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Determining Risk Factors That Influence Cycling Crash Severity, for the Purpose of Setting Sustainable Cycling Mobility

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Abstract: This paper has, for the purpose of setting sustainable cycling mobility, identified and assessed basic risk factors influencing crash severity. The study has examined risk factors for cyclist injuries and fatalities, according to the characteristics relative to cyclists, roads, vehicles and environment posing the risk of cyclist fatalities or serious injuries. The method of Binary logistic regression has been used as the study to analyze a sample of 21,235 traffic crashes involving cyclists in Serbia, over the period 2010–2021. The task was not to define the equations for risk prediction, but to determine the injury and fatality risk factors for cyclists. The results of this study show that cyclists older than 60 have a higher probability of being injured. Cyclists are more likely to be injured or killed on weekdays than on weekends, as well as in conditions of twilight. The odds of fatality and injury outside built-up areas are higher, while the odds of sustaining a serious injury are higher in built-up areas. The results of this study indicate significant overlapping with the previous research related to the analysis of factors influencing the severity of cyclist crashes. These results can be important for the policy makers and stakeholders involved, as they can help them gain clear understanding of the current road safety situation, for the purpose of creating an opportunity for developing best action plans and practical measures in the process of implementing sustainable urban mobility planning.

Keywords: cyclist; road safety; sustainable mobility; risk; factors; binary logistic regression

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1. Introduction

Bicycle traffic has an increasing share in the modal split [1–3], especially for making the short to medium length trips that characterise much of city travel [2] and micro-mobility [4]. Based on conservative estimates, the current levels of cycling in the EU bring benefits valued at around EUR 150 billion per year [5] and cycling is one of the keys to sustainable mobility because of its benefits such as zero emission, low land use and positive effect on overall health [6,7]. In addition to the terrain, climate and elevation [7], development of bicycle traffic, cycle-friendly design, design of the cycle network (design manual for bicycle traffic), the main prerequisites for the development of bicycle traffic is tradition, or cycling culture [8]. However, cyclists represent a large group of vulnerable road users, because they have no physical protection in case of a crash with motorized vehicles [9]. Hence, they are almost 12 times more vulnerable than passenger car drivers [10]. In the guide *"Supporting and encouraging cycling related to European Commission's Sustainable Urban Mobility Planning (SUMP)"*, one of the primary reasons why people do not ride a bike is the perceived insecurity of sharing the road with motorized transport [11].

According to a pilot exposure study conducted in Serbia in 2019, the average travel time spent while cycling is 7.3% of the total travel time. According to the average number of trips, the use of bicycles accounts for 7.8% of the total number of trips, while in the total number of persons–km, cyclists represent about 3.0%.

When compared to the average annual cyclist deaths per million inhabitants, in the period 2016–2018, Serbia (6.8) ranks 28th out of 32 countries, according to the value of this indicator, which is about 1.6 times higher than the European average (4.2) [12]. The enforcement of the Road Traffic Safety Law (RTSL) in 2009 significantly changed the cyclist safety in Serbia. The implementation of the RTSL in 2009 resulted in the decrease of both fatalities and injuries for vulnerable road users, regardless of whether these included minor or serious injuries sustained by cyclists. Thus the number of minor injuries was reduced by 27.1%, the number of seriously injured by 29.2% and of fatalities—by 27.9% [13]. The main reasons for this are new provisions of the RTSL governing reduction in speed limit in urban areas, from 60 to 50 km/h, as well as provisions related to the introduction of pedestrian zones, slow traffic zones, 30 km/h zones and school zones. Bearing that in mind, collision speeds in crashes with vulnerable road users were also reduced, which led to the previously described results. The new RTSL does not oblige the cyclists to use protective helmets. Still, safer cycling conditions were created, which might result in more cycling. However, in the period following the enforcement of this law, the number of killed cyclists has had no clearly defined downward trend. This indicates that the road traffic safety system, the awareness of motor vehicle drivers and other required factors have not been firmly established. In the period 2010–2021, the number of traffic crashes involving cyclists decreased at the average annual rate of 2.5%, i.e., it was reduced by 22.7% in comparison with the baseline year of 2010 (Road Traffic Safety Agency). The 2010–2021 period has also seen the decreasing trend of the number of seriously and slightly injured cyclists. However, this decline was not constant in that period, because in 2016, the number of injured and killed cyclists increased by 2.2% when compared to 2015. On average, cyclists are included in 4.8% of the total number of traffic crashes, while they are considerably more present in traffic crashes with injuries and fatalities—in about 7.9% of cases [14], which certainly creates additional concern and uncertainty.

Bearing in mind the situation of cyclist safety in Serbia and rare research studies addressing cyclist safety, it is required to conduct studies in this field in order to eliminate any unknown facts and uncertainties. Focusing on cyclist safety research helps identify the key elements of the cyclist safety in Serbia. Previously conducted studies and their results can be used as guidelines in that process. Some of the previous studies are based on the quantification of the problem's size [15–19], while others are centred upon the demographic and behavioural characteristics. In their study, Boufous et al. [19] examined whether the characteristics of cyclists (age, gender and wearing a safety helmet), road (type of the road, road geometry, speed limits, rural or urban location) and collisions (time and day, other involved vehicles, collision type) were related to the severity of injuries of the cyclists involved in traffic crashes in Victoria (Australia). The motivation for the research presented in this paper was to examine the contribution of risk factor analysis to cyclist safety in Serbia.

The *"Guide to Urban Road Safety and Active Travel in Sustainable Urban Mobility Planning"* [20] highlights the importance of establishing associations between different data elements to understand what types of traffic accidents occur and which road users and social groups are involved in which parts of the city, them all being a basis for identifying the most suitable measures that can improve road safety. The aim of this research is to determine the risk factors that influence crash severity, for the purpose of establishing sustainable cycling mobility. The task of the research is to examine the possible existence of and the impact the characteristics related to cyclists (gender, age, etc.), road (condition of the carriageway, carriageway characteristics, etc.), vehicles (number of vehicles involved in crashes, vehicle types, etc.) and environment (day, hour, light conditions, etc.) have on the risk of cyclist fatalities or serious injuries. Potential correlations and the way in which the impact of the observed parameters is exerted were analysed for three different models regarding the data related to bicycle riders and bicycle passengers (cyclists).

The paper consists of five parts. The introduction gives an overview of the importance of cycling, as a micro-mobility means of transport, as well as an overview of the general situation of cyclist safety in Serbia and a brief overview of previous research studies related to the analysis of factors that influence the severity of cyclist collisions, which are used as guidelines. The second part contains a description of the materials and research methods used and a description of the data used, as well as the specific features and steps in using the binary logistic regression method (BLR). The third part contains a presentation of the research results through a descriptive analysis of traffic accidents with cyclists, and characteristics of binary logistic models. The fourth part offers a discussion in which the results of risk factors contributing to injuries and deaths of cyclists in Serbia are discussed and compared with other similar studies. This part also gives main conclusions, contribution, limitations and guidelines for future research. The paper ends with conclusions from the conducted research, as well as a description of future research in this area.

2. Materials and Methods

2.1. Crash Database

Road Safety Database is publicly available through the WEB GIS application, at http://bazabs.abs.gov.rs/ [14]. The Road Traffic Safety Agency receives data on traffic crashes and their consequences from the Ministry of Interior of the Republic of Serbia, and these data are available in the Integrated Road Safety Database of the Republic of Serbia.

The latest major revision of the road crash database was conducted in 2015 and 2016. Following these revisions, the road crash database is now completely harmonised with the requirements of the European Commission's Common Accident Data Set (CADaS), and since January 2016, traffic police have been collecting data on road crashes in accordance with the CADaS recommendations.

Traffic police must attend the scene of all road crashes with fatalities and injuries and crashes with significant material damage. For other crashes, parties involved are allowed to fill in a special form without calling the traffic police. However, if one of the parties involved in a crash requests the presence of the police, the police shall attend the crash scene in that case. Data on crashes not covered by the traffic police are collected by insurance companies.

Information on injury severity is recorded by the traffic police, and is based on information from hospitals. Hospitals are obliged to inform the police of every person admitted to hospital claiming to have been involved in a road crash. There is no information on the level of under-reporting.

It should be noted that there are bicycle crashes that are not reported (so called "grey" bicycle crashes). Namely, there is a significant level of under-reporting of bicycle crashes in police crash reports, and this phenomenon is present worldwide. As an average, only 10% of all crashes are reported to the police, ranging from the minimum of 0.0% (Israel) and 2.6% (Croatia), to a maximum of 35.0% (Germany) [21].

In addition to the basic, independent variables from the main road crash database for the period 2010–2021 [14], the paper also includes the data on the position of the Sun [22] on the date of the crash, which served for the calculation of the corresponding light condition. All the data used in the research were organized in a Microsoft Office Excel database, within which the research results were filtered, cross-referenced, encoded and presented in tables. The data were imported in the SPSS Software (by IBM SPSS Statistics, Version 26.00, Armonk, NY, USA) where the normality and multicollinearity tests and binary logistic regression were performed.

Definitions

A crash is any crash that occurred on the road or start of the road, in which at least one moving vehicle was involved and in which at least one person was killed or injured or material damage occurred. The driver, or another person involved in a traffic crash in which a person sustained bodily injuries or died, or in which a great material damage was caused (amounting to more than EUR 1700) is obliged to report the traffic crash to the police.

In the case of a cyclist, he/she is obliged to call the police if an injury or damage occurred exceeding the prescribed amount. Road fatality: any person who is killed immediately or within 30 days, as a result of a road crash. Injured: Any person who was not killed but sustained one or more serious or slight injuries as a result of a road crash.

Serbia has not yet adopted a definition for a serious or slight injury in police records [23]. Nevertheless, there are criteria for both categories enabling doctors to determine the injury severity of a person involved in a road crash. In 2017, Serbia conducted research addressing the options for introducing/implementing the Maximum Abbreviated Injury Scale (MAIS3+) for determining injury severity of those injured in road crashes in Serbia. The process of establishing a system for recording road injuries in accordance with the MAIS3+ injury scale began in mid-2019.

2.2. Sample

The total sample consisted of 21,234 road crashes involving cyclists, with the total number of 38,971 vehicles and 42,120 road users. Out of the total number of road users, cyclists (bicycle riders, bicycle passengers) amounted to 21,840 (20,808 of them with known consequences). However, since the binary logistic regression only considers the variables without missing data, the model involved 20,808 cases. For a sample of 20,808, confidence level of 99% and confidence interval of 2%, the required sample is 3743, therefore, a sample of 20,808 is sufficient in this case.

2.3. Selection and Determination of Statistical Methods

The research into risk factors was preceded by an analysis of previous research studies, and focused on statistical modelling factors that contribute to the severity of the consequences of road crashes involving cyclists. Several other researchers used the binary lo-gistic regression to investigate the risk factors contributing to cycling crash severity. Lo-gistic regression analysis had been widely used to analyse road crash risk factors for which the dependent variable is binary. Like other regression analyses, it establishes a re-lationship between a dependent and independent variable(s) and allows simultaneous investigations of many other variables [24].

Binary logistic regression has been chosen as a method since it offers a possibility for comparing the results with several similar studies addressing the topic of determining risk factors that influence the severity of a bicycle crash and using the same method (Table 1).

Table 1. Different models used in previous studies that investigated the factors influencing bicycle crash severity.

Study	Response Variable	Dataset	Location	Methodology	Factors
Klop et al. [25]	Cyclist crashes	1025	North Carolina, USA	Probit regression	Average Annual Daily Traffic, Light Conditions, Road Character, Right Shoulder Width, Location, Speed Limit, Traffic Control Type, Weather Condition
Boufous et al. [19]	Cyclist crashes	6432	Victoria, Australia	Binary logistic regression	Age, Helmet use, Light condition, Crash type, Speed limit, Location, Road curvature
Kim et. al. [26]	Cyclist crashes	2934	North Carolina, USA	Multinomial Logistic regression	Age, Gender, Alcohol, Helmet use, Vehicle speed, Vehicle type, Bicycle direction, Type of accident, Party at fault, Speeding, Road defects, Location, Type of Traffic control, Road Geometry, Asphalt characteristics, Road type, No. of traffic lanes, Land use, Temporal characteristics, Time, Weather, Light, Road surface
Bil et. al [27]	Cyclist injuries	5428	Czech Republic	Binary logistic regression	Cause, Road geometry, Crash direction, Visibility, Gender, Age, Alcohol

Table 1. *Cont.*

Study	Response Variable	Dataset	Location	Methodology	Factors
Lin and Fan [28]	Cyclist crashes	8049	North Carolina, USA	Mixed logit	Daytime, Gender, Age, Cyclist direction, Alcohol, Cyclist position, Vehicle type, Speed limit, Rural/Urban, Road condition, Traffic control, Light condition, Region, Work zone, Development, Crash type, Crash location
Jaber et al. [29]	Cyclist injuries	14,000	Hungary	Binary logistic regression	Roadway, Traffic Control, Surface Condition, Lighting, Marking, Topography, Pavement, Location Type, Weather, Area, Roads Hierarchy
Baran et al. [30]	Crashes involving all aging (65+) roadway users (drivers, passengers, bicyclists and pedestrians)	161,322	United States compels	Multivariate random parameter tobit model	65+PF Density, AADT, Truck AADT, Speed Limit, Bike Lane, Arterial Rd, County Rd, Median Width Shoulder Type, Shoulder Width, Sidewalk Width, Intersection, Health Facility, Hospital School, Religious Facility Supermarket

Due to the advantage mentioned above, this study has utilized the binary logistic model to analyse the underlying factors towards injury severity in crashes involving cyclists.

2.3.1. Binary Logistic Regression

Logistic regression measures the relationship between the categorical dependent variable and one or more independent variables by estimating probabilities using a logistic function, which is the cumulative logistic distribution [31]. In the model used, all predictor variables are tested in a single block to assess their predictive ability while controlling the effects of other predictors in the model [32]. The function was first introduced by the Belgian mathematician Wehulst [33]. At the beginning of the twentieth century, a large number of scientists investigated its properties and the possibility of use. Cox was the first one to use the regression function in 1958. With the logistic function, the value is limited between 0 and 1. It can be seen from the basic setting that the value 0 is obtained in the case that $k = -\infty$, the value 1 is for $k = \infty$ and for $k = 0$, the value of the function is 0.5. The binary logistic regression model is the following (Equation (1)):

$$\pi(x) = \frac{e^{\beta_0 + \sum_{j=1}^{k} \beta_j \cdot x_j + \varepsilon}}{1 + e^{\beta_0 + \sum_{j=1}^{k} \beta_j \cdot x_j + \varepsilon}} \tag{1}$$

π: Probability that Y = 1 given X
Y: Dependent Variable
X_k: Independent Variables
β_k: Model Parameters 0.

For a binary dependent or response variable 'Y' and an independent or predictor variable 'X', $\pi(X)$ to represent the probability that Y = 1 and $1 - \pi(X)$ to represent the probability of Y = 0 [34].

If the likelihood of occurrence of an event "A" is $p(A)$, the odds that A will occur are defined as *Odds* Equation (2):

$$Odds(A) = \frac{p(A)}{1 - p(A)} \tag{2}$$

2.3.2. Model

Variables, the number of levels of each variable and encoding of the data was conducted as presented in Table 2. It should be mentioned that the variables (factors) were encoded so that the digit 0 marked the assumed lower-risk category, while the digit 1 represented the assumed higher-risk category.

Table 2. Characteristics of traffic crashes involving cyclists.

	(BLR Code) Factor	% No Injury (n = 2228)	% Killed (n = 596)	% Seriously Injured (n = 4991)	% Slightly Injured (n = 12,993)	% Casualties (n = 18,580)	% Total (n = 20,808)
Gender	(2) Male	81.6%	85.7%	66.5%	64.1%	65.5%	67.2%
	(1) Female	18.4%	14.3%	33.5%	35.9%	34.5%	32.8%
Age	(0) 0–9	4.5%	1.2%	2.8%	5.1%	4.4%	4.4%
	(1) 10–19	16.2%	4.0%	12.2%	18.0%	16.0%	16.0%
	(2) 20–29	15.3%	3.4%	6.8%	11.2%	9.8%	10.4%
	(3) 30–39	15.2%	6.5%	7.4%	10.8%	9.8%	10.3%
	(4) 40–49	14.2%	8.6%	11.6%	12.2%	11.9%	12.2%
	(5) 50–59	17.5%	19.0%	19.9%	15.8%	17.0%	17.0%
	(6) 60+	17.0%	57.4%	39.3%	26.9%	31.2%	29.7%
Day of the week	(0) Workday	75.4%	70.8%	74.3%	77.2%	76.2%	76.1%
	(1) Weekend	24.6%	29.2%	25.7%	22.8%	23.8%	23.9%
Light condition	(0) Day	72.8%	49.7%	70.0%	73.1%	71.6%	71.7%
	(1) Civil	3.9%	5.2%	4.4%	4.0%	4.1%	4.1%
	(2) Nautical	3.6%	12.1%	4.9%	4.9%	5.1%	5.0%
	(3) Astronomical	3.1%	10.1%	4.1%	3.4%	3.8%	3.7%
	(4) Night	16.6%	23.0%	16.5%	14.7%	15.4%	15.6%
Hour (24)	0:01–6:00	3.3%	7.9%	3.4%	2.4%	2.9%	2.9%
	6:01–10:00	13.1%	18.5%	18.7%	16.9%	17.4%	17.0%
	10:01 –14:00	28.1%	17.1%	26.8%	28.3%	27.5%	27.6%
	14:01–18:00	29.8%	24.2%	25.8%	27.0%	26.6%	26.9%
	18:01–22:00	21.9%	25.0%	21.3%	22.1%	22.0%	22.0%
	22:01–24:00	3.9%	7.4%	3.9%	3.4%	3.6%	3.7%
Carriageway features	(0) No damage	92.5%	91.3%	91.9%	93.0%	92.6%	92.6%
	(1) Damaged	7.5%	8.7%	8.1%	7.0%	7.4%	7.4%
Carriageway state	(0) Dry	88.6%	84.6%	87.8%	88.4%	88.1%	88.1%
	(1) Wet	8.8%	11.9%	9.6%	9.6%	9.7%	9.6%
	(2) Ice/Snow	2.6%	3.5%	2.6%	2.0%	2.2%	2.3%
Location	(0) Built-up area	95.2%	73.0%	91.6%	94.9%	93.3%	93.5%
	(1) Outside built-up areas	4.8%	27.0%	8.4%	5.1%	6.7%	6.5%
Type of other vehicles	(0) Only bicycle	29.4%	12.8%	27.3%	19.6%	21.4%	22.3%
	(1) Bicycle	11.5%	0.2%	3.5%	2.2%	2.5%	3.4%
	(2) Two-wheeler	4.2%	2.3%	2.9%	2.3%	2.5%	2.7%
	(3) Passenger car	49.8%	61.7%	56.9%	67.9%	64.8%	63.2%
	(4) Heavy-duty/Bus	4.4%	21.5%	8.7%	7.4%	8.2%	7.8%
	(5) Pedestrian	0.6%	1.5%	0.8%	0.6%	0.6%	0.6%

The aim of the research is to determine which independent factors have an impact on the severity of consequences of road crashes and the way in which their impact is exerted. This analysis was conducted by means of the binary logistic regression. The task of the analysis was not to define the equations for risk prediction calculation, but to determine the risk factors for cyclist injuries and fatalities. The first step of the analysis included checking the normality of 10 independent factors, whereby it turned out that normality of distribution was not confirmed: Gender (GEN); Age (AGE); Day of the week (DoW); Light condition (LiC); Hour (HOUR); Carriageway features (CAF); Carriageway condition (CAC); Location (LOC); Type of the other participant (TOP).

Following the normality test, it was required to check whether there were any correlations between the independent factors in order to fulfil the conditions regarding the non-existence of multicollinearity between the independent factors. Multicollinearity was examined using the Spearman's correlation coefficient (rho). If the correlation coefficient is higher than 0.500 (Choen), it means that there is multicollinearity which disables understanding of the impact of independent factors on dependent factors.

Three binary logistic models were formed with the aim to examine the impact of the independent factors on the three dependent variables:

- M1: Injury or fatality risk (odds of injuries or fatalities—including deaths in comparison to no injuries, cyclists involved in road crashes),
- M2: Risk of serious consequences 1 (odds of a serious injury occurring in comparison to slight injuries or no injuries),
- M3: Risk of serious consequences 2 (odds of a serious injury occurring in comparison to slight injuries).

The application of the Omnibus test examined the statistical significance of each model. After the suitable models had been defined, the above-mentioned statistical package was used to calculate the logistic regression coefficients in the models for each factor. Whether a particular factor partially significantly affected the severity of consequences was evaluated by the Wald test and the 95% confidence interval for the exponentiated logistic regression coefficient.

3. Results

3.1. Descriptive Analysis of Road Crashes Involving Cyclists

Descriptive analysis of included and excluded data is shown in Table 2. Two thirds of the injured and killed cyclists were male (65.5%), 20.4% were cyclists aged up to 20, while 48.1% were older than 50. The most represented age categories in the sample were 60 and older (31.2%) and 50–59 years (17.0%).

When it comes to the ratio of workdays and days of the weekend, somewhat less than a quarter of traffic crashes involving cyclists occur at weekends. Most cyclist injuries and fatalities happen during the day (71.6%), while 15.4% occur at night. On the other hand, 13.0% injuries and fatalities are recorded in the twilight. The periods around noon (from 10 a.m. to 2 p.m.) and afternoon (from 2 p.m. to 6 p.m.) have the highest share of cyclists (about 27%).

Almost all observed cyclists were involved in road crashes which occurred on the carriageway without any particular damage (92.6%). Furthermore, in 88.1% of the cases, the carriageway was dry at the time of crash. About 9.7% of cyclist injuries or fatalities were recorded in road crashes that occurred on the wet carriageway, while 2.2% were registered on the carriageway covered with ice or snow.

The largest number of road crashes with cyclist injuries and fatalities (as many as 93.3%) occur in built-up areas. There were no other vehicles included in road crashes in 21.4% of cyclist injuries and fatalities. Passenger cars prevail (64.8%) in road crashes involving other vehicles.

3.2. Characteristics of Binary Logistic Models

The normality test of the independent variables showed that the assumption of the normality of distribution was not confirmed (Table 3). On the basis of the obtained values of the Spearman coefficient (rho), it can be concluded that none of the factors has a correlation coefficient above the set threshold, while the strongest correlations are found between the *Carriageway condition* and *Weather conditions*, which is to be expected, given that the road is wet if it rains. The presented results show that all the observed factors are independent and as such can be applied in the binary logistic regression.

Table 3. Intercorrelation of the factors.

	GEN	AGE	DoW	LiC	HOUR	CAF	CAS	U/RA	TOP
GEN	1	0.009	−0.038 **	−0.051 **	−0.087 **	−0.029 **	0.006	−0.083 **	0.084 **
AGE		1	−0.031 **	−0.062 **	−0.223 **	−0.037 **	0.069 **	0.005	0.122 **
DoW			1	0.015 *	0.025 **	0.020 **	−0.020 **	0.034 **	−0.079 **
LiC				1	0.311 **	0.008	0.137 **	0.065 **	−0.036 **
HOUR					1	0.030 **	0.001	0.044 **	−0.116 **
CAF						1	0.015 *	0.065 **	−0.113 **
CAS							1	−0.015 *	0.034 **
LOC								1	−0.028 **
TOP									1

** Correlation is significant at the 0.01 threshold; * Correlation is significant at the 0.05 threshold.

The application of the binary logistic model aims to examine the impact of several independent (predictor) variables on a dependent variable. The dependent variable is injury and fatality risk which can have two values (M1—no consequences and killed/injured, M2—no consequences/slight injury and killed/serious injury, M3—slight injury and killed/serious injury). All nine independent factors are included in the model.

The statistical significance of the observed models was examined by means of the Omnibus test. The null hypothesis was proposed: "All logistic regression coefficients in the model equal 0". With 47 degrees of freedom and the 0.000 statistical significance of this test (which means that $p < 0.05$), the obtained value of the χ^2 test amounted to 1101.371 in the case of M1 and 1192.358 in the case of M2 and M3. On the basis of the obtained Omnibus test results, the null hypothesis is rejected while the alternative hypothesis is accepted in all three observed models. This shows that the observed predictors having an impact on cyclist injuries and fatalities are included in a road crash. In addition, the obtained results indicate that the M1 model explains between 5.2% and 10.4% of the variance, while the M2 and M3 models explain between 5.6% and 8.1%.

The classification table shows how accurately the model predicts the category for each examined case, i.e., the improvement achieved by including predictor variables in the model (Figure 1 and Table 4). The success (compatibility of the results obtained in the model and the actual results) of the model which does not include predictor variables is 89.3% for the M1 model and 73.1% for the M2 and M3 models (Table 4). The models without predictors envisage that all cyclists will sustain injuries or die in a road crash, which is the consequence of the fact that most cyclists get killed or injured.

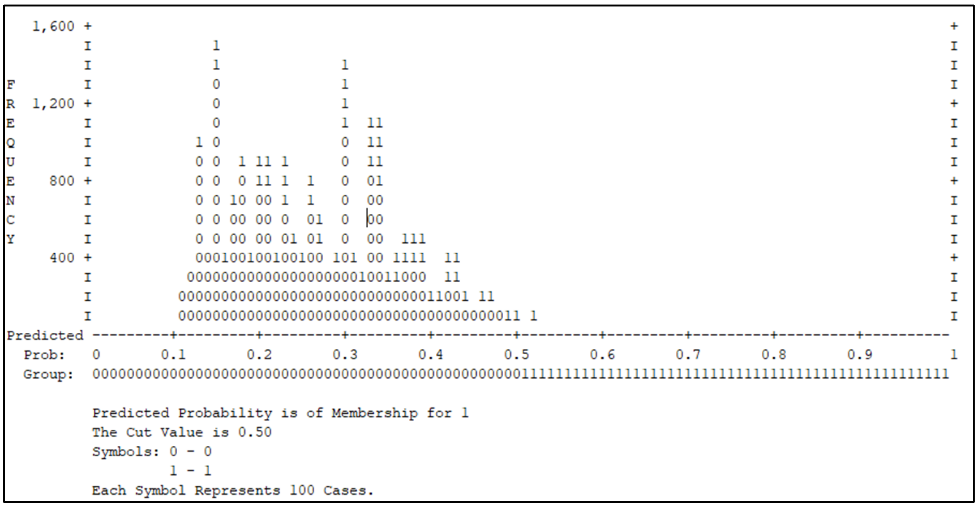

Figure 1. Observed groups and Predicted Probabilities Plot.

Table 4. Classification table—models without predictors/with predictors.

Recorded			Predicted 0	Predicted 1	Accuracy Percentage
M1	without predictors	0	0	2228	0.0%
		1	0	18,580	100.0%
		Total			89.3%
	with predictors	0	81	2147	3.6%
		1	62	18,518	99.7%
		Total			89.4%
M2/M3	without predictors	0	15,221	0	100.0%
		1	5587	0	0.0%
		Total			73.1%
	with predictors	0	14,998	223	98.5%
		1	5301	286	5.1%
		Total			73.5%

Those new models, which include predictor variables, have a more successful prediction of injury and fatality than the models without predictor variables. The success of these models amounts to 89.4% in M1 and to 73.5% in the M2 and M3 models. Taking into account that the same values were obtained in the two independent models M2 and M3, they will be shown below as one column—value.

3.3. Main Results of Binary Logistic Models

This part of the paper presents the odds of injury or fatality and the odds of serious consequences as the value of Exp (B) (Table 5). Taking into account that the main objective of this paper is not to obtain an equation for risk prediction or to develop a predictive model, the significance (sig.) column in Table 5 was not taken into consideration. Thus, significance indicates whether a particular variable has a significant contribution to the predictive capabilities of the model or not. Thus, regardless of the value of sig., the odds relationship exists and is relevant. Female cyclists are 2.63 times more likely to be injured and killed, and 1.01 times more likely to sustain a serious injury than male cyclists, when involved in a road crash. Cyclists older than 60 have the highest probability of being injured in a road crash. Cyclists older than 60 are 1.82 times more likely to be injured than children aged 0–9 and the odds that a serious or fatal injury will occur is 3.21 times higher than with children aged 0–9. Considering the odds of occurrence of a serious or fatal injury in a road crash, the second age category is cyclists aged 50–59, with 2.27 times higher odds than the odds of children aged 0–9. Cyclists aged 30–39 have the lowest odds of being injured and killed, while cyclists aged 20–29 have the lowest odds of a serious injury.

Table 5. Evaluation of risk factors for the occurrence of serious and fatal injuries—binary logistic regression.

		M1					M2/ M3				
				95% Limit of CI					95% Limit of CI		
(BLR Code) Factor		Exp(B)	Rank of Exp(B)	Lower	Upper	Sig.	Exp(B)	Rank of Exp(B)	Lower	Upper	Sig.
Gender	(2) Male	0.00	2	0.00	0.00	0.00	0.00	2	0.00	0.00	0.00
	(1) Female	2.63	1	2.34	2.96	0.00	1.01	1	0.95	1.09	0.70
Age	(0) 0–9	0.00	3	0.00	0.00	0.00	0.00	6	0.00	0.00	0.00
	(1) 10–19	1.05	2	0.82	1.33	0.72	1.14	4	0.94	1.39	0.19
	(2) 20–29	0.62	6	0.48	0.79	0.00	0.92	7	0.75	1.14	0.46
	(3) 30–39	0.60	7	0.47	0.77	0.00	1.13	5	0.91	1.39	0.26
	(4) 40–49	0.77	5	0.60	0.99	0.04	1.61	3	1.32	1.96	0.00
	(5) 50–59	0.86	4	0.67	1.09	0.20	2.27	2	1.87	2.76	0.00
	(6) 60+	1.82	1	1.43	2.31	0.00	3.21	1	2.67	3.87	0.00
DoW	(0) Workday	1.03	1	0.92	1.14	0.63	1.18	1	1.09	1.27	0.00
	(1) Weekend	0.00	2	0.00	0.00	0.01	0.00	2	0.00	0.00	0.00
Light condition	(0) Day	0.00	4	0.00	0.00	0.01	0.00	5	0.00	0.00	0.00
	(1) Civil	1.08	3	0.85	1.38	0.53	1.25	3	1.06	1.48	0.01
	(2) Nautical	1.47	1	1.14	1.88	0.00	1.26	2	1.08	1.46	0.00
	(3) Astronomical	1.31	2	0.99	1.73	0.06	1.45	1	1.22	1.73	0.00
	(4) Night	0.94	5	0.81	1.10	0.44	1.22	4	1.10	1.35	0.00
Hour (24)	0:01–6:00	0.00	2	0.00	0.00	0.00	0.00	1	0.00	0.00	0.00
	6:01–10:00	0.95	4	0.70	1.30	0.75	0.78	3	0.64	0.96	0.02
	10:01 –14:00	0.74	6	0.55	1.00	0.05	0.65	6	0.53	0.80	0.00
	14:01–18:00	0.78	5	0.58	1.04	0.09	0.75	5	0.61	0.91	0.00
	18:01–22:00	0.95	4	0.72	1.26	0.72	0.75	4	0.62	0.91	0.00
	22:01–24:00	1.18	1	0.83	1.66	0.35	0.92	2	0.73	1.17	0.50
Carriageway features	(0) No damage	0.00	2	0.00	0.00	0.00	0.00	2	0.00	0.00	0.00
	(1) Damaged	1.13	1	0.95	1.35	0.17	1.09	1	0.97	1.23	0.14
Carriageway state	(0) Dry	0.00	1	0.00	0.00	0.15	0.00	2	0.00	0.00	0.23
	(1) Wet	0.97	2	0.83	1.14	0.73	0.94	3	0.85	1.05	0.28
	(2) Ice/Snow	0.75	3	0.56	1.00	0.05	1.14	1	0.93	1.39	0.21
Location	(0) Built-up area	0.00	2	0.00	0.00	0.00	0.00	2	0.00	0.00	0.00
	(1) Outside built-up areas	1.62	1	1.32	2.00	0.00	1.97	1	1.75	2.21	0.00
Type of road user	(0) Only bicycle	0.00	5	0.00	0.00	0.00	0.00	3	0.00	0.00	0.00
	(1) Bicycle	0.24	7	0.20	0.29	0.00	0.74	5	0.61	0.89	0.00
	(2) Two-wheeler	0.66	6	0.52	0.84	0.00	0.78	4	0.64	0.96	0.02
	(3) Passenger car	1.59	3	1.43	1.77	0.00	0.67	6	0.62	0.72	0.00
	(4) Heavy-duty/Bus	2.20	2	1.76	2.75	0.00	1.01	2	0.89	1.15	0.87
	(5) Pedestrian	1.19	4	0.66	2.13	0.57	1.19	1	0.82	1.73	0.36
	(6) Other	6.04	1	0.00	0.00	0.00	0.30	7	0.00	0.00	0.00

Cyclists have the higher probability of being seriously and fatally injured on workdays, the probability of road injury and death is 1.03 times higher, while the probability of sustaining a serious injury is 1.18 times higher than on weekdays.

The parts of the day with the highest odds of injury and fatality for cyclists are the nautical twilight, when the odds are about 1.47 times higher than under daytime conditions, while during the astronomical twilight, the probability of being injured and killed is 1.31 times higher than under daytime conditions. On the other hand, the odds of occurrence of a serious injury are highest during the astronomical twilight when getting injured is 1.45 times more likely than under daytime conditions. The probability for a serious injury to occur is 1.22 times higher at night than in daytime conditions.

In terms of the hourly distribution, the highest probability of cyclist injury and fatality is in the period from 10 p.m. to 12 a.m. The odds of cyclists being seriously injured are significantly higher in the period from 10 p.m. to 12 a.m. when the probability is 1.18 times higher than it is in the period from 12 a.m. to 6 a.m. The odds of occurrence of a serious injury are higher in the period from 12 a.m. to 6 a.m. and 1.54 times higher than in the period from 10 a.m. to 14 p.m.

Cyclists are somewhat more likely to be injured and killed while travelling on a damaged carriageway—1.13 times more likely than when riding on a carriageway without damages. The probability of occurrence of a serious injury is 1.09 times higher on a damaged carriageway than on the carriageway with no damages. Travelling on the carriageway covered with snow or ice makes the odds of occurrence of a road crash with cyclist injury or fatality significantly higher than travelling on a dry or wet carriageway. The odds of occurrence of a serious injury are 1.14 times higher on a carriageway with snow/ice than on a dry carriageway.

When it comes to road crashes occurring outside built-up areas, the odds of an injury and fatality are 1.62 times higher, while the odds of occurrence of a serious injury are 1.97 higher than in road crashes occurring in built-up areas.

Considering traffic crashes with cyclists where other vehicles include a heavy-duty vehicle or a bus, the odds that an injury and fatality will occur are 2.2 times higher than in those crashes involving only a cyclist, whereas these odds are 1.59 times higher in road crashes involving passenger cars. On the other hand, the likelihood that a serious injury will occur is highest in road crashes involving pedestrians, then in crashes involving only a cyclist, whereas it is lowest in road crashes involving passenger cars.

4. Discussion

In this subsection, the results on risk factors for cyclist injuries and fatalities in Serbia are discussed and compared with another similar research. Despite the fact that men are involved in two thirds of traffic crashes, female cyclists have a higher probability of being injured or killed in road crashes, and are also most likely to be seriously injured. Cyclists older than 60 have the highest probability of being injured or killed and are most likely to be a road casualty (seriously or fatally injured). Therefore, it can be concluded that cyclists older than 60 are significantly more likely to be injured and killed when involved in a road crash. This can be explained by the fact that the increase in the injury level leads to a decrease in the share of children and the rise of older people involved in crashes. This result was also obtained by the researchers who studied factors affecting the severity of cyclists' injuries while being involved in traffic crashes in Victoria [19]. They determined that cyclists over the age of 50 had a twofold higher probability of occurrence of a serious injury. Similar results were reached in a study on road crashes involving bicycles and motor vehicles on two-lane roads in North Carolina [25]. The reason why older cyclists are more represented among the seriously injured, or why they are more likely to be seriously injured, can be the resistance of the body to injuries [35]. Namely, when compared to children, older cyclists have larger and more massive bodies, and also a greater energy while falling off the bicycle. Illnesses related to bone and muscle degeneration are more prevalent in older people, which leads to their increased fragility and slower responses [27].

A cyclist is more likely to be injured or killed in a road accident on weekdays than on weekends. The cause of this phenomenon may be that on weekends, in cases of recreation, bicycle drivers are more careful and capable. Different results were obtained by [26] in their research, according to which driving for recreational purposes is more risky.

Although the largest percentage of road crashes involving cyclists occur during the day, the highest odds of a cyclist being injured or killed are during the nautical twilight and astronomical twilight. At night, the odds of cyclists being injured and killed are smaller, but at the same time, they are more likely to be seriously injured at night than in daytime. The reason for this may be the fact that at night, there is less traffic flow and probability of an accident to happen, however, when an accident occurs, the consequences are fatal. Therefore, the twilight decreases the cyclists' safety in terms of the increased likelihood of occurrence of an injury or fatality and likelihood of occurrence of a serious injury. Boufous et al. [19] and Klop et al. [25] obtained similar results while simultaneously analysing the level of street lighting. In addition to the lowered response ability in poor visibility conditions, Klop et. al [25] correlated road crashes on unlit roads with rural areas, i.e., the areas the emergency crews might take longer to reach. Under poor visibility conditions, the car driver may fail to detect the cyclist and react in time [9]. The research has also found that cyclists overestimate at what distance they would be visible [36]. Numerous studies have shown an increased risk for cyclists who did not have adequate visibility aids [37–39].

The results show that the likelihood of occurrence of an injury or fatality and the odds of occurrence of a serious injury are greater on the roads with no damages. This result can be correlated with the fact that the road damages might lead to the occurrence of road crashes involving only cyclists and resulting in slight injuries.

The observed sample included only 6.5% of road crashes which occurred outside built-up areas. However, in these areas the odds of fatality and injury are higher, while the odds of occurrence of a serious injury are higher than in those crashes occurring in built-up areas. Boufous et al. [19] explained the higher risk of road crashes involving cyclists in rural areas by the fact that rural areas witness faster vehicle speeds and lack of cycling infrastructure, while the emergency crews may take longer time to reach them.

As for the road crashes involving cyclists, where the other vehicle involved is a heavy-duty vehicle or a bus, the odds of fatality and injury are higher than in road crashes involving only a cyclist. The probability of a serious injury occuring is the highest in road crashes involving pedestrians, then in crashes involving only a cyclist, while it is lowest in road crashes involving passenger cars. Prati et al. [9] emphasized two critical manoeuvres concerning bicycle–truck collision: cyclists attempting to pass trucks on the nearside at junctions [40] and trucks overtaking or being alongside the cyclists [41]. Namely, the reason for this distribution is definitely infrequent recording/reporting of road crashes involving only a cyclist who has sustained no injuries. The impact of the fact that a significant number of road crashes with slight injuries of cyclists are not reported to the police [42] was also recognized in the research on the impact of factors related to alcohol used by cyclists and on the characteristics of cycling infrastructure [19], in road crashes involving only the cyclist, as well as in the crashes involving pedestrians [43]. In the study on risk factors contributing to the occurrence of serious consequences in Victoria [19], a passenger car, as the other involved vehicle, was involved in 83% of road crashes with cyclists and in 50% of crashes with the seriously injured.

Contribution, Limitations and Future Research

This paper seeks to explore the risk factors that influence crash severity in order to provide sustainable cycling mobility. There is relatively little knowledge about the current situation, at the moment when cycling is becoming more popular as a type of mobility. The results obtained in this study are comparable with the existing research in other countries, and can be confirmed by them to a significant degree. Compared to a similar study conducted by Boufous et al. [19], which investigated seven factors, the proposed study investigates nine factors, of which three are overlapping, while helmet use, crash type, speed limit and road curvature are not included in the proposed study. On the other hand, the proposed study additionally includes the following factors in the analysis: Gender, Day of the week, Hour, Pavement characteristics, Pavement condition, Type of road user. In addition, compared to the study by Boufous et al. [19], this study provides a detailed methodology with a description of the model, as well as an interpretation of model parameters. While Boufous et al. [19] oriented the conclusions in their studies to specific proposals in terms of speed, lighting and modification of curved sections in terms of the length of the curve, the proposed study directs the application of the study in terms of opportunities for creating conditions in which the best safety action plans will be developed and practical measures defined for all policy creators and relevant stakeholders involved.

Limitations of the study:

- The main limitation of the research refers to the availability of complete data, having in mind that the binary logistic regression does not consider the variables with missing data, so a number of variables have been excluded from the research, such as the road characteristics, weather conditions and crash type.
- Single bicycle crashes are often strongly underreported, and there are no other factors in the database such as the driving speed of motorized vehicles on the crash road, speed limit or road conditions in terms of the existence of bicycle paths and lanes.
- Precise definition of the light condition, since the available database does not state the exact time of occurrence of a road crash, but it nevertheless provides the hour in which the road crash occurred. Sometimes it seems that the distributions of crashes seem to reflect the exposure of cyclists—people cycle at daytime, in good weather, in urban areas etc.
- The fact that males are overrepresented may largely be the result of the fact that they cycle more than females do. More detailed data on traffic exposure, with data on demographics and other characteristics, would significantly expand the focus on understanding the cyclist risk factors, as well as investigating other potential risk factors such as road characteristics, weather conditions and crash type.

Future research should be directed:

- At a more detailed examination of the defined risk factors, particularly the factors related to cyclist age, weather conditions and the time of the day, as well as the research of other potential risk factors,
- At a more detailed examination of the defined risk factors, as well as the study of other potential risk factors, particularly the factors related to the age of the cyclist, weather conditions and time of day.
- Application of other models for determining risk factors, such as Tobit regression, as well as other advanced techniques such as neural networks, etc. [30,44–50].

5. Conclusions

A strong analysis of the current mobility situation is important for a good and effective SUMP [20] in the process which develops the visions, action plans etc. The aspect of road safety monitoring the level of road safety and understanding the reasons why collisions happen and why road users feel unsafe on the roads is crucial to improving road safety. The Safe System approach including 'Vision Zero' should be the source from which to define the right measures, starting from a strong analysis of how the traffic system should and can function, by taking into account the interacting factors, such as: infrastructure, vehicles, traffic law enforcement, drivers and other road users.

The risk factors for cyclists were assessed in this paper by means of applying the binary logistic regression, examining the validity and the impact of the characteristics related to the cyclist, road, vehicle and the environment on the risk of cyclist fatality or occurrence of a serious injury. The correlation and the aspect of impact of the observed parameters were analysed for three different models regarding the data related to road crashes involving cyclists in Serbia, in the period from 2010 to 2021. The results of this study show that cyclists older than 60 are 1.82 times more likely to be injured in a road crash, when compared to child cyclists. Due to their physical characteristics, older cyclists, particularly those older than 60, have 3.21 times higher odds of being more seriously injured, when compared to child cyclists. A cyclist is more likely to be injured or killed in a road accident on weekdays than on weekends, while twilight decreases the cyclists' safety in terms of the increased likelihood of occurrence of an injury or fatality and the odds of occurrence of a serious injury. Outside built-up areas, the odds of occurrence of fatalities and injuries are higher, while the odds of occurrence of a serious injury are higher in built-up areas. The likelihood of occurrence of fatalities and injuries is higher in road crashes involving cyclists where other vehicles involved are a heavy-duty vehicle or a bus. On the other hand, the probability that a serious injury will occur is the highest in road crashes involving pedestrians.

This paper has, for the purpose of setting sustainable cycling mobility, identified and assessed basic risk factors influencing crash severity. These factors can be important for having a clear understanding of the current road safety situation, in order to create an opportunity to develop the best safety action plans and define practical measures. The results of this study can help us to understand the problem of risk factors for cyclists and be beneficial for sustainable road safety stakeholders, helping them to develop initiatives for reduction in the severity of cyclist crashes, by influencing specific factors and eliminating them. Therefore, the analysis in this study can help policy makers and involved stakeholders integrate road safety in each step of the planning cycle of the SUMP and keep high road safety on the agenda while developing and implementing the SUMP.

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