement surface. As a result, this empirical model has a drawback in defining the desired operating speed across the design period of the road.

$$f_{\max} = \frac{V^2}{127 R_{\min} - 0.01 e_{\max}}$$

Equ. 1

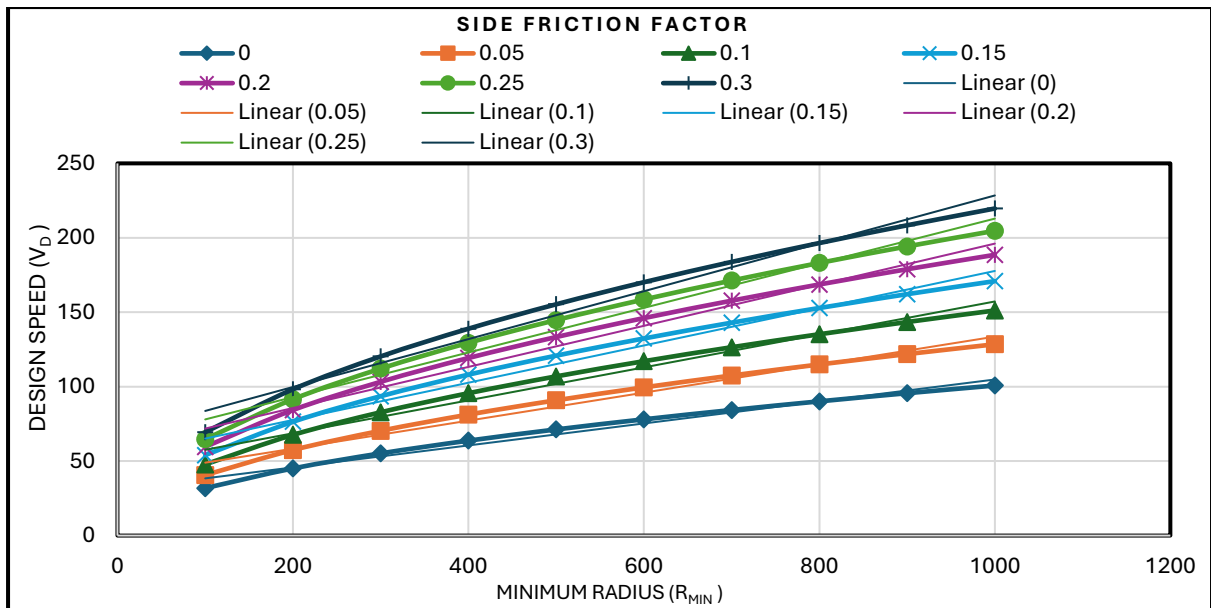


Figure 5. Desired operating speed and minimum radius at varying f_{max} and $e_{max} = 8\%$

This study directed that the desired operating speed (D_S) of a vehicle depends on the side friction factor of the road. Equation 2 below is functional at a maximum superelevation, minimum radius of curvature with a referenced side friction factor, which gradually changed across the design period at the horizontal curvature of the road, except at the opening phase.

$$D_S = \frac{1}{2} \sqrt{254} \sqrt{R_{min} \left(\left(\frac{1 - f_{max}}{1 + f_{max}} \right) - 0.05e_{max} \right)} \quad \text{Equ. 2}$$

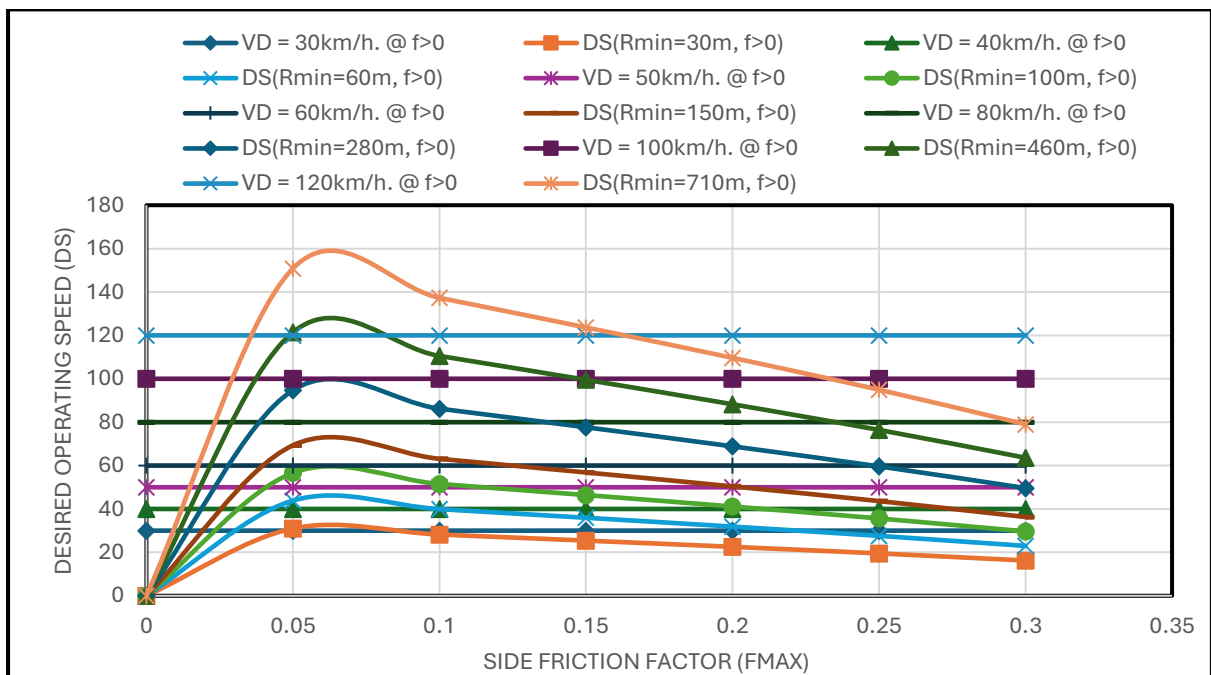


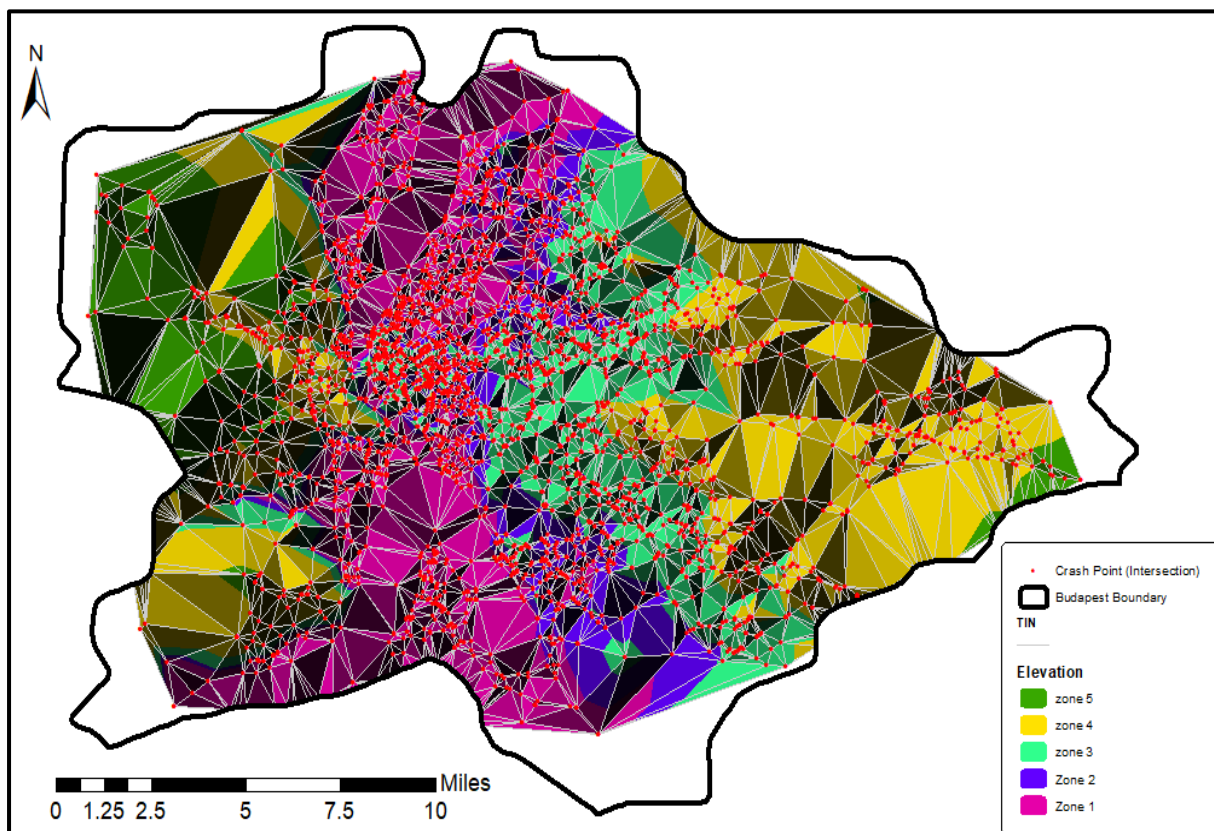
Figure 6. Effects of change of f_{max} on speed at recommended R_{min} , and $e_{max} = 8\%$

Thesis 5

I present a newly triangular irregular network (TIN) approach that is used to analysis center of the traffic crash attraction zone based on the topographic formation of the earth. Based on the concept of triangular irregular network (TIN), the impacts of the topographic formation of the earth on the occurrences of traffic crashes were analyzed at the macroscopic level of the road network. To define the center of the traffic crash attraction zone elevation difference, slope variation, and terrain formation between the traffic crash location/point was examined.

In addition to the geometry formation of the road, other aspect also contributes to the creation of a risky zone on the road network, there is the location of traffic crashes. The distribution and frequency of traffic crashes were related to the existing formation of the earth structure (topographic formation). Elevation difference, slope variation, and terrain formation significantly correlated with road traffic crashes and their causation. In the study area, the majority of traffic crashes were reported in locations or points with lower elevation and its difference, steeper or cliff slopes, and flat terrain formations.

Based on the nature of the data and elevation difference, zone 1 of the research areas of the road network is a risky zone that ranges with an elevation interval from 96 to 110 meters. Based on slope variation between traffic crash locations, the study demonstrated that the study area's slope varies from 78 to 90 degrees between the traffic crash location or point, which was a highly severe road section. At last, the study revealed that the majority of traffic accidents occurred in flat terrain. For more information, see the figure below.



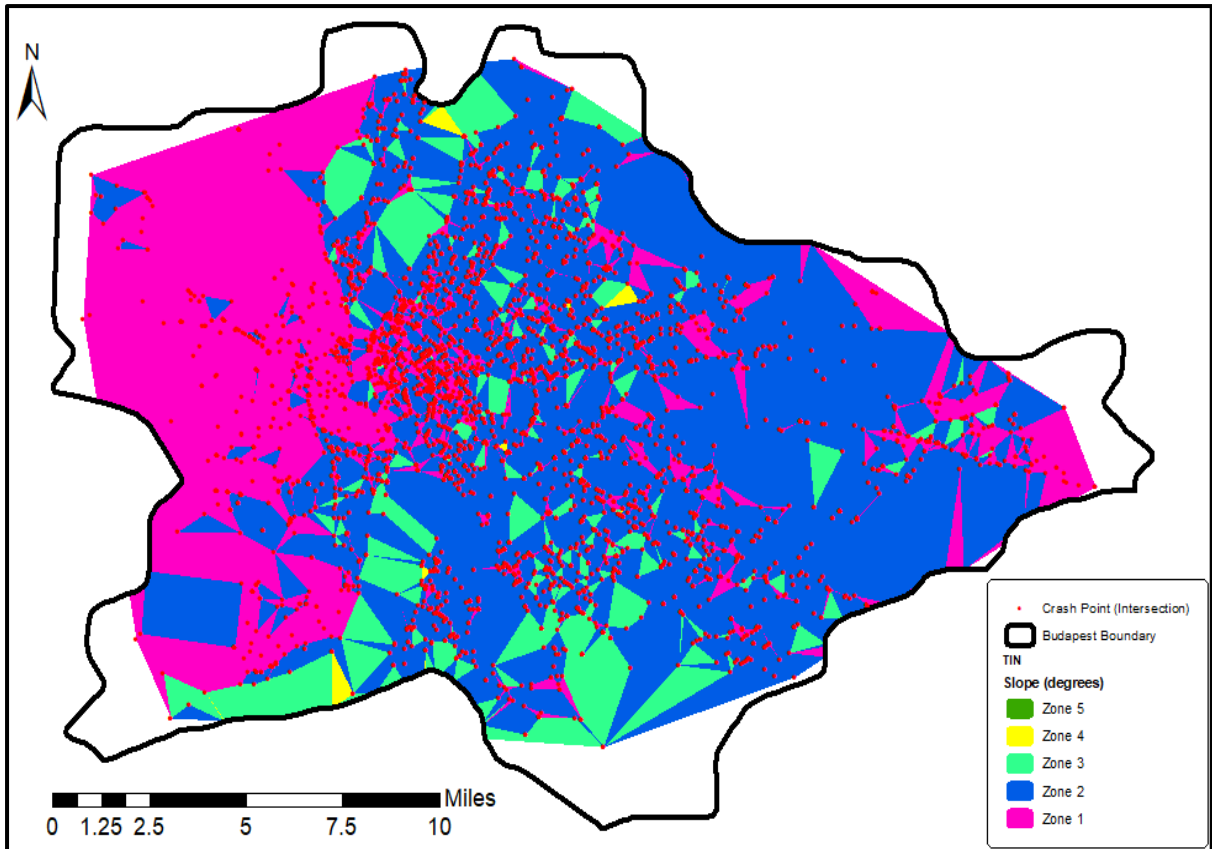


Figure 8. Slope variation between traffic crash locations or points

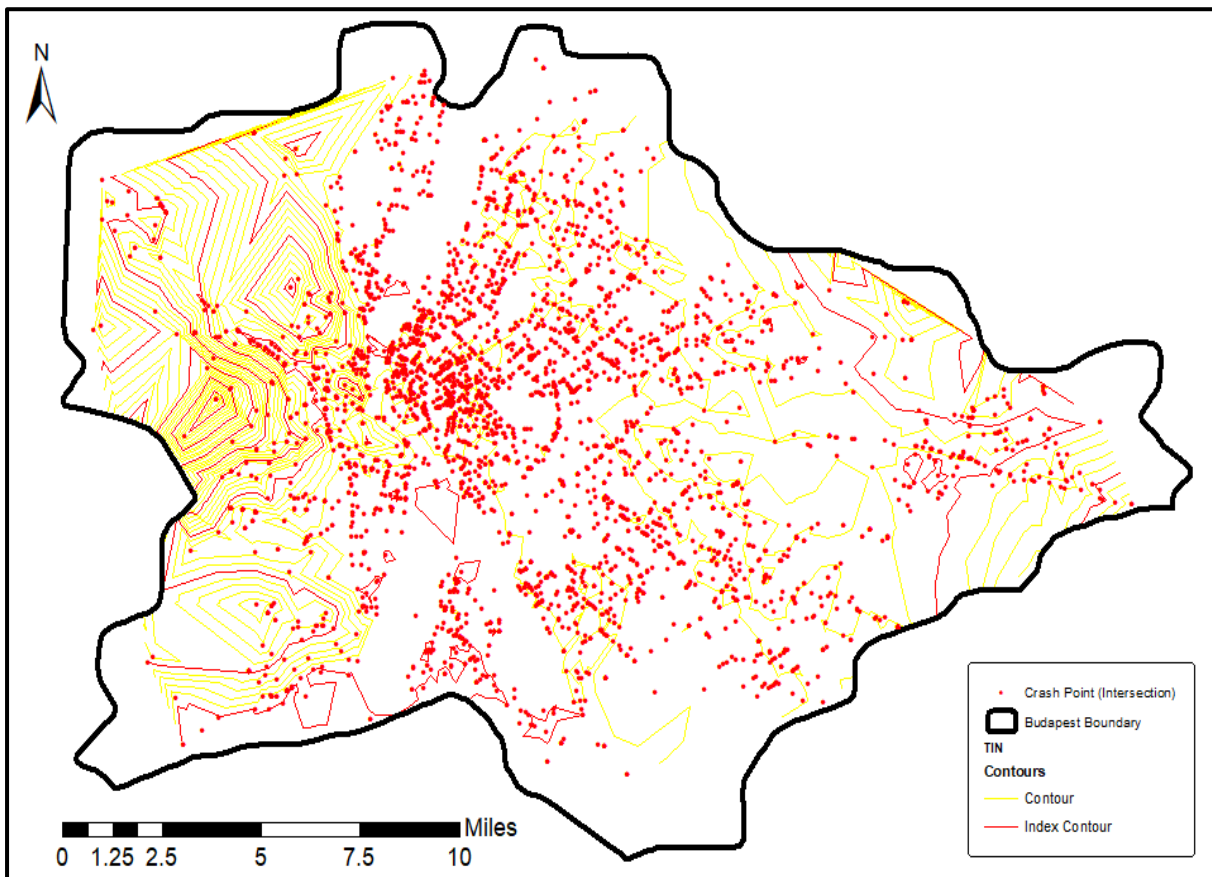


Figure 9. Contour development and road traffic crash location/point

Thesis 6

I assessed the global market and service trend of micromobility. I present a micromobility-related accident and its causes. Factors affecting micromobility usage are also illustrated. The demography of the global population affected by micromobility vehicles is explored. The impacts of income on micromobility usage and related issues were examined. To avoid micromobility accidents, remedial action based on the causes was indicated. In addition to that, micromobility vehicles-related socio-economic, behavioral, and cultural factors also reflected.

Like other means of transportation micromobility also results enormous lose of life and physical injuries. To illustrate the impacts of micromobility vehicle on human the study used explanatory review and related case study. Based on this general overview the study identified that most younger men with an age of 14 and above affected by micromobility vehicles. Micromobility market trend indicated 5.4 times than automotive growth rate. Micromobility accident basically happen due to technical problems that cause fire, riders not using helmets, collisions with other vehicles, pedestrians, and fixed objects, the nature of the vehicles by themselves, visibility, and seasonal variation.

Globally most micromobility related accident happened due to e-scooters and e-bike. To visualize the impacts of those vehicle the study tried to consider USA and Germany due to highly associate with indicated micromobility accident.

Table 6. E-scooter and e-bike accident in USA and Germany (2021-2023)

Country	Year	Population Size (Million)	Fatality	E-scooter		Fatality	E-bike	
				Injury	Total		Injury	Total
Germany	2021	83.2	5	4882	4887	131	20000	20131
	2022	83.8	11	8700	8711	208	23600	23808
	2023	84.48	22	8400	8422	188	23900	24088
USA	2021	332	40	42200	42240	35	11800	11835
	2022	333.3	36	51700	51736	53	24400	24453
	2023	334.9	41	40400	40441	76	34200	34276

Table 7. Population, e-scooters and e-bikes accident ratio of USA to Germany (2021-2023)

USA / Germany Ratio						
Year	Population	E-scooters		E-bikes		
		Fatality	Injury	Fatality	Injury	
2021	3.990	8.000	8.644	0.267	0.590	
2022	3.977	3.273	5.943	0.255	1.034	
2023	3.990	1.864	4.810	0.404	1.431	

The population ratio between the USA and Germany was approximately four (4). From 2021 to 2023, the ratio of fatalities due to e-scooters was approximately 8, 3, and 2. Whereas the ratio of fatalities due to e-bikes was approximately 0.3, 0.3, and 0.5. This implied that the number of fatalities in the USA due to e-scooters was higher than in Germany. Even though population ratio indicates that the population size in the USA is four (4) times that of Germany, in contrast, the number of fatalities in the USA due to e-bikes was lower than in Germany.

Micromobility usage and availability depends on the population size of country/regions and economic background of society. Globally, Africa is quite left behind to shared micromobility development [57].

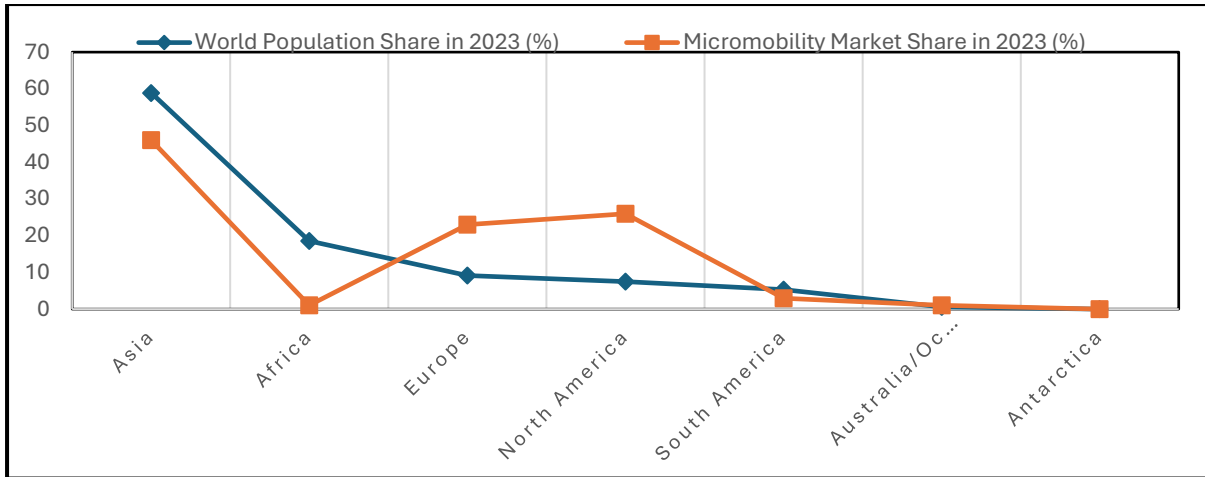


Figure 10. Global population share vs. micromobility market share Source: [58] [59]

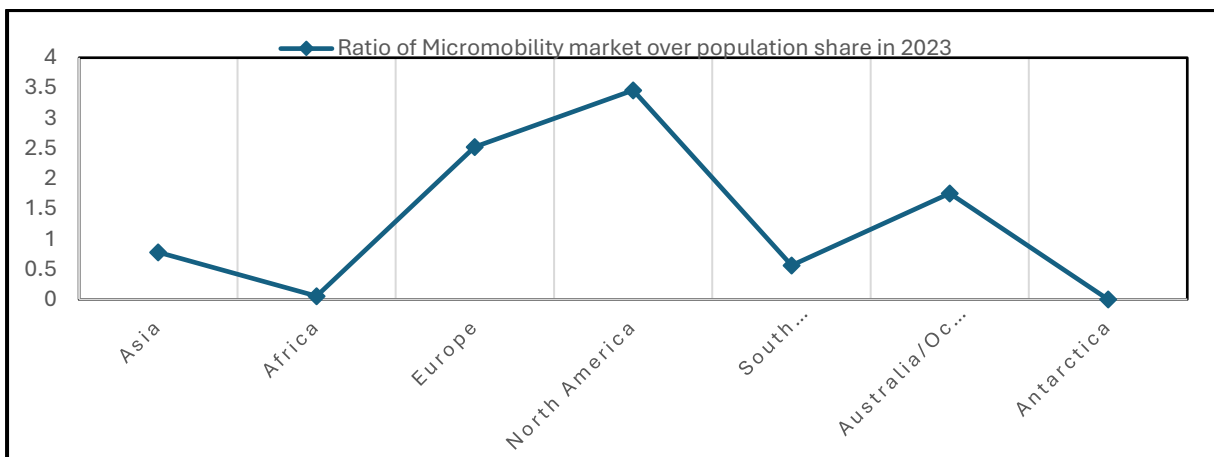


Figure 11. The ratio of micromobility market share to population size in 2023

5. Application of scientific findings

The findings of this dissertation have practical application in reducing traffic crash occurrences that promote road safety. The impacts of road geometry formation present the contribution of road geometry formation on the occurrences of traffic crashes. The density estimation approach and proximity techniques bring an indication of how road traffic crashes and their center of attraction interact with the area, spacing, and distance between the traffic crash's location. An alternative severity level analysis approach brings combined effects of traffic crashes, traffic accidents, and crash costs to define an effective severity value that is used to manage road safety. The desired operating speed is basically applicable on a horizontal curved road that results in a reduction in traffic crashes. In case the topographic formation is another concern that leads to the occurrences of traffic crashes. So, analyzing the elevation difference, slope variation, and terrain formation based on triangular irregular network (TIN) is significantly used to define the center of traffic crash attraction. All the above suggested approaches and ways are used to reduce the circumstances of traffic crashes and advance road safety. The findings of this dissertation basically have long-term effects on policymaking. The applications and findings of each thesis points are presented as follows:

The output of **thesis point 1** had a benefit to policymakers, road geometry designers, and stakeholders in developing strategies that were used to minimize road traffic crash occurrences. As the findings provide insights about the impacts of road geometry formation on traffic crash occurrences. It confirmed that traffic crash occurrence was deliberately related to the geometry formation of the road. Particularly, this thesis points forward to an emphasis on motorways,

straight alignment, two-way road formation and its carriageways, and a flawless one-lane that encourages the occurrence of traffic crashes and their outcomes that promote traffic safety by minimizing traffic crashes and accidents.

In the study area, even though a large number of traffic crashes were registered on the straight segment of the road network, the severity level was high at the horizontal curved segment of the road network. Researchers, policymakers, and stakeholders must emphasize the curved road geometry formation of the road network to minimize the number of traffic accidents. At most, the finding indicated that horizontally curved roads have a positive and strong relationship with road traffic fatalities. The primary reasons for the occurrences of a road traffic crash at an intersection, horizontal curve, and straight road geometry formation were the improper use of traffic signs, pavement condition, and stopping sight distance problems, respectively. The regression model indicated that light conditions, collision type, road geometry, and speed had a significant effect on traffic accidents.

The above finding had a strong remark on the impacts of road geometry formation that used to manage traffic crash occurrences that forced the stakeholders to develop and implement traffic crash policies concerning design and manuals, traffic safety rule and regulation standards, and policy. In the future, the trend of traffic crash occurrences and their outcomes (accidents) will be minimized by undertaking proper remedial action concerning the design, construction, and maintenance of road infrastructure, particularly the geometry formation of the road network. Road geometry designers can get input data on their traffic safety concern on the reduction of traffic crashes and outcomes, which advances road safety.

The findings of **thesis point 2** had value to traffic safety policymakers in developing strategies that used to identify dangerous sections of road segments used to identify proper causes and minimize road traffic crash occurrences. As the findings in thesis point 1 prevailed, road geometry had an impact on traffic crash occurrences. It confirmed that traffic crash deliberately related to the intersection segment (crossroad) of the road geometry.

Mostly the density of traffic crashes defines the blackspot location of the road network. Point density estimation, kernel density estimation, and multipoint-to-multipoint distance proximity are used to identify dangerous road sections by identifying the dense location and distance proximity between traffic crashes at a macroscopic level. In comparison, point density estimation highly recommended to the stakeholders to identify blackspot location.

Based on this density estimation approach, this study discovered that intersection zones with an enormous number of legs are more likely to experience high traffic crashes. In addition to that, multipoint-to-multipoint distance proximity plays a significant role in identifying the sever road segment based on the mean and skewness, mode, and mean-mode variation. So, road segments with multiple legs had a positive and strong impact on the occurrences of traffic crashes. The newly approached multipoint-to-multipoint had decisive power in identifying the road section highly severed based on the distance proximity between traffic crashes' location.

In the study area, even though a large number of traffic crashes were registered on the intersection part of the road network, the severity level was high at the road segment with \geq four legs and above. Researchers, policymakers, and stakeholders must emphasize the point density estimation approach to analyze the blackspot location of the road network at a macroscopic level that is used to identify highly dangerous road sections used to minimize traffic crashes by identifying the proper causes and factors.

The above finding had a strong remark on road geometry formation and its severity level that was used to manage traffic crash occurrences by motivating the stakeholders to develop and implement traffic crash control mechanisms and policies. In the future, the trend of traffic crash occurrences and their outcomes (accidents) will be minimized by undertaking proper mechanisms/methods used to identify dangerous road segments. By implementing the stated

approach, the road safety management team plays significant roles in the reduction of traffic crashes and outcomes.

The results of **thesis point 3** had an advantage to traffic safety policymakers in developing strategies that used to analyze the severity level of road segments based on the number of traffic crashes, traffic accidents, crash costs, and other determinant factors. Based on the existing severity level analysis approach, this thesis points to a newly alternative approach that incorporates the number of traffic crashes, traffic accidents, and crash costs, plus other determinant factors that use combined parameters utilizing relative percentage share. Based on the geometric formation of the study area road network, the findings of this thesis revealed that the road geometry had a correlation with the traffic crash occurrences. Based on the existing and an alternative severity indexing approach, even though the Bend road was a severe segment, greater than 60% of traffic crashes were registered on the straight road.

Compared to the existing severity level analysis approach, utilizing the relative percentage share of road traffic crashes, accidents, and crash costs in a combined approach had a significant impact on defining the severity level. It confirmed that traffic crash occurrence was deliberately related to the formation of the road segments. So, stakeholders must utilize the stated alternative approaches to analyze road segment severity level.

Even though the weight of the severity level of the road segment varies between the existing and an alternative approach, this study discovered that the bend road had a higher severity level for both approaches. As a result, stakeholders must emphasize the bend in the road to minimize the severity level of the road segments. In comparison to the existing and an alternative approach, the severity level analysis way, an alternative approach showed that the severity level of straight roads was higher than cross roads, and the severity value of cross roads was reduced.

In the study area, due to traffic crashes, the country lost on average around 0.2% of GDP annually. Researchers, policymakers, and stakeholders must emphasize the bend road segment to minimize traffic crashes, related accidents, and economic losses.

The above finding revealed that an alternative approach had a strong remark on road segment severity level analysis that was used to manage traffic crash occurrences. In the future, the trend of traffic crash occurrences and their outcomes (accidents) will be minimized by undertaking proper mechanisms/methods used to assess the severity level of the road segment. By implementing the stated approaches, the road safety management team would play significant roles in the reduction of traffic crashes and outcomes.

The output of **thesis point 4** had value to traffic safety policymakers in developing strategies that were used to analyze the desired operating speed of bend road. Based on the thesis point indicated above, the higher severity level was registered on the bend road due to the high speed and roughness of the road pavement. The theoretical concept and the practical analysis of speed across the design period of the road varied. As a result, based on the theoretical background of design speed, the desired speed across the design period for the bend road was analyzed using a novel empirical model derived from the existing design speed formula. Traffic crash occurrences are deliberately related to the existing vehicles maneuver speed.

The newly developed empirical model for desired speed analysis is used to analyze speed as the roughness of the bend road varies across the design period of the road. Even though the existing concept of speed is defined based on the minimum radius of curvature, maximum super elevation, and friction factor of the pavement, that design speed remains constant across the design period of the road. This conceptual framework of seep was not fictional due to the variation in roughness of the road that causes a change in the friction factor.

To overcome traffic crash-related problems that happen due to the speed of maneuvers, this thesis point will bring significant outcomes in minimizing traffic crash occurrences and their outcomes. The newly introduced empirical model will improve the safety of the road by optimizing speed usage according to the existing condition of the road pavement roughness.

Compared to the existing conceptual framework in speed analysis, the newly introduced empirical model has a significant impact on defining operating speed based on the design period of the road, except at the opening phase of the project. So, stakeholders must utilize the stated alternative approaches to analysis vehicles maneuver speed that minimize the occurrences of traffic crashes.

The above finding revealed that a novel speed analysis approach had a strong remark on road segment severity level analysis that was used to manage or minimize traffic crash occurrences. In the future, the trend of traffic crash occurrences and their outcomes (accidents) will be minimized by undertaking proper mechanisms/methods used to analyze the operating speed based on the current condition of the road pavement roughness. By implementing the stated empirical formula, the road safety supervision team/stakeholders would play significant roles in the reduction of traffic crashes and outcomes.

The findings of **thesis point 5** had a benefit to traffic safety policymakers in developing strategies that consider the topographic formation of the roads and the traffic crashes. In most dangerous road section analysis approaches, the topographic formation of the earth was not considered in the occurrences of traffic crashes. Based on the thesis point indicated above, the triangular irregular network (TIN) is more powerful to detect dangerous road sections based on the elevation difference, slope variation, and terrain formation between traffic crash locations. The topographic formation of the road is directly related to traffic crashes.

Even though a triangular irregular network was used to analyze spatial data using GIS techniques, the application of this approach is also applicable as a mechanism to analyze dangerous zones of the road network that lead to more traffic crash occurrences. As a result, this approach was used as a novel method to analyze black spot locations of the road network based on the topographic formation of the road based on elevation difference, slope variation, and terrain formation of the road network. The applicability of this method basically depends on spatial data formation that uses vector data (x, y, z).

Based on the analysis and the outcome of the study, traffic crash occurrences are deliberately related to the existing topographic formation of the earth. As indicated above, even though road geometry formation had a significant impact on the occurrence of traffic crashes, topographic formation of the road had a significant influence on the occurrences of traffic crashes. To detect the black spot location and severity level of the road segment using a triangular irregular network (TIN) plays a significant role at the macroscopic level of the road network.

To overcome traffic crash-related problems that happen due to elevation differences, slope variations, and terrain formations, this thesis point will bring significant outcomes in minimizing traffic crash occurrences and their outcomes. The newly introduced approach will improve the safety of roads by optimizing topographic formation and its usage. So, stakeholders must utilize the stated substitute approaches to analyze center of traffic crash attraction that are used to overcome the occurrences of traffic crashes. By implementing the triangular irregular network (TIN), it is easy for stakeholders to identify locations highly affected by traffic crashes and their outcomes.

Finally, the outcome of this **thesis point 6** had a value to traffic safety policymakers in developing strategies that consider the abrupt growth of micromobility vehicles and related accidents. In most policy and strategy markets, the service trend of micromobility vehicles and related problems was not in consideration, particularly in highly populated and developing regions. Based on this thesis point, the concerned body will understand the market and service trend of micromobility vehicles, factors that deter the accessibility of micromobility vehicles and their causes for accidents that minimize losses of life and injuries, and economic costs.

Based on the analysis and the outcome of the study, micromobility accidents are deliberately associated with technical problems of micromobility vehicles that cause fires, riders not using helmets, collisions with other vehicles, pedestrians, and fixed objects, the nature of the vehicles

by themselves, visibility, and seasonal variation. Identifying the cause of micromobility accidents is one step towards minimizing related problems. If the group concerned emphasizes the stated problem and undertakes proper action, the situation will degrade.

The reviewed information and the remedial action assessed will improve the safety of micromobility vehicles. So, stakeholders must understand the probable factors that cause micromobility accidents that are helpful in strategy and policy implementation that maximizes traffic safety. By understanding the ultimate growth of micromobility and its accidents, the stakeholder must use this review finding as an input to commence a solution that minimizes micromobility accidents.

6. List of publications

Thesis 1

- Debela Jima and Dr. Tibor Sipos, The Impact of Road Geometric Formation on Traffic Crash and Its Severity Level, Sustainability, doi.org/10.3390/su14148475. **IF-3.3**
- Debela Jima and Dr. Tibor Sipos, Explanatory Review of Road Geometric Formation Effects on Traffic Crashes in European Union (EU), XIV International Conference on Transport Sciences, Győr, Hungary.
- Debela Jima and Dr. Tibor Sipos, Long Term, Pre, and Post Impacts of SARS-CoV-2 Pandemic on Road Traffic Crashes in the Case of Budapest, Hungary, Periodica Polytechnica Transportation Engineering, doi.org/10.3311/PPtr.20765. **Scopus Indexed**
- Debela Jima, Tibor Sipos, Retta Zewdie, A Review of Environmental Impact of Motorized Vehicle on Human, 8th TAE 2022, 20 - 23 September 2022, Prague, Czech Republic. **Scopus Indexed**

Thesis 2

- Debela Jima and Dr. Tibor Sipos, Examining Traffic Crash Scene Using Density Estimation and Its Relevance to Determine Intersection Zone Road Network Blackspot Location, The Egyptian Journal of Remote Sensing and Space Sciences, doi.org/10.1016/j.ejrs.2023.07.002. **IF-4.1**

Thesis 3

- Debela Jima and Dr. Tibor Sipos, Road geometry-related crash distribution, economic losses, and an alternative severity level analysis approach using combined parameters utilizing relative percentage share, Innovative Infrastructure Solutions, doi.org/10.1007/s41062-024-01815-9. **IF-2.4**
- Debela Jima and Dr. Tibor Sipos, Impacts of Traffic Accident and Crash Costs in Severity Level Analysis, Quality Festival 2025, May 21st – May 23rd, Kragujevac, Serbia.

Thesis 4

- Debela Jima and Dr. Tibor Sipos, Empirical Model and Side Friction Effect on Desired Speed at Horizontal Curved Road, Journal of Engineering Research, doi.org/10.1016/j.jer.2024.01.026. **IF-2.2**

Thesis 5

- Debela Jima and Dr. Tibor Sipos, Interactive Effects of Elevation Difference, Slope Variation, and Terrain Formation on Road Traffic Crashes Occurrences Using Triangular Irregular Network (TIN), Engineering Reports, doi.org/10.1002/eng2.12971. **IF-2**

Thesis 6

- Debela Jima and Dr. Tibor Sipos, An Organized Review of Micromobility Factors Contributing to Accidents, Market and Service Trend, and Related Mishaps, International Journal of Crashworthiness, doi.org/10.1080/13588265.2025.2492994. **IF-2**

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