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Research

Multivariate analysis of road crashes involving two-wheelers at Vienna's roads

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Abstract
In order to determine the critical elements influencing the frequency and severity of two-wheeler-related traffic crashes, this study explores these incidents along eleven years in Vienna. Applying sophisticated multivariate statistical approaches, a comprehensive dataset is used and includes variables about rider demographics, weather conditions, vehicle features, and crash circumstances to reveal intricate correlations and interactions among these elements. Is there significant and distinctive difference based on gender and age with specific conditions under which crashes are occurring influencing different injury degree. Multiple regression undoubtedly points fields for action in statistically based findings providing the most important answer to this research: why there are so many crashes and what is leading cause of injured two-wheelers. The research yields insightful information that politicians and practitioners of road safety may use to improve two-wheeler safety regulations and lower the number of serious injuries and fatalities.

Highlights

- The stunning fact that just one rider in every fourteen may be uninjured
- Every second two-wheel rider sustain light injury and every eight severe
- Lane type, crash circumstance and consequence proves to be significant predictors for crash

Keywords Road safety · Two wheelers · Crash · Stepwise · Predictors · Regression

1 Introduction

Urban roads make 72% of road network in Austria and they do generate high traffic volume. Likewise, more often than not, they generate loses as well. Road crashes frequently result in injuries and financial losses. According to information available in the most recent road safety report for Austria shows the cost of road crashes in year 2021 was 2.8% of GDP or 11.2 billion euros of which 4801.407 € is cost generated by severe injuries. Almost one third of road fatalities recorded in Austria in year 2022 were among two-wheelers, 29% respectively [1].

From Fig. 1 above it is visible injury degree distribution among researched group of two-wheelers in Vienna. If we were to apply cost of light, severe and fatal injury from year 2022, then only those crashes in Vienna had cost of almost two billion of euros, 1.8 billion respectively.

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The primary objective of this study is to identify the leading characteristics of two-wheeler crashes in order to determine the trends in crash occurrence within the Vienna municipality between Year 2010 and 2020. Is there significant and distinctive difference based on gender and age with specific conditions under which crashes that are occurring are resulting in different injury degree.

To address this main problem of research it is performed: descriptive analysis to give summarized view of data; inferential analysis with focus on determining statistically significant differences, if any, among two-wheelers based on gender and age. Regression analysis is used to explain causal interconnection of continuous high number of crashes with certain predictors.

The persistent high and overall number of crashes did not receive the required social attention, and as far as the author is aware, no recent studies have more extensively investigated this trend. These factors served as the driving forces for doing this research.

2 Main research problem and research questions

The problem of research is defined by the question; which and how much individual factors can predict and generate continuous high number of crashes and injury severity at intersections/roads of urban centres among two-wheelers? The following research questions are defined in order to address the given research problem:

1. Is there significant and distinctive difference based on gender and age among riders with specific conditions under which crashes are occurring influencing different injury degree?
2. Which predictors and in what range of influence are predicting continuous high number of crashes involving two-wheelers in Vienna's urban city centre? Do they differ among bike, light and heavy motorcycle riders?

3 Methodological approach

Secondary analysis is used on original police data using sophisticated regression analytical methods in response to a defined knowledge gap. The goal is to identify key indicators and predictors that are significantly influencing the increasing trend in the number of crash events involving two-wheelers in the city of Vienna.

On the original data collected by the police after each crash involving two-wheelers, which occurred at the intersections/roads of Vienna between 2010 and 2020, it's applied cleaning, rearranging, and recoding on all variables, thus adapting them for IBM's SPSS program to apply the more complex data processing techniques that this program allows.

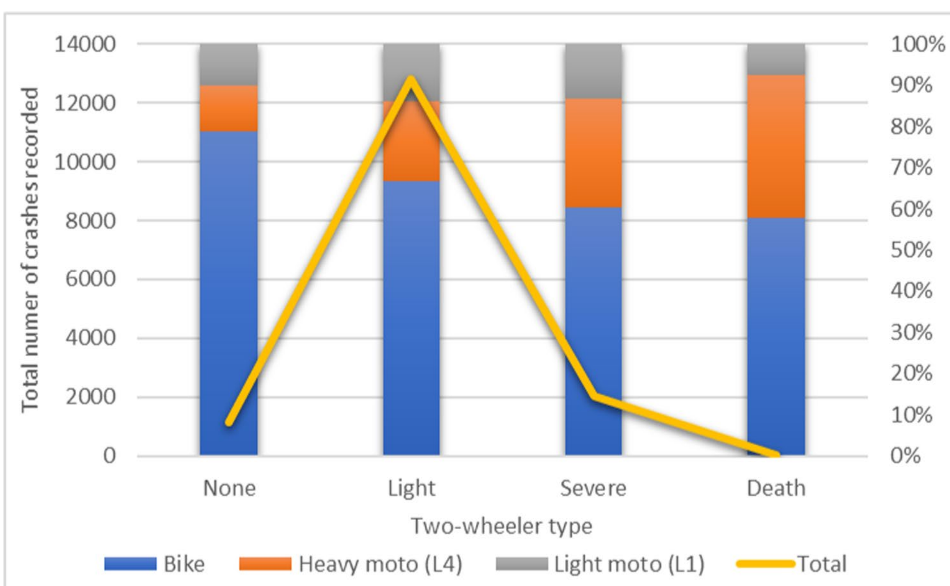

Fig. 1 Graphical distribution of injuries involving two-wheelers along observed period

Cleaning data included tasks of finding mistakes and/or missing information, inconsistencies, and inaccuracies in a dataset to enhance quality and guarantee dependable findings in analyses. Rearranging task included creation of new variables. Recoding task included coding variables in modalities spanning from less to high and/or from less dangerous to more dangerous. Cleaning, rearranging, and recoding variables in SPSS is crucial for preparing data for analysis.

IBM's statistical software SPSS version 28 is used for all data analysis [2, 3]. The majority of its global users are scientists because of its unique characteristics for quantitative, in-depth data analysis. Models made with SPSS are a vital part of quantitative exploration since they empower the recognition of examples that would somehow go undetected, the detailing of forecasts, and the assessment of the experimental legitimacy of our perspectives [4–6].

Descriptive analysis does not go beyond data, and it is used to make statements about the data set used in this research. It will provide facts on injuries and crash specifications among two-wheelers in city of Vienna along eleven years of investigated period.

Inferential analysis is used to conclude (*inferentia* lat. = reasoning) whether the resulting difference between the two sets of entities is statistically significant or not. To check the significance of differences, chi square test is used and from its size and size of the number of entities the coefficient contingent is calculated, which shows whether the modalities in one independent variable significantly associate (correlate) with the modalities of the dependent variable. Inferential analysis used in this research was to test whether there is statistically significant difference based on gender, and age when crossed with other variables.

Every scientific study, in the opinion of Blaikie [7], should aim to provide an explanation for why a given phenomenon arises, occurs, persists, or changes. For this reason, explanatory analysis is performed. The question of what causes the crash event under study is answered with explanatory analysis, which looks for explanations. This is accomplished using a statistical process known as regression analysis. The various forms of this analysis lead to the discovery of key factors that substantially impact the variation of the phenomenon under study and forecast its progression. By using a multivariate approach, multiple regression analysis for categorical variables is applied. Multivariate analysis application is spanning among various and diverse fields of research, in environmental research for spatial predictions [8], financial services for exploring usage of banking apps [9] and medical research for visualizing and modelling changes [10] to mention a few.

In this research, criterion variable is constructed by taking year with the highest number of crashes as modality eleven and the year with the lowest number as modality one while all other years are distributed among them in terms of growth by size expressed in number. This approach allowed getting variable that vary in number of crashes to show what significantly affected the greater growth of crashes in Vienna involving two-wheelers. Power of two-wheelers that are covered with this research distinguish bike, light (maximum design speed not exceeding 50 km/h) and heavy motorcycle riders (maximum design speed exceeding 50 km/h).

As predictor variable in this multiple regression analysis using IBM'S CATREG are used predictors that predict variations of the mentioned criterion variable. The criteria behind what predictors to use is based on predictors obtained by variance analysis (F-test significant at the probability level of less than 5%). To look at the magnitude of the influence of individual significant predictors it's applied the stepwise procedure. With this procedure, some predictors are gradually included in the regression equation in the order of significance (determined by the size of the F-test) and their multiple correlation (R) is calculated to expresses the determination coefficient ($R^2 \times 100$) which tells us what the percentage of the common variance of the criterion variable and the individual group of predictors. In this way, with this stepwise procedure, we get an insight into how much individual predictors contribute to the explanation of the variation of the criterion variable by their inclusion in the regression equation. Cut-off value is $F \leq 10.000$ due to low contribution in explaining variation of common variance at criterion variable. Through the height of the coefficient of the multiple correlation and the coefficient of determination, it's looked at what contributes to the explanation of the continuous high number of traffic crashes involving two-wheelers in recent eleven years of observation. Moreover, the two-wheelers data set was segmented into bike, light, and heavy motorcycle riders to examine if the same predictors predict crashes across all subsets or if there are differences between the three two-wheeled groups.

For this two-wheeler crash study, discriminant analysis is used to distinguish between three subgroups of two-wheelers and the major contributing factors to crash events. Predictors coming from regression analysis are included in discriminant analysis territorial maps in SPSS visually represent the separation of different groups based on predictor variables, aiding in the interpretation of how distinct categories, such as types of two-wheeler crashes, are differentiated. By plotting these territorial maps, researchers can easily identify the boundaries and overlap between groups, enhancing the understanding of the factors that contribute to each crash type. This visualization tool is crucial for effectively communicating findings and developing targeted interventions to improve two-wheeler safety. This understanding enables the development of targeted safety measures and interventions, ultimately aiming to reduce the frequency and severity of two-wheeler crashes.

In all scientific domains, multivariate approaches are becoming a more significant field of statistics. It is the most appropriate methodology to address this complex problem of road safety, as numerous studies have already confirmed, as it provides a more sophisticated analysis of data and relationships between variables as well as the ability to anticipate future results [11–14].

4 Descriptive analysis results

Total of thirty-seven variables presented with Table 1 below, were included in this research making sample of N = 16,045 crash events recorded among two-wheelers in eleven years of observed period.

Along eleven-years of observed period, from 2010 to 2020, highest number of crashes is recorded in two last years, N = 1789 in year 2020 and N = 1746 in year 2019, worth mentioning is in none it was below 1000 crashes. Spring and summer are seasons that generated more than 60% crashes of two-wheelers at streets of Vienna that occurred dominantly in the beginning of the week, 50% of all crashes are recorded until Wednesday.

From Table 2 above it is visible that highest number of two-wheelers involved in crashes in the city of Vienna are with light injuries, 80% respectively. Severe injuries make 13% in researched sample followed by not injured riders. When looking at time of the day when crash event occurred, highest number was between 13 p.m. until 17 p.m. and lowest in late night hours, from 01 a.m. until 05 a.m. respectively. More than half of crashes recorded, N = 8516, are in spots with maximum of 50 km/h speed allowed. In crashes when driving manoeuvre was evidenced by police, the leading once were evading and spinning and/or drifting and consequently specific disregards to traffic rules when evidenced, were highest for keeping too small safety distance and priority violation. Participation in traffic in previously described way caused crash with stationary vehicle (N = 10,344) and guard rail/wall (N = 3948).

Those indicators of dangerous riding will be further investigated in following inferential analysis.

5 Inferential analysis results

Two-wheelers gender showed statistically significant differences when crossed with variables referring to age of rider, rider's vehicle type and year of issuing first license. Strength of association expressed through coefficient of contingency was weak ($CC < 0.1$) and these results do not allow generalization but only shows tendency.

When it comes to age of two-wheelers, there is tendency that age differ significantly when crossed with temporal variables (artificial lighting, seasons, days in the week, amount of daylight, hours in the day assigned to sleep, work and rest), personal characteristics (gender, impairment, crash circumstance) and physical (intersection shape, lane type, street type, zebra marking). Due to $CC < 0.1$ we can talk about tendency and not firmly make conclusions.

Medium strength of association at level of contingency coefficient ($0.2 \le CC < 0.3$) allows conclusions that crashes involving older two-wheelers will be during night in later hours and months close to the end of the year. Older foreign two-wheelers sustain severe and/or death injuries in town zones with highest concentration of crashes in one-way streets when the most jeopardizing behaviour was noted; distraction, drugs/alcohol, fatigue and overtaking. The contrary is yielded for younger population of two-wheelers. At statistically significant level younger riders are involved in crashes in early morning hours in months at the beginning of the year. Moreover, they sustain light injuries and are predominately domestic population. Crashes in zones with low count of crashes along observed period include technical failure of vehicle, obstacle and health impairment and underpass or not defined facility in the spot.

Other influential variables that are at statistically significant level differentiate younger and older pedestrians involved in crashes are listed according to the size of chi-square test. They are all statistically significant at level of significance lower than 5% and they are: cycling path ($\chi^2 = 718.573$; df = 504; sig.001; CC = 0.202), crash involving person with mark "on the way to school" ($\chi^2 = 741.496$; df = 84; sig.001; CC = 0.210), general travel movement ($\chi^2 = 923.655$; df = 756; sig.001; CC = 0.233), immediate consequence ($\chi^2 = 1362.499$; df = 756; sig.001; CC = 0.280) and variable named riding manoeuvre ($\chi^2 = 1565.616$; df = 1176; sig.001; CC = 0.298).

Very strong strength of association at level of contingency ≤ 0.3 is telling us about older riders on light motorcycles that are involved in crashes during late night hours. Crash involved child and disobeying traffic rules was recorded. The

Table 1 Categorial variables included in research

	Mean	Standard deviation
Vehicle		
Two-wheeler type	1.47	0.723
Vehicle condition	1.01	0.219
Temporal		
Days of the week	3.59	1.813
Hour in a day	14.75	4.551
Light conditions joint	2.22	1.087
Road conditions	1.12	0.375
Seasons	2.07	0.932
Weather joint	1.10	0.495
Year	6.42	3.133
Road		
Cycling	1.70	1.751
Intersection regulation	1.54	1.122
Intersection shape	2.75	2.145
Lane type	1.75	0.582
Road layout	1.28	0.655
Road path	1.10	0.507
Separation island	1.03	0.163
Traffic lights	1.51	1.123
Zebra	1.09	0.401
Environment		
Facilities	3.48	4.400
Street type	3.79	0.424
Town zone	6.48	2.502
Traffic zone	1.03	0.226
Rider	37.55	15.299
Age		
Children	1.05	0.219
Circumstance	1.59	1.032
Consequence	2.92	3.097
Crash type	6.21	2.578
Driving maneuver	2.85	3.296
Gender	1.72	0.449
General travel direction	1.73	1.192
Impairment	1.08	0.539
Nationality	1.22	0.415
Behavior	7.00	3.586
School	1.00	0.064
Speed	5.76	2.955
Traffic rules	2.14	2.630
"Hit and run"	1.01	0.088

most dangerous ones; disregarding red light, irregular behaviour of driving against one-way and ghost driving. Younger bike riders had crash during early morning when children were not involved but disregarding of stated traffic rules was recorded along with braking out of column and too small safety distance.

Undoubtedly those results give right to make this generalization to all Austrian population.

Table 2 Distribution of injury degree according to age of riders

	Rider's age						Total	
	≥ 18	18–21	22–29	30–49	50–69	70 ≤	N	%
Injury degree								
None	158	91	291	420	185	17	1162	7.2
Light	1064	775	2849	5249	2513	374	12,824	79.9
Severe	109	102	322	832	573	95	2033	12.7
Death	2	1	1	7	10	5	26	0.2
Total								
N	1333	969	3463	6508	3281	491	16,045	100.0
%	8.31%	6.04%	21.58%	40.56%	20.45%	3.06%		

6 Regression analysis results

A total of thirty-seven variables were included in regression analysis and F-test bigger or equal to cut-off value 10.000 extracted those twelve predictors using CATREG procedure which significantly predict the increasing size of the crash event involving two-wheelers in streets of Vienna. CATREG is developed by Leiden University and incorporated in IBM's SPSS making it only correct choice when preforming regression with categorial variables. Results are presented with Table 3.

The first predictor in the model describing amount of daylight is first predictor in the model with impact on the size of the crash event explaining around 10% of the common variance at criterion variable. Meaning that dark conditions with artificial lighting, are influencing crash occurrence but in small percentage. Next two predictors added in the model are referring to presence of "zebra" crossing and rider's impairment. Not defined presence of "zebra" crossing and/or sideway island and other impairments combined with fist predictor are explaining 10.69% variation of common variance. When intersection regulation predictor is added in the model, the explanation of common variance at criterion variable is slightly increased, proving regulated intersections as spots generating more crashes involving two-wheelers than roundabouts. Next predictor in the model tells us that crash typology that wasn't frequent in repeating itself along observed eleven increases explanation of common variance at criterion variable. When predictor intersection shape is added in the model, it explains 11.69% variation of common variance at criterion variable, meaning that higher crash occurrence at streets of Vienna is at five-leg intersections. Predictor describing intersection typology distinguishes general intersection typology that was applied until year 2017, roundabout, crossing with offset branches, and number of legs in intersection; 3, 4 and 5 respectively. When we add crash consequence in the model it increases explanation of common variance and causes first big "jump" significantly increasing explanation of common variance at criterion variable,

Table 3 Results of stepwise regression analysis in contribution of multiple coefficients to the criterion variable—the size of the number of crash event

Criterion variable	Predictor variables	F test	R	$R^2 \times 100$ (%)
Size of the number of crash events	Light conditions joint	F = 13.763	r = 0.322	$R^2 = 10.36$
	Zebra	F = 15.224	R = 0.327	$R^2 = 10.69$
	Impairment	F = 15.859	R = 0.327	$R^2 = 10.69$
	Intersection regulation	F = 16.724	R = 0.330	$R^2 = 10.89$
	Crash type	F = 18.770	R = 0.336	$R^2 = 11.28$
	Intersection shape	F = 25.538	R = 0.342	$R^2 = 11.69$
	Consequence	***F = 43.029***	***R = 0.853***	$\boldsymbol{R^2 = 72.76}$
	Crash circumstance	***F = 70.369***	***R = 0.891***	$\boldsymbol{R^2 = 79.38}$
	Separation island	F = 70.417	R = 0.891	$R^2 = 79.38$
	Rider's behaviour	F = 76.277	R = 0.898	$R^2 = 80.64$
	Speed	F = 81.876	R = 0.900	$R^2 = 81.00$
	Lane type	***F = 149.207***	***R = 0.913***	$\boldsymbol{R^2 = 83.35}$

Highest "jump" in explanation of total variance coming from certain variables in model, meaning that they are very significant in further explanation of model as whole (in bold italics)

72% respectively. Two-wheelers are more prone to rollovers due to their inherent instability and higher centre of gravity than they show to be prone to crash with stationary vehicle. These rollovers often occur during sudden manoeuvres or when navigating uneven surfaces, posing a significant risk to riders. Crash circumstance is next predictor in the model and the one referring to human factor causing next big "jump" in the model. When predictor—human factor is added it explains 79% of common variance to criterion variable. Typology and specifications of crash spot can be seen as fixed and harder for interventions than the human predictor is. Model shows that fixed predictors even when impairment is included, are explaining around 12% of common variance at criterion variable and more flexible ones, or the ones more prone to interventions, like human factor as predictor is indicating biggest influence in crash occurrence involving two-wheelers in streets of Vienna. Spanning from not defined and not listed in crash causing circumstance, this predictor is capturing irregular behaviour that was applied until year 2017 across visual restrictions, to carelessness and/or distraction and boarding/disembarking from public transport where latest modality is mixture of aforementioned predictors. Highest crash occurrence for two-wheelers is when there is registered two or more dangerous actions. Next predictor is model is safety measure "separation island" and with it, model still explains 79% of variation at criterion variable. This predictor confirms highest crash occurrence that involves two-wheelers in Vienna is in sideway spots more than in spots characterized with separation island. Traffic situation changes more when rider's behaviour predictor is added in the model. Technical failure, obstacle on the road and health impairments are predictors with lower crash occurrence when compared with more severe impairments. Highest crash occurrence involves two-wheelers that are participating in traffic intoxicated, drugged, distracted, and violating safety distance and/or red light. Adding maximum speed allowed in the model, explanation increases for 0.5%, explaining in total 81% of variation at criterion variable. This confirms higher speed as predictor for higher crash occurrence. Latest predictor in the model is traffic lane giving complete model that explains total of 83% variation at criterion variable. Lane predictor shows lanes with no directional carriageway as predominant crash spots than ascending/descending lanes.

Observing all predictors in model that are of importance for predicting the size of crash event involving two-wheelers, three are human characteristics and the others are road specifications. Stepwise procedure gives us the model that clearly indicated highest jumps in the model when predictors crash consequence, circumstance and lane type are included in the model. This clearly indicates interconnection of environment and traffic participants. If we want to eliminate 83% of crashes involving two-wheelers in Vienna, corrective measures directed towards those predictors are defined as starting points.

To further distinguish and look at predictors in each group of two-wheelers and find if they are aligned with those results or are different as there is difference among two-wheelers as well, three separate subsets are extracted, and regression analysis results are presented below.

6.1 Regression analysis in bike subset

A total of thirty-seven variables were included in regression analysis and F-test bigger or equal to cut-off value 10.000 extracted those ten predictors using CATREG procedure which significantly predict the increasing size of the crash event involving bike riders in streets of Vienna. Results are presented with Table 4.

First predictor in the model is not contributing to significant explanation of common variance at criterion variable as it explains almost 3% of variation, but is shows regulated intersections with priority and/or stop sign as spots accumulating higher crash occurrence involving bike riders. Next predictor is speed, and it causes "big jump" in the model,

Table 4 Results of stepwise regression analysis in contribution of multiple coefficients to the criterion variable—the size of the number of crash event involving bike riders

Criterion variable	Predictor variables	F test	R	$R^2 \times 100$ (%)
Size of the number of crash events	Intersection regulation	F = 12.235	r = 0.161	$R^2 = 2.59$
	Speed	***F = 12.839***	***R = 0.633***	$\boldsymbol{R^2 = 40.06}$
	Lane type	***F = 20.848***	***R = 0.891***	$\boldsymbol{R^2 = 79.38}$
	Intersection shape	F = 20.949	R = 0.892	$R^2 = 79.56$
	Crash type	F = 21.247	R = 0.892	$R^2 = 79.56$
	Rider's behaviour	F = 30.935	R = 0.895	$R^2 = 80.10$
	Separation island	F = 68.877	R = 0.896	$R^2 = 80.28$

Highest "jump" in explanation of total variance coming from certain variables in model, meaning that they are very significant in further explanation of model as whole (in bold italics)

explaining 40% of variation at criterion variable. Considering that speed developed by bike riders is more often than not, lower than light and heavy motorcycle, still is an important predictor showing higher speeds are predicting higher crash occurrence. Lanes with no direction carriageway are predicting higher crash occurrence involving bike riders at streets of Vienna. This predictor causes second "jump" in the explanation of variation at criterion variable, making model that so far explained 79% of crashes with predictors included. Predictor with intersections modalities increases a little bit explanation of variation at criterion variable, reaching 80%. Highest crash occurrence for bike riders is intersection typology not further defined and lower at five and/or four-leg intersections. Crash typology predictor keeps the same percentage, 80% respectively. This predictor indicates crash type that was not frequent in repeating itself along investigated eleven years' time period contributes with other predictors in the model, in explaining high crash occurrence. Some of them are left agreement in left turn, pedestrian crossing road, right agreement in right-hand curve and crash with railway. Predictor riders' behavior captures modalities from less severe ones e.g. obstacle, and/or technical impairment to more severe ones, e.g. drug and/or alcohol intoxication. More severe, intoxicated irregular behavior we find even in bike riders where with this predictor in model explanation increases a little, explaining 80.10% of variation at common variance. No separation island is crash spot specification generating more bike crashes than spots with separation island. This as well is last predictor in the model where total of 80.28% of variation at criterion variable is explained.

Observing all predictors in model that are of importance for predicting the size of crash event involving bike riders, three are human characteristics and three are road specifications. Traffic picture at Vienna indicates highest crash occurrence when intoxicated bike riders are speeding at regulated intersection areas that is not protected with corrective measure as separation island and crashing on the straight and/or right-hand curve. Proving that bike rider crashes often involve a combination of speed and intoxication, we are looking at hazardous situation for both the rider and others on the road. High speeds reduce reaction times and increase the severity of crash, making it difficult for riders to navigate obstacles or sudden changes in their environment. When combined with intoxication, the risks are exacerbated as alcohol or drugs impair judgment, coordination, and the ability to make quick decisions. This dangerous mix not only endangers the rider's life but also poses significant risks to pedestrians, other cyclists, and motorists. The correlation between high speed and intoxication in bike crashes underscores the need for stringent measures to promote safe riding practices, such as enforcing speed limits and discouraging riding under the influence. Stepwise procedure gives us the model that clearly indicated highest jumps in the model when predictors speed and lane typology are included in the model. This clearly indicates interconnection of environment and bike riders as traffic participants. If we want to eliminate 82% of crashes involving bike riders in Vienna, corrective measures directed towards those predictors are defined as starting points.

6.2 Regression analysis in light motorcycle subset

A total of thirty-seven variables were included in regression analysis and F-test bigger or equal to cut-off value 10.000 extracted those ten predictors using CATREG procedure which significantly predict the increasing size of the crash event involving light motorcycle riders in streets of Vienna. Results are presented with Table 5.

First predictor in the model already explains high, 74% of variation at criterion variable and in its modalities are crash consequences. Light motorcycle riders are more prone to crashes with stationary vehicles than rollovers. Variable "driving manoeuvre" describes riders' movement and has modalities that are starting with none of mentioned, than spanning from evade riding to reversing, to mention a few of them. This predictor increases explanation of variation at criterion variable just a little bit and shows false and incorrect perception of traffic situation for light motorcycle riders in streets of Vienna. Highest crash occurrence involves riders reversing, cornering and/or insufficient right-hand driving and driving on the wrong side of the road. Those traffic situations are not reserved only for Vienna, as changing lanes and entering

Table 5 Results of stepwise regression analysis in contribution of multiple coefficients to the criterion variable—the size of the number of crash event involving light motorcycle riders (L1)

Criterion variable	Predictor variables	F test	R	$R^2 \times 100$ (%)
Size of the number of crash events	*Consequence*	***F = 12.244***	***r = 0.861***	***$R^2 = 74.13$***
	Driving manoeuvre	F = 12.996	R = 0.862	$R^2 = 74.30$
	Separation island	F = 23.203	R = 0.863	$R^2 = 74.47$

Highest "jump" in explanation of total variance coming from certain variables in model, meaning that they are very significant in further explanation of model as whole (in bold italics)

lanes with forbidden direction is everyday situation on streets with riders which would be much harder to perform with personal vehicle. Third and least predictor in model is road safety measure—separation island where it proves to be part of crash spots involving light motorcycle riders (which was not the case in bike subset previously presented). Together those three statistically significant predictors make model explaining total of 74.47% of variation at criterion variable—the size of the crash event.

Light motorcycle riders are involved in crashes predominately involving stationary vehicles that often stem from a variety of risky behaviours, including reversing, driving on the wrong side of the road, and navigating around separation islands. When riders reverse or drive against the flow of traffic, they significantly increase the likelihood of crash with parked cars, as these actions are unexpected and give little time for correction. Additionally, separation islands, designed to enhance traffic safety, can become hazardous when riders attempt to circumvent them improperly, leading to unpredictable movements and reduced visibility. These behaviours not only endanger the light motorcycle rider but also create chaotic situations that can result in severe damage to stationary vehicles and potential injuries. Addressing these issues requires better rider education, stricter enforcement of traffic rules, and improved infrastructure to ensure safer road-sharing practices.

6.3 Regression analysis in heavy motorcycle subset

A total of thirty-seven variables were included in regression analysis and F-test bigger or equal to cut-off value 10.000 extracted those ten predictors using CATREG procedure which significantly predict the increasing size of the crash event involving riders of heavy motorcycles that are exceeding speed 50 km/h in streets of Vienna. Results are presented with Table 6.

First predictor in the model is crash consequence and it explains 72% of common variance. Riders of heavy motorcycles are with higher tendency to rollover and/or fall from moto in crash event. Heavy motorcycle riders often face the risk of severe crashes and rollovers, which are less common among light motorcycle riders. While heavy motorcycles can become unstable and roll over due to their weight during high-speed manoeuvres or sudden stops, light motorcycle riders are more likely to experience crashes involving stationary vehicles, as their smaller size and agility lead them to navigate tighter spaces where such vehicles are parked. Consequently, the nature of crashes differs significantly between heavy and light motorcycle riders, necessitating distinct safety strategies for each. When added speed we notice first "jump" in the model, reaching higher speeds as predictor for explanation 75% of variation at criterion variable—the size of the crash event involving heavy moto riders. When added rider's behaviour as predictor, explanation of common variance reaches 75.51%, indicting heavy motorcycle riders participating in crash events when intoxicated, drugged, and/or distracted. Variable "crash circumstance" have modalities of irregular behaviour, visual restriction, carelessness and/or distraction, and least boarding or disembarking from public transportation. Adding this predictor in the model besides observing second "jump" in explanation of variation at criterion variable—the size of the crash event, we are looking at model that with previously mentioned predictors explains 81,54% of common variance at criterion variable.

Heavy motorcycle rider crashes often involve rollovers, higher speeds, intoxication, distraction, or boarding/disembarking from public transportation. The substantial weight of heavy motorcycles makes them more prone to rollovers during abrupt manoeuvres or high-speed travel, exacerbating the impact of crashes. Intoxication further impairs a rider's judgment, coordination, and reaction time, significantly increasing the likelihood of crash event. Distractions, whether from mobile devices or environmental factors, compound these risks, diverting attention from the road. Additionally, the interaction with public transportation, such as buses or trains, can create hazardous conditions for heavy motorcycle riders, especially when boarding/disembarking or navigating around these larger vehicles. This confluence of factors

Table 6 Results of stepwise regression analysis in contribution of multiple coefficients to the criterion variable—the size of the number of crash event involving heavy moto riders (L4)

Criterion variable	Predictor variables	F test	R	$R^2 \times 100$ (%)
Size of the number of crash events	Consequence	F = 11.170	r = 0.850	$R^2 = 72.25$
	Speed	***F = 14.123***	***R = 0.867***	$\boldsymbol{R^2 = 75.16}$
	Rider's behaviour	F = 28.373	R = 0.869	$R^2 = 75.51$
	Crash circumstance	***F = 45.211***	***R = 0.903***	$\boldsymbol{R^2 = 81.54}$

Highest "jump" in explanation of total variance coming from certain variables in model, meaning that they are very significant in further explanation of model as whole (in bold italics)

highlights the critical need for comprehensive safety measures, including rider education, stricter enforcement of traffic laws, and public awareness campaigns to mitigate the dangers faced by heavy motorcycle riders.

If we were to decrease 85% crashes involving all two-wheelers at streets of Vienna, then twelve predictors indicated with regression model pointed are calling for attention. Separation island, intersection regulation, crash circumstance and travel direction caused highest jumps in explaining the common variance at criterion variable meaning that multifaced approach is essential. This entails enforcing traffic laws more strictly and launching frequent public awareness campaigns about the value of safe driving habits. Infrastructure upgrades are essential. Examples include clean, well-kept roads, obvious signage, and designated pedestrian crossings. To make driving safer for everyone, government organizations, local communities, and citizens must work together.

Understanding and reducing the likelihood of bike crashes for 80% requires an understanding of road safety predictors in relation to speed and lane typology that among seven predictors caused highest "jump" in explanation of variation at criterion variable. By managing the flow of traffic, efficient intersection regulation, can dramatically lower the number of crash sites. The implementation of speed limits that are appropriate for particular road types and conditions is crucial for managing speed because higher speeds are associated with more severe injuries. By clearly defining travel routes and minimizing confusion, lane typology, which includes the design and marking of lanes, influences on rider behaviour can help prevent crashes. Enforcing speed limits in areas with high bicycle traffic can lower the risk of crash, providing a safer environment for all participants. Strictly monitoring and penalizing intoxicated bike riders is crucial to reducing the likelihood of crashes, as impaired cyclists are more prone to making errors that could lead to crash event.

When we observe more powered two-wheelers, three predictor variables are included in the model to predict light and four to predict heavy motorcycle crashes. Thus, significant reductions in motorcycle crashes can be achieved by addressing those specific factors for both light and heavy motorcycles riders. Research indicates that light motorcycle crashes can be reduced by 74% when interventions focus on implementing clear signage and barriers to discourage riding on the wrong side of the road and navigating around separation islands. Enhancing rider education on the dangers of reversing and the importance of adhering to traffic rules can reduce crashes with stationary vehicles. Additionally, improved urban planning with designated lanes can create safer environments and minimize the risk of crash event. For heavy motorcycles, an 82% reduction in crashes can be attained by targeting crash consequences, speed, rider behaviours, and circumstances. Lowering crash events involving heavy motorcycle riders requires targeted interventions such as enforcing stricter speed limits and implementing sobriety checkpoints to reduce the risk of rollovers and crashes due to higher speeds and intoxication. Enhancing rider education on the dangers of distractions can mitigate crashes caused by inattention. Additionally, improving infrastructure and designated boarding areas for public transportation can help create safer interactions between heavy motorcycle riders and other participants.

By concentrating efforts on these critical areas, the safety of all two-wheel riders can be significantly enhanced, leading to fewer crashes and safer roads. By closely analysing and optimizing these predictors, authorities can design safer road systems and enhance overall traffic safety. Observing this model, where riders' way in which they participate in traffic are identified as predictors for the size of the crash event, it opens question whether transfer of knowledge and gaining skills for understanding traffic is adjusted to them and if it has pass key principles making roads safe for all participants. Measures and actions directed towards these predictors are with potential to significantly decrease number of crash occurrence involving riders in the city of Vienna.

7 Discriminant analysis results

Discriminant analysis on two-wheelers set was performed with significant predictors coming from regression analysis. Significant predictors included were joint lighting conditions, "zebra" crossing, impairment, intersection regulation, crash type, intersection shape, crash consequence and circumstance, separation island, rider's behaviour, speed and lane type. Total of N = 16,045 crash records were analysed. Univariate ANOVA revealed and confirmed previous findings, two-wheelers differ significantly on each of twelve predictors. Two discriminant functions were calculated. The first function accounts for 71.3% of discriminating ability of the discriminating variables and the second function accounts for 28.7%. The values of both functions were significantly different between two-wheelers, $\chi^2 = 1078.455$, df = 18, p = 0.001 and $\chi^2 = 313.138$, df = 8, p = 0.001. The correlations between predictor variables and the discriminant functions (≥ 0.300) suggest that speed, rider's behaviour, separation island, "zebra" crossing and immediate consequence were best predictors for first function while for the second one are speed and immediate crash consequence. Due to negative correlation in first function actually absence of "zebra" marking, technical failure or obstacle (rather than alcohol and drugs) make riders crash with stationary vehicle (rather than rollover). Beside standardized canonical discriminant function coefficients, the structure matrix is another way of indicating the relative importance of predictors and is used to see if the same patterns are obtained. The cut-off value will not be applied in this analysis, allowing for a more comprehensive evaluation of the data set. This approach ensures that all data points are considered, avoiding potential biases introduced by excluding values below or above a certain threshold. Consequently, the analysis will provide a more accurate and complete understanding of the trends and patterns within the data. Largest absolute correlation between first function and separation island, crash type, intersection shape, "zebra" marking, and intersection regulation are observed. Only negatively related is "zebra" marking confirming crash spots are predominately predicted for spots without this safety measure. In the second function it is speed, crash consequence, rider's behaviour, crash circumstance, lane type, light conditions and nature of impairment showing those predictors differentiating crashes among two-wheelers. Here is worth mentioning that lane type is negatively correlated indicating ascending and descending lanes better in predicting crashes than lanes with no directional carriageway. Second predictor in second function in negative correlation is rider's impairment. Meaning that health and other impairments are better in predicting crashes among two-wheelers than narcotics. Figure 2 shows territorial map or graphical presentation of those results.

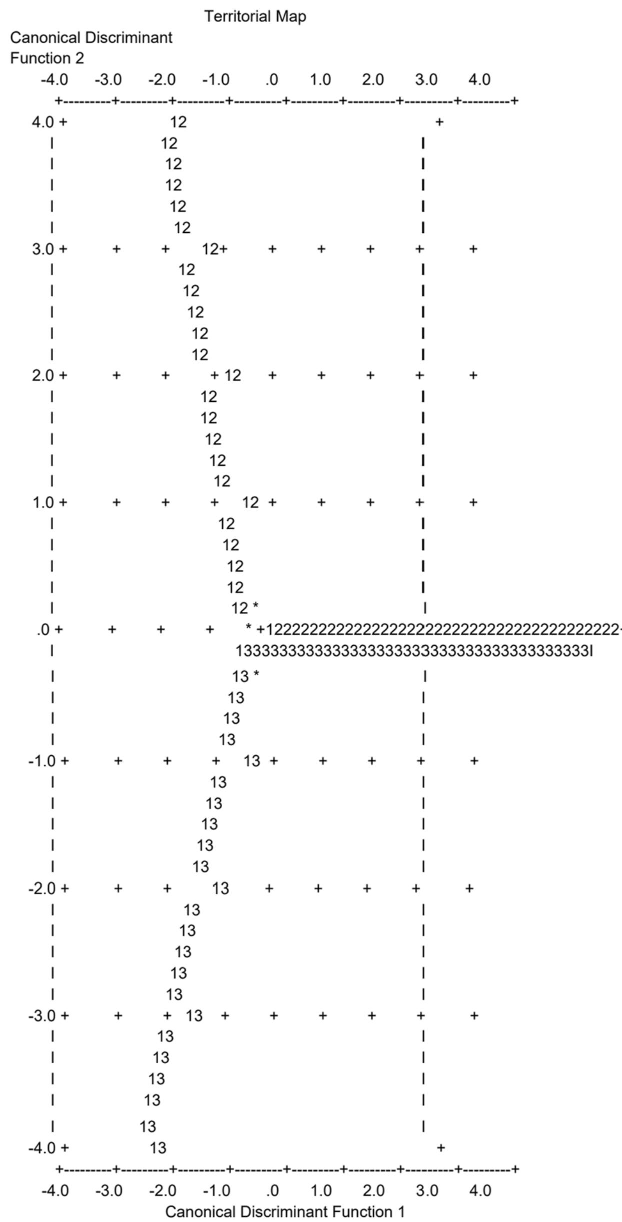

Fig. 2 Graphical presentation of the relationship between predictors and groups

Looking at the first function on horizontal axis, it can be observed that bike riders are separated from both powered two-wheelers, light and heavy engine powered. Since, it is strongly positively correlated with separation island, crash type, intersection shape and intersection regulation, it suggest that bike riders are involved in very frequent crash type. They are crashes with stopping or parked vehicle and right-angle crashes at five-leg regulated intersections on crash spots without separation island. The second function separates light and heavy moto riders. Heavy moto riders are participating in crashes intoxicated where their higher speeds are causing rollovers in lanes with no directional carriageway. Intoxication influences their judgment abilities, so distraction and/or involvement of public transportation is noted as crash circumstance.

Crashes involving two-wheelers are differentiated based on various contributing factors such as rider behaviour, road conditions, and vehicle dynamics. Discriminant analysis plays a crucial role in this differentiation by statistically identifying which variables are most influential in predicting specific types of crashes, such as rollovers versus collisions with stationary objects. This method allowed creation of models that highlighted the distinct characteristics and risk factors associated with each group of two-wheeler. By understanding these distinctions, policymakers and safety experts can develop targeted strategies and interventions to mitigate the most common and severe types of two-wheeler crashes, ultimately enhancing rider safety and reducing overall crash rates.

8 Discussion

Large-scale data analysis is a difficult and time-consuming procedure. Statistical package for the social sciences (SPSS) is used in many road safety research [15–18] and reasons to use it in this research is due to efficient handling and analysis of large datasets it allows, providing reliable results that helps understanding the complex interaction between multiple factors like rider behaviour, environmental conditions and other.

The literature on road safety demonstrates a variety of methodologies and trends, ranging from how riders may be affected by sleepiness [19], associated costs [20], injury patterns [21], lifestyle and risky behaviour [22], analysis of factors affecting road safety [23] to recognition of need for integration broader urban sustainable measures [24].

Reduced traffic volumes can be linked to lower crash rates at night since fewer cars on the road lessen the chance of crash event. Though overall crash rates may be lower, it's crucial to remember that nighttime crashes can still be more severe because of things like less visibility and a higher chance of driving while intoxicated. Statistically significant differences, chi-square, proved relative risk of death in night crash is 1.3 times higher than during daytime and being higher for motorcyclist than car occupants [25] that is aligned with results coming from research where very strong strength of association is revealed for older riders in Vienna during nighttime when disobeying traffic rules. Low engine size two-wheeler riders are more likely to indulge in distracted driving and they used mobile phone more frequently [26]. The findings of the model estimation demonstrate that the intention of riders to break traffic laws and their propensity for crash events are significantly influenced by descriptive norm, conformity tendency, and past behaviour [27]. Regarding how gender might influence cyclists' performance, the descriptive results indicate that women spend more time travelling and undertake longer trips than men (30 s and 0.4 km difference for cyclists) [28]. Tendencies showed that in Vienna female riders use bikes more than heavy powered two-wheelers which are preference of male riders.

The multivariate statistical approach in road safety is a thorough methodology that evaluates multiple elements at the same time. This method offers a comprehensive comprehension of the intricate relationships impacting traffic safety. Patterns and connections between these factors are found using methods like regression analysis. For motorised two-wheelers, type of colliding vehicle has the highest influence on crash severity followed by collision type, driver age, and visibility of the road [29]. Application of stepwise regression allowed to identify lane type, crash circumstance and consequence as key factors driving variability in the dependent variable—the crash event involving two-wheelers in Vienna city centre. This allows valuable insights for the creation of safety-enhancing initiatives and policies. When dataset is split on bike, light and heavy moto riders' regression models showed which predictors in each two-wheeled group are safety concerns allowing authorities to take proactive steps to lessen crash occurrence. Using driving simulation, the performance of drivers making right turns while different bicycle infrastructure treatments are present at intersections while segments was monitored, it was discovered that more people look right at protected intersections before making a right turn [30]. When modelling crash event in Vienna among bike riders, stepwise regression showed speed and lane type to cause highest jump of variance explanation to criterion variable. When comparing bike and moto riders, it is expected to find out that head injury risks of bicyclists increase with vehicle moving velocity [31]. Turning/crossing accidents were the most commonly observed scenario where 'looked but failed to see' remains a key problem for powered two-wheelers and bicycles [32]. In Barcelona, pedestrians and two-wheel motor vehicle occupants, besides accounting for two-thirds of motor vehicle injury cases, are the user groups with a greater risk of a more severe injury, as well as a higher chance of a hospital admission, independently of demographic and health care factors [33]. Regression model showed crash consequence as the most significant predictor for crash event involving light moto riders in Vienna, while modelling crash event involving heavy moto riders showed crash circumstance and speed as predictors of crash event. Traffic errors are the main predictor of crash risk for Indian riders [34]. The likelihood that two-wheelers will accept the essential lateral distance is strongly positively correlated with the type of two-wheelers, how they will evade obstacles, whether a platoon of two-wheelers will move, and their yaw rate ratio [35]. Crash types associated with high severity of two-wheelers are run-off-the-road and head-on crashes [36]. Speed significantly impacts crash risk and severity [37, 38], with more often than not witnessing gap between perceived and objective risks [39] that in urban traffic can be translated in risk of hitting a pedestrian that among the different categories of powered two-wheelers, moped drivers run the highest risk [40]. Vehicles, such as cars and trucks, occupy more space on the road and often follow more restrictive traffic lanes compared to two-wheelers. Two-wheelers can manoeuvre through traffic more easily, often utilizing lane splitting in some regions to navigate congested areas and results showed that two-wheelers speeds are always considerably higher than passenger car speeds [41–44]. When added finding that average experienced motorcycle riders and novice do not achieve breaking deceleration suitable for road traffic [45] than traffic situation is alerting and calling for action. Motorcyclist crash risk was also directly influenced by the number of miles ridden in the past 12-months [46].

Motorcycle training courses are essential for enhancing rider safety, teaching critical skills such as balance, manoeuvring, and hazard recognition. Present ones are calling for updates due to findings showing that those individuals who took beginning rider training courses were more likely to be involved in crash than those who did not [15, 47–49]. Training programs are out of scope of this research article but addressing critical age and experience related factors as proved with this research might be good direction in redefining our understanding of safety problem.

Integration of various data sources and the discovery of subtle insights available through the multivariate statistical method serves as instrument for enhancing road safety initiatives that promote safer transportation settings for all users of the roads.

Austria's national safety program for road safety focuses on reducing traffic fatalities and serious injuries through a comprehensive approach involving education, enforcement, and engineering [50]. Key initiatives include enhancing public awareness campaigns, implementing stricter traffic law enforcement, and improving road infrastructure for safer travel. The program also emphasizes the importance of collaboration between government agencies, local authorities, and the community to achieve its safety objectives. Urban environment needs more attention and continuous studies if we as society, independent of place where we live want safe road networks were reaching zero deaths and injuries is target for all stakeholders.

9 Conclusion and recommendations

These findings provide the following conclusions with regard to the purpose and research problem previously established. There are answers to research questions. Descriptive statistics served as crucial for summarizing and interpreting large datasets allowing transformation of raw data into understandable insights. Sample of all investigated two-wheelers involved in crash event in Vienna had 72% male and 28% female participants.

Statistically significant differences in crash data depending on age and gender reveal distinct patterns in crash involvement. The data indicates that older riders on light motorcycles tend to have crashes during nighttime hours, while younger riders are more likely to crash in the early morning. In both age groups, a common factor contributing to these crash events is the disregard for traffic rules. This pattern suggests that targeted safety campaigns and stricter enforcement of traffic regulations may be necessary to address the specific behaviours leading to these crashes in different age demographics.

The movement of cars, bikes, and pedestrians throughout a transportation network is referred to as general traffic movement. It is impacted by various elements, including road layout, traffic signals, and peak travel periods. In order to reduce traffic and maintain safety, efficient traffic flow depends on a well-coordinated infrastructure and efficient traffic management techniques. On the other hand, interruptions such as crash, construction, and unfavourable weather patterns can greatly affect the efficient flow of traffic, resulting in delays and heightened likelihood of crash. Observing significant variables in the stepwise regression model for estimating the magnitude of a two-wheeler crash event, lane type, crash circumstance and consequence proved significant.

Because they identified underlying risk differences and influences, the multivariate methodologies utilized in this research to unearth new understanding of contributing elements in the two-wheelers' group have been valuable for every analysis conducted. The methodology applied has proven valuable for characterizing the circumstances of crashes and injuries in the metropolitan area of Vienna involving two-wheelers, thus holding potential for use in other developed urban centres.

Even with its valuable insights, this research has several limitations that must be acknowledged. The study's scope might be confined to specific geographic regions, which can affect the generalizability of the findings to other areas with different road conditions, traffic laws, and cultural factors. The reliance on historical data may also fail to capture emerging trends or recent changes in road safety dynamics, such as the impact of new traffic regulations or advancements in vehicle safety technology. Despite having large and representative sample, stepwise regression sometimes has potential of overfitting and biased parameter estimation. This research is limited by its inability to capture the impact of recent changes in traffic laws and regulations, which could significantly influence road safety outcomes. Additionally, the study does not account for the behaviour and involvement of all road participants, such as pedestrians and public transportation users, potentially overlooking critical interactions and risks associated with these groups. These omissions suggest that the findings may not fully reflect the current and comprehensive dynamics of road safety, indicating a need for further research that includes these crucial factors. The lack of reported crashes poses a significant limitation in research. This gap can result in an underestimation of the true incidence and causes of crashes, hindering the development of effective safety measures. Consequently, the findings may not accurately reflect the real-world scenario. Besides mentioned limitations, undoubtedly this research contributed to explanation of underlying factors in crashes involving two-wheelers in Vienna, but further research is needed in other traffic groups.

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References

1. International Transport Forum. Austria: Road Safety Country Profile. 2021. https://www.itf-oecd.org/sites/default/files/austria-road-safety.pdf. Accessed 10 July 2024.
2. Field A. Discovering statistics using IBM SPSS statistics. Thousand oaks: SAGE Publications Limited; 2018.
3. Brace N, Kemp R, Snelgar R. SPSS for psychologists: a guide to data analysis using SPSS for windows (versions 12 and 13). London: Palgrave MacMillan; 2006.

4. Tolmie A, Muijs D, McAteer E. Quantitative methods in educational and social research using SPSS. Maidenhead: Open University Press; 2011.
5. Seethalakshmi M, et al. Study of injury pattern in human beings in road traffic accidents involving two wheelers. J Evol Med Dent Sci. 2015;4(77):13436.
6. Jain A, Menezes RG, Kanchan T, Gagan S, Jain R. Two wheeler accidents on Indian roads—a study from Mangalore, India. J Forensic Leg Med. 2009;16(3):130–3. https://doi.org/10.1016/j.jflm.2008.08.019.
7. Blaikie N. Designing social research: the logic of anticipation. Polity. 2009.
8. Cao G, Yoo Eh, Wang S. A statistical framework of data fusion for spatial prediction of categorical variables. Stoch Environ Res Risk Assess. 2014;28:1785–99. https://doi.org/10.1007/s00477-013-0842-7.
9. Majumdar S, Pujari V. Exploring usage of mobile banking apps in the UAE: a categorical regression analysis. J Financ Serv Mark. 2022;27:177–89. https://doi.org/10.1057/s41264-021-00112-1.
10. Jones M, Hockey R, Mishra GD, et al. Visualising and modelling changes in categorical variables in longitudinal studies. BMC Med Res Methodol. 2014;14:32. https://doi.org/10.1186/1471-2288-14-32.
11. Valenti G, Lelli M, Cucina D. A comparative study of models for the incident duration prediction. Eur Transp Res Rev. 2010;2:103–11. https://doi.org/10.1007/s12544-010-0031-4.
12. Chalya PL, Mabula JB, Dass RM, et al. Injury characteristics and outcome of road traffic crash victims at Bugando Medical Centre in Northwestern Tanzania. J Trauma Manag Outcomes. 2012;6:1. https://doi.org/10.1186/1752-2897-6-1.
13. Arita A, Sasanabe R, Hasegawa R, et al. Risk factors for automobile accidents caused by falling asleep while driving in obstructive sleep apnea syndrome. Sleep Breath. 2015;19:1229–34. https://doi.org/10.1007/s11325-015-1145-7.
14. Lefering R, Huber-Wagner S, Nienaber U, et al. Update of the trauma risk adjustment model of the TraumaRegister DGU™: the Revised Injury Severity Classification, version II. Crit Care. 2014;18:476. https://doi.org/10.1186/s13054-014-0476-2.
15. Glendon AI, McNally B, Jarvis A, Chalmers SL, Salisbury RL. Evaluating a novice driver and pre-driver road safety intervention. Accid Anal Prev. 2014;64:100–10. https://doi.org/10.1016/j.aap.2013.11.017.
16. Mekonnen TH, Tesfaye YA, Moges HG, et al. Factors associated with risky driving behaviors for road traffic crashes among professional car drivers in Bahirdar city, northwest Ethiopia, 2016: a cross-sectional study. Environ Health Prev Med. 2019;24:17. https://doi.org/10.1186/s12199-019-0772-1.
17. Seid M, Azazh A, Enquselassie F, et al. Injury characteristics and outcome of road traffic accident among victims at Adult Emergency Department of Tikur Anbessa specialized hospital, Addis Ababa, Ethiopia: a prospective hospital based study. BMC Emerg Med. 2015;15:10. https://doi.org/10.1186/s12873-015-0035-4.
18. Distefano N, Leonardi S, Consoli F. Drivers' preferences for road roundabouts: a study based on stated preference survey in Italy. KSCE J Civ Eng. 2019;23:4864–74. https://doi.org/10.1007/s12205-019-1363-9.
19. Bougard C, Davenne D, Espie S, Moussay S, Léger D. Sleepiness, attention and risk of accidents in powered two-wheelers. Sleep Med Rev. 2016;25:40–51. https://doi.org/10.1016/j.smrv.2015.01.006.
20. Corazza MV, Musso A, Finikopoulos K, Sgarra V. An analysis on health care costs due to accidents involving powered two wheelers to increase road safety. Transp Res Proc. 2016;14:323–32. https://doi.org/10.1016/j.trpro.2016.05.026.
21. Leijdesdorff HA, Gillissen S, Schipper IB, Krijnen P. Injury pattern and injury severity of in-hospital deceased road traffic accident victims in the Netherlands: Dutch road traffic accidents fatalities. World J Surg. 2020;44(5):1470–7. https://doi.org/10.1007/s00268-019-05348-6.
22. Stanojević D, Stanojević P, Jovanović D, Lipovac K. Impact of riders' lifestyle on their risky behavior and road traffic accident risk. J Transp Saf Secur. 2019;12(3):400–18. https://doi.org/10.1080/19439962.2018.1490367.
23. Damani J, Vedagiri P. Safety of motorised two wheelers in mixed traffic conditions: literature review of risk factors. J Traffic Transp Eng. 2021;8(1):35–56. https://doi.org/10.1016/j.jtte.2020.12.003.
24. McLeod S, Curtis C. Integrating urban road safety and sustainable transportation policy through the hierarchy of hazard controls. Int J Sustain Transp. 2020;16(2):166–80. https://doi.org/10.1080/15568318.2020.1858376.
25. Ackaah W, Apuseyine BA, Afukaar FK. Road traffic crashes at night-time: characteristics and risk factors. Int J Inj Contr Saf Promot. 2020;27(3):392–9. https://doi.org/10.1080/17457300.2020.1785508.
26. Gupta M, Pawar NM, Velaga NR, Mishra S. Modeling distraction tendency of motorized two-wheeler drivers in time pressure situations. Saf Sci. 2022;154:105820. https://doi.org/10.1016/j.ssci.2022.105820.
27. Ziakopoulos A, Nikolaou D, Yannis G. Correlations of multiple rider behaviors with self-reported attitudes, perspectives on traffic rule strictness and social desirability. Transp Res Part F Traffic Psychol Behav. 2021;80:313–27. https://doi.org/10.1016/j.trf.2021.05.011.
28. Cubells J, Miralles-Guasch C, Marquet O. Gendered travel behaviour in micromobility? Travel speed and route choice through the lens of intersecting identities. J Transp Geogr. 2023;106:103502. https://doi.org/10.1016/j.jtrangeo.2022.103502.
29. Panicker AK, Ramadurai G. Injury severity prediction model for two-wheeler crashes at mid-block road sections. Int J Crashworthiness. 2020;27(2):328–36. https://doi.org/10.1080/13588265.2020.1806644.
30. Deliali K, Christofa E, Knodler M Jr. The role of protected intersections in improving bicycle safety and driver right-turning behavior. Accid Anal Prev. 2021;159:106295. https://doi.org/10.1016/j.aap.2021.106295.
31. Huang Y, Zhou Q, Koelper C, Li Q, Nie B. Are riders of electric two-wheelers safer than bicyclists in collisions with motor vehicles? Accid Anal Prev. 2020;134:105336. https://doi.org/10.1016/j.aap.2019.105336.
32. Brown L, Morris A, Thomas P, Ekambaram K, Margaritis D, Davidse R, Usami DS, Robibaro M, Persia L, Buttler I, Ziakopoulos A, Theofilatos A, Yannis G, Martin A, Wadji F. Investigation of accidents involving powered two wheelers and bicycles—a European in-depth study. J Saf Res. 2021;76:135–45. https://doi.org/10.1016/j.jsr.2020.12.015.
33. Cirera E, Plasència A, Ferrando J, et al. Factors associated with severity and hospital admission of motor-vehicle injury cases in a southern European urban area. Eur J Epidemiol. 2001;17:201–8. https://doi.org/10.1023/A:1017961921607.
34. Chouhan SS, Kathuria A, Sekhar CR. Examining risky riding behavior in India using motorcycle rider behavior questionnaire. Accid Anal Prev. 2021;160:106312. https://doi.org/10.1016/j.aap.2021.106312.
35. Guo Y, Sayed T, Zaki MH. Examining two-wheelers' overtaking behavior and lateral distance choices at a shared roadway facility. J Transp Saf Secur. 2020;12(8):1046–66. https://doi.org/10.1080/19439962.2019.1571549.

36. Montella A, De Oña R, Mauriello F, Riccardi MR, Silvestro G. A data mining approach to investigate patterns of powered two-wheeler crashes in Spain. Accid Anal Prev. 2020;134:105251. https://doi.org/10.1016/j.aap.2019.07.027.
37. Dubos N, Varin B, Bisson O. A better knowledge of powered two wheelers accidents. Transp Res Proc. 2016;14:2274–83. https://doi.org/10.1016/j.trpro.2016.05.243.
38. Broughton P, Fuller R, Stradling S, Gormley M, Kinnear N, O'dolan C, Hannigan B. Conditions for speeding behaviour: a comparison of car drivers and powered two wheeled riders. Transp Res Part F Traffic Psychol Behav. 2009;12(5):417–27. https://doi.org/10.1016/j.trf.2009.07.001.
39. Maestracci M, Prochasson F, Geffroy A, Peccoud F. Powered two-wheelers road accidents and their risk perception in dense urban areas: case of Paris. Accid Anal Prev. 2012;49:114–23. https://doi.org/10.1016/j.aap.2011.05.006.
40. Clabaux N, Fournier J, Michel JE. Powered two-wheeler drivers' risk of hitting a pedestrian in towns. J Saf Res. 2014;51:1–5. https://doi.org/10.1016/j.jsr.2014.07.002.
41. Perco P. Comparison between powered two-wheeler and passenger car free-flow speeds in urban areas. Transp Res Rec. 2008;2074(1):77–84. https://doi.org/10.3141/2074-10.
42. Quddus M. Exploring the relationship between average speed, speed variation, and accident rates using spatial statistical models and GIS. J Transp Saf Secur. 2013;5(1):27–45. https://doi.org/10.1080/19439962.2012.705232.
43. Navon D. The paradox of driving speed: two adverse effects on highway accident rate. Accid Anal Prev. 2003;35(3):361–7. https://doi.org/10.1016/s0001-4575(02)00011-8.
44. Yuan Q, Li Y, Xing S, et al. Correlation between residual speedometer needle reading and impact speed of vehicles in traffic accidents. Int J Automot Technol. 2015;16:1057–63. https://doi.org/10.1007/s12239-015-0108-0.
45. Vavryn K, Winkelbauer M. Braking performance of experienced and novice motorcycle riders–results of a field study. In: International Conference on Transport and Traffic Psychology. 2004.
46. Sexton BF, Baughan CJ, Elliott MA, Maycock G. The accident risk of motorcyclists. 2004.
47. Savolainen P, Mannering F. Effectiveness of motorcycle training and motorcyclists' risk-taking behavior. Transp Res Rec. 2007;2031(1):52–8. https://doi.org/10.3141/2031-07.
48. Simpson HM, Mayhew DR. The promotion of motorcycle safety: training, education, and awareness. Health Educ Res. 1990;5(2):257–64. https://doi.org/10.1093/her/5.2.257.
49. Möller H, Senserrick T, Rogers K, Sakashita C, De Rome L, Boufous S, Davey C, Cullen P, Ivers R. Crash risk factors for novice motorcycle riders. J Safety Res. 2020;73:93–101. https://doi.org/10.1016/j.jsr.2020.02.003.
50. Austrian Road Safety Strategy 2021–2030. (nd.). https://www.bmk.gv.at/en/topics/transport/roads/safety/vss2030.html. Accessed 25 Jan 2023.