Transportmetrica A: Transport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ttra21

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To cite this article: Subasish Das, Md Mahmud Hossain, M. Ashifur Rahman, Xiaoqiang Kong, Xiaoduan Sun & G.M. Al Mamun (2022): Understanding patterns of moped and seated motor scooter (50 cc or less) involved fatal crashes using cluster correspondence analysis, Transportmetrica A: Transport Science, DOI: 10.1080/23249935.2022.2029613

To link to this article: https://doi.org/10.1080/23249935.2022.2029613

TRANSPORTMETRICA A: TRANSPORT SCIENCE
https://doi.org/10.1080/23249935.2022.2029613

Understanding patterns of moped and seated motor scooter (50 cc or less) involved fatal crashes using cluster correspondence analysis

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ABSTRACT

Moped and seated motor scooter (50 ccs or less) riders have a relatively high risk of becoming crash casualties. Comparison between 2015 and 2019 fatal crash data indicates that fatal moped crashes have increased by 76%, whereas fatal motorcycle crashes have decreased by 2%. This study collected moped and seated motor scooter-related fatal crash data for five years (2015–2019) from the Fatality Analysis Reporting System (FARS) to perform the analysis. Using an innovative categorical data analysis method known as cluster correspondence analysis (CCA), this study identified some critical clusters with a group of co-occurring variable categories. The contextual understanding of fatal crash patterns could guide authorities in developing data-driven interventions and countermeasures aiming to minimize moped collisions and related fatalities. The findings of this study can provide a better understanding of the patterns of contributing factors in moped and seated motor scooter fatal crashes.

ARTICLE HISTORY
Received 16 August 2021
Accepted 10 January 2022

KEYWORDS
Moped and seated motor scooter; crash data analysis; fatal crash patterns; cluster correspondence analysis; dimension reduction

Introduction

In transportation safety analysis, the term moped, or motorised cycle, is used when a two-wheeled vehicle is a speed-limited seated motor-driven cycle capable of moving by a less powerful (50 ccs or less) motor (Salatka et al. 1990). Seated motor scooters have been designed with a step-through frame comparable to a moped, except with an equal or more powerful engine (50 ccs to 250 ccs). Therefore, a motorised vehicle with an engine of 50 cc can be either a moped or a seated motor scooter. In police-reported crash documents, a person operating a moped or less powerful motorised bicycle/scooter (50 ccs or less) is classified as a non-motorist. However, in the Fatality and Injury Reporting System Tool (FIRST), which contains information from both the Fatality Analysis Reporting System (FARS) and

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General Estimates Systems (GES), a person operating a moped or less powerful motorised bicycle/scooter is coded as a motor vehicle occupant rather than as a non-motorist.

Moped vehicles are heavier, bigger, and faster than bicycles. Moped and light-moped riders have a relatively high risk of becoming crash casualties, primarily due to a high riding speed in relation to the vulnerability to the rider. Motorcycle and moped riders are obliged to wear a helmet, but light-moped riders are not. Although moped and light moped riders face risks similar to motorcycle riders, the safety and training of these riders are not emphasised like that of motorcyclists. Only a few states in the U.S. have enacted universal moped or seated scooter helmet legislation. As a result, there are misconceptions and a lack of understanding in perceiving the safety of moped and seated light moped riders. Additionally, as mopeds and seated motor scooters can exceed speeds of up to 30 mph, the riders are vulnerable to severe and fatal injuries.

Disregarding roadway rules, such as a lack of helmet wearing, unlicensed riding, and impaired riding, is involved in risk-taking. In many cases, mopeds are less capable of overspeeding; however, moped speeds are higher than those of conventional bicycles. Some studies identified moped riding as riskier than motorcycle riding, but other studies disagree (Haworth, Greig, and Nielson 2009). Additionally, moped fatal crashes have increased significantly in the last few years. Comparison between 2015 and 2019 fatal crash data indicates that moped fatal crashes have increased by 76%, while motorcycle fatal crashes have decreased by 2%. The national census of motorcycle-associated exploratory crash characteristics conducted by the National Highway Traffic Safety Administration (NHTSA) includes both motorcycles and mopeds collectively (NHTSA 2021a; NHTSA 2021b), and the observable helmet use trend is tracked for motorcycle riders only (NHTSA 2021c). In 2019, the Federal Highway Administration (FHWA) performed a comprehensive study to determine the causation of motorcycle collisions (FHWA 2019); however, there is a critical research gap in understanding the complex nature of crash risk factors associated with moped and seated motor scooter use that can produce fatal consequences. Thus, the enactment of moped-related policies is difficult for policymakers. As a result, there is a need for a thorough examination of the issues unique to moped-related safety so that suitable actions can be taken to mitigate these crashes.

This study aims to mitigate the research gap by performing an unsupervised learning algorithm on recent (2015-2019) moped and seated motor scooter-related fatal crash data from the FARS. An advanced categorical data mining method, known as cluster correspondence analysis (CCA), was applied to identify the critical clusters that describe the patterns of influencing factors associated with fatal crashes involving mopeds and seated motor scooter riders. It is well known that conventional statistical methods rely on prior assumptions. One of the key unique aspects of this method is that no pre-assumptions are needed to conduct CCA. The findings of this study can help roadway safety engineers in intervention design and strategy development to improve moped safety.

Literature review

This section provides a broad overview of moped-related safety studies. The current literature review mainly focused on four primary areas. These areas were selected after conducting a thorough exploration of the relevant studies. The key focus areas are: (1)

moped-related safety issues, (2) survey and focus groups, (3) helmet usage, and (4) agency practices.

Moped related safety issues

There are a handful of studies that focus on moped-related safety issues. More than a decade earlier, Haworth, Nielson, and Greig (2008) studied moped crashes by analyzing six years of vehicle registration and crash information from Queensland Transport. From simple descriptive analysis, the study pointed out that 'fall from vehicle' and 'angle' were the most prevalent crash types. Compared to motorcycles, moped crashes tended to occur among female and young riders, during weekdays, on roadways with low posted speed limits, and in tourist areas. In another study, Brandau et al. (2011) identified subtypes of young moped riders using cluster analysis, and assessed their characteristics in crash involvement and risk preferences. The study argues that young, moped drivers did not share characteristics as a homogenous group, according to the injury prevention and intervention measures. Understanding moped crashes among different focus groups and associated safety treatment determinations is critically important. Fonseca and Okumura (2010) discussed potential safety treatments for traffic crashes involving university student moped riders. Helmet usage is a critical factor in the severity outcomes of motorcycle and moped crashes. Another dominant factor leading to injury collisions for moped riders is traffic rules and regulations violation (Ahmad et al. 2019). Wang et al. (2012) studied the violation patterns of moped riders in China to provide guidance on potential countermeasures. The authors recorded 125 min of video from 10 signalised intersections and coded the rider behaviour of 1,455 vehicles. The outcomes of descriptive statistics showed disregarding traffic signals, improper actions or turning, and overloading as common violation behaviours. Moped users who acted in violation of traffic laws at intersections were more likely to be engaged in frequent and more severe injuries compared to other riders who were not involved in violations. Moreover, moped crashes were more severe at night and in speed zones of 55 mph or more. Violation manoeuvres were not significantly associated with the vehicle and driver-related factors. Theofilatos and Ziakopoulos (2018) investigated the moped-related occupant injury severity on the urban motorway in Greece. Firth logistic regression model was applied to handle the low number of killed and severely injured (KSI) users with respect to slightly injured occupants. The findings revealed that traffic and speed variations were likely associated with severe injuries; however, weather conditions had no significant effect. Multiple studies also performed comprehensive analysis and investigated many factors. Johnson et al. (2019) investigated the characteristics of adult riders involved in moped crashes to identify patterns of relations among the key contributing factors. The results from binary regression analyses exhibited that summer months and weekdays were the most common crash times. Other human factor-related dominant factors were male, rider age of 23–59 years, Caucasian, helmet usage, and low-speed roadways. Females were more likely to be in collisions with multiple riders compared to males. In addition, males and older riders had a higher crash likelihood when intoxicated by alcohol and drugs. Montella et al. (2020) utilised association rule mining and classification trees to examine how the association of crash risk factors changed with the modes of powered two-wheelers. In relation to mopeds, collisions with sport utility vehicles (SUVs) were associated with rainy weather, female riders, and poor lighting conditions, whereas head-on crashes were more frequent on curve roadways in rural areas. Glaser et al. (2017) investigated naturalistic driving study (NDS) data to recognise the influence of driving behaviour, traffic, and environment-related factors on moped-involved conflicts in urban areas. Most of these events occurred on branch roads and secondary main roads. Weaver et al. (2018) explored injury severity in moped crashes in comparison to motorcycle crashes. In line with previous studies, they reported fewer helmet usage among moped riders. Although the injury severity score was higher for motorcycles than mopeds, the mortality rate was equivalent.

Besides the above-mentioned factors, other factors associated with the moped-involved crashes were also investigated, such as riding speed, rider experience, and licence regulations of the riders. Blackman and Haworth (2013) investigated five years of police-reported crash information from Queensland to compare the crash contributing factor of motorised two-wheelers. The study used an ordered probit regression model to identify influential factors in terms of crash severity. Moped riders had a higher severe crash probability at night and on roads with a posted limit of 55 mph or more, whereas scooter crashes were more severe during weekdays and in a speed zone of 45 mph. Tagliabue and Sarlo (2015) examined training methods for safe moped riding, focusing on young riders' physiological responses to hazardous events. The authors employed the Honda Riding Training (HRT) simulator to record skin conductance responses (SCR) and determine if training scenarios with active riding behaviour in dangerous scenarios elicited varied physiological reactions, leading to improved learning outcomes. The performance differed significantly among experienced and inexperienced riders. Bonander, Andersson, and Nilson (2015) estimated the effect of Sweden's moped driving licence regulations on non-fatal moped associated traffic injuries. By conducting a time-series intervention analysis with generalised additive models on monthly aggregated traffic crash data, the effect size on moped-related injury events involving a sub-group of teenagers was examined. These findings offered quasi-experimental evidence that stricter licencing restrictions can influence non-fatal moped-related injuries. However, the study did not consider the heterogeneous effects of multiple crash variables that could influence the road crash frequencies (Saeed et al. 2020a).

Survey and focus group

Following are examples of common types of surveys and focus groups adopted in previous studies. Steg and van Brussel used a modified version of the Driver Behaviour Questionnaire to investigate the reasons behind moped-related crashes and crash injury types (Steg and van Brussel 2009). The results identified some rider traits such as lapses, mistakes, and violations. These traits were not significantly correlated with crash involvement. However, a moped driver had a greater tendency of violating the posted speed limits when they have positive experience towards speeding. Blackman and Haworth (2010) examined stationary powered two-wheelers in designated parking areas at six-month intervals. Over one-third of these crashes were either larger scooters or mopeds, while motorcycles made up the majority. Time efficiency, traffic congestion, cost, parking availability were a few key motivating factors of using mopeds. Zhang et al. (2018) conducted a cross-sectional study in China to recognise the association between potential risk factors and injuries of moped-related collisions. More than 3,000 riders were interviewed who were involved in relevant crashes within three years of the study period. The outcomes from regression analysis indicated that the prevalent attributes were careless operation, speeding, disobeying traffic signs or signals, and riding in the wrong direction. Møller et al. (2021) adopted the Theory of Planned Behaviour (TPB) to characterise underlying viewpoints of violations among teen moped riders. Violation behaviours were related to sentimental and operational advantages such as saving time, convenience, excitement, and parent involvement.

Helmet usage

Helmets have been proven to be beneficial in preventing and reducing the severity of injuries resulting from motorcycle and moped-related collisions. Galanis et al. (2014) reviewed the hospital reports of emergency patients (riders) that were affiliated with police crash reports involving motorcycles and mopeds. They found that more than 60% of riders were without a helmet among the admitted riders. The likelihood estimation from multivariate logistic regression analysis demonstrated that riders without helmets were found to be more likely (around 45%) to be admitted to the hospital than helmeted riders. The results also revealed that riders without helmets were more than twice as likely to suffer a fatal injury than riders with helmets. Later, the authors further investigated moped and motorbike riders who necessitated medical and emergency care at a hospital for an injury, with the goal of measuring the state-level healthcare impact of riders that do not wear helmets (Galanis et al. 2016). By comparing 1,965 patient care reports from emergency medical service (EMS) providers from 2007 to 2009 with relevant hospital medical records, the study identified that the protective association of helmet use with moped riders is weaker compared to motorcycle riders. Bandzar, Gupta, and Atallah (2016) investigated nine years of moped-related injury information from emergency departments in the U.S. to establish national estimates of moped injury incidence over time. Most of the injuries were on the head, allied with moped use without wearing a helmet. Chen, Saeed, and Labi (2017) emphasised moped riding without a helmet as a primary cause of death in related collisions, which is in accordance with regular motorised vehicles. Furthermore, the macroscopic statistical analysis classified by vehicle types showed the significance of minimising the encounter of mopeds with large vehicles to reduce crash frequencies as well as fatal injuries. Boone et al. (2018) explored the corresponding association via a census of fatally injured moped riders in the United States. The authors constructed a logistic regression model to analyze data accumulated from the Fatality Analysis Reporting System (FARS) to investigate risk factors associated with helmet nonuse. Overall, universal moped helmet laws were found to lead to an increase in the use of helmets. The study revealed that the odds of helmet use (found by comparing crashes in states with universal moped helmet laws to those without) was 69 times, considerably higher than expected. Additional research is required to examine the implemented helmet laws regarding non-fatal injury crashes with moped riders.

Agency practices

Each state agency has its definitions of mopeds and associated helmet laws, and jurisdictional licencing types also vary. In many cases, standing e-scooters are considered a part of mopeds. The current study is limited to mopeds and seated motor scooters (50 ccs or less). Table 1 lists the definition of mopeds and safety laws and rules for the four states with the highest moped fatal crashes in 2015–2019.

Table 1. Moped definition and safety law/rules for the top four states with high moped fatal crashes.

State	Moped Definition	Safety Law/Rules
Florida	50 ccs or less, 2 brake horsepower or less, and operating speed < 30 mph	Rider must be at least 16 years old and hold at least a regular operator driver's licence (Class E).
South Carolina	A cycle with pedals or without pedals. 50 ccs or less, and operating speed < 30 mph	Age > 12 years. Valid driver's licence or a valid moped operator's licence
North Carolina	Two or three wheels, 50 ccs or less, no external shifting device, and operating speed < 30 mph	Must travel the right–hand side of the lane. No 'squeezing' between parked cars and moving traffic. Wear a helmet.
California	Two or three wheels, 50 ccs or less, and operating speed < 30 mph	Must wear a safety helmet

In essence, a wide array of crash-based studies have been conveyed to connect the injury risk of moped-related collisions with a multitude of driver, road, environment, vehicle, and crash-related factors. Most of them applied either simple descriptive statistics (Haworth, Nielson, and Greig 2008; Wang et al. 2012; Glaser et al. 2017) or conventional parametric models (Blackman and Haworth 2013; Johnson et al. 2017; Theofilatos and Ziakopoulos 2018; Johnson et al. 2019) to assess the effect of crash risk factors on a response variable. However, these techniques have already been criticised for their predefined assumptions (e.g. covariates are mutually exclusive), which might not be valid in real-world scenarios (Das, Dutta, and Sun 2019; Hossain et al. 2021a). On the contrary, one recent study adopted association rule mining (ARM) to discern the interdependencies of attributes that caused moped-related collisions (Montella et al. 2020). However, this data mining approach must be performed within controlled item sets to avoid unimportant pattern generation; therefore, it is not a suitable method in determining long-term patterns from crash datasets comprising a vast number of contributing factors (Hossain et al. 2021b). This research applies CCA to reveal the fatal crash patterns of moped and seated scooter riders using the national crash database (FARS). The FARS stores all deadly motor vehicle collisions in the U.S. and is, therefore, a reliable and extensive fatal crash database for extracting a high number of fatal crash observations. In traditional correspondence analysis, such as multiple correspondence analysis (MCA) and joint correspondence analysis (JCA), the selection of a cluster or a combination of attributes depends on the analyst's judgment. However, CCA incorporates both correspondence analysis and clustering techniques to recognise the patterns of influencing factors with relative contribution measures. This unsupervised learning algorithm can identify the association among crash attributes from a complex multidimensional crash dataset without imposing predefined hypotheses. The combinations of contributing factors identified from CCA represent real-world crash scenarios that can help safety officials in designing effective strategies for safe and secure mobility of moped and seated motor scooters.

Methodology

Data collection and exploratory data analysis

The crash frequencies involving mopeds and seated motor scooters have increased as the exposure of these mobility options has increased, but little research has been conducted to compare the safety of mopeds with motorcycles. The national fatal crash dataset FIRST was

Table 2. Moped and motorcycle fatal crashes in the U.S. (2015–2019).

Year	Moped Fatal Crashes	Motorcycle Fatal Crashes	Moped and Motorcycle Fatal Crashes
2015	222	4789	5011
2016	238	5091	5329
2017	454	4901	5355
2018	413	4714	5127
2019	391	4667	5058

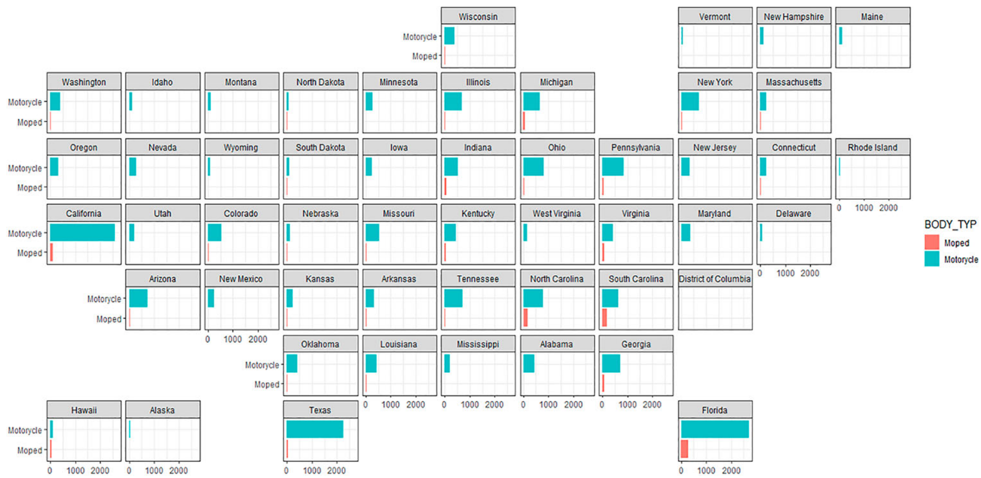

Figure 1. Moped and motorcycle fatal crashes in the U.S. (2015–2019).

considered as a potential dataset to explore moped and motorcycle-related fatal crashes. Table 2 lists the fatal crashes of mopeds and motorcycles in the U.S. during 2015–2019. A simple comparison between 2015 and 2019 indicates that moped fatal crashes have increased by 76%, while motorcycle fatal crashes have decreased by 2%. Thus, understanding safety laws, exposures, and crash outcomes (e.g. crashes with different injury levels, near-crash) are critical in exploring the risk factors associated with mopeds and seated motor scooters. Some of the recent statistics such as FIRST show that there are higher crash consequences for moped and motor scooter riders than for other motorcycles.

The fatal crashes associated with mopeds compared with motorcycles are shown in Figure 1 by presenting the results of fatal crash counts in the U.S. during 2015–2019. There has been a rapid increase in moped and motorised scooter usage where it has conventionally been unusual in the past decade. Higher exposures are often associated with higher risks. For example, Hawaii experienced 39 fatal moped crashes compared to 93 fatal motorcycle crashes (around 42% of motorcycle fatal crash counts). Risk-taking behaviours of the riders (such as over-speeding and impairment) were more common in single rather than in multivehicle crashes. However, these manoeuvres vary with state and counties as each of them has their own sets of laws and regulations (Saeed et al. 2020b). Alcohol and drug-related intoxications were associated with less compliance with helmet usage, over-speeding, and riding without proper licencing.

Table 3. Top 20 states with high number of moped and motorcycle fatal crashes.

State	Moped Fatal Crashes (2015–2019)	Motorcycle Fatal Crashes (2015–2019)	Moped and Motorcycle Fatal Crashes (2015–2019)
Florida	281	2696	2977
California	111	2591	2702
Texas	55	2250	2305
North Carolina	163	791	954
Pennsylvania	54	856	910
Ohio	32	806	838
South Carolina	176	637	813
Arizona	40	742	782
Georgia	70	712	782
New York	24	715	739
Tennessee	25	707	732
Illinois	27	688	715
Michigan	63	648	711
Indiana	74	522	596
Missouri	37	546	583
Colorado	16	528	544
Virginia	64	421	485
Kentucky	32	445	477
Louisiana	20	439	459
Oklahoma	19	423	442

The risk patterns between motorcycle and moped riders differ. For example, overspeeding was less likely to be common in moped crashes. However, it is also important to note that the speeds of mopeds are higher than bicycles and can go up to 30 mph. Moderate speed, less safe surroundings, and fewer restrictions on helmet usage can make moped riders the most vulnerable riders. Table 3 lists the frequencies of fatal crashes of mopeds and motorcycles by state. Florida, South Carolina, North Carolina, and California are the top four states with the highest numbers of moped fatal crashes. The absence of readily available exposure and other relevant data such as licencing status, moped ownership records, helmet laws, and activation of helmet laws is a critical gap in assessing risks.

Table 4 presents the categories of the categorical variables and the percentage of each category in the dataset. This dataset provides information about riders, such as gender, age, and helmet usage, and crash information, such as time and crash type. Information about the roadway characteristics of the crash location is reported as well. This roadway information includes traffic way type, roadway alignment, number of lanes, and intersection type. Weather conditions such as lighting conditions and weather are included in this dataset. The speed of the crash-involved vehicle is collected in the data as well. The rider age is divided into seven levels at a ten-year increment. The youngest group is 15–24 years old. About 14 percent of riders involved in the crashes are in this age group. 5 percent of riders in this dataset are older than 74 years old. This table also shows some variables with skewed distributions. For example, about 88 percent of riders involved in the crashes are male. For the movement prior to the crash, 72 percent of riders were going straight. In terms of speeding behaviour prior to the crash, more than 87 percent of riders were not speeding. About 85 percent of crashes occurred at the straight alignment. For most cases, moped crashes occurred in urban centres.

Table 4. Proportions of key variable categories.

Variable	Category	Percent	Barplot
Rider age (Age)	15-24	14.15	
	25-34	14.41	
	35-44	12.93	
	45-54	22.1	
	55-64	20.7	
	65-74	9.17	
	> 74	5.15	
	Unk	1.4	
Rider Condition (Cond)	Failure to Yield Right-of-Way	7.77	
	Failure to Obey	5.76	
	Careless Driving	5.68	
	None	57.47	
	Other	23.32	
Rider Gender	Male	87.77	
	Female	12.23	
Collision Type (Coll)	Angle	33.8	
	Front-to-Rear	23.14	
	Not a Collision with MV	21.57	
	Other	21.48	
Day of the Week	MTWT	56.59	
	FSS	43.41	
Lighting Condition (Lgt)	Daylight	50.57	
	Dark - Lighted	23.58	
	Dark - Not Lighted	20.26	
	Dusk	2.45	
	Other	3.14	
Trafficway (Traf)	Two-Way Undiv	60.26	
	Two-Way Div Unprotect Median	18.17	
	Two-way Undiv LTL	7.25	
	Two-Way Div Barrier	5.33	
	Other	9	
Most harmful event (Mharm)	Motor Vehicle In-Transport	72.05	
	Rollover/Overturn	7.95	
	Curb	2.53	
	Tree (Standing Only)	2.53	
	Fell/Jumped from Vehicle	2.1	
	Utility Pole/Light Support	1.83	
	Other	11	
Number of vehicles	Single	58.08	
	Multi	41.92	

Variable	Category	Percent	Barplot
Prior crash (PCrs)	Going Straight	72.31	
	Negotiating a Curve	8.91	
	Turning Left	6.9	
	Changing Lanes	2.45	
	Other	9.43	
Helmet usage (Res)	No Helmet	45.94	
	None Used/Not Applicable	24.02	
	Helmet, Unknown if DOT Compliant	17.55	
	DOT-Compliant Motorcycle Helmet	8.65	
	Other	3.84	
Speeding (Spd)	No	87.42	
	Yes, Too Fast for Conditions	4.45	
	Yes, Exceeded Speed Limit	2.79	
	Other	5.33	
Vehicle speed (VSpd)	25 MPH	13.8	
	35 MPH	17.82	
	45 MPH	16.77	
	55 MPH	15.63	
	Other	35.98	
Alignment (Algn)	Straight	85.07	
	Curve Left	5.94	
	Other	9	
Number of lanes (Ln)	Two lanes	63.93	
	Four lanes	10.83	
	Three lanes	10.48	
	Other	14.76	
Weather condition (Wea)	Clear	77.12	
	Cloudy	12.05	
	Rain	4.02	
	Other	6.81	
Intersection type (Rej)	Non-Junction	49.69	
	Intersection	32.05	
	Intersection-Related	10.13	
	Other	8.12	
Facility trpe (Rur)	Urban	70.74	
	Rural	29.26	
Season (Sesn)	Summer	33.36	
	Autumn	26.29	
	Spring	24.45	
	Winter	15.9	

Cluster corresponding analysis

In recent years, researchers have utilised advanced parametric and non-parametric algorithms to minimise the potential heterogeneous effects of explanatory variables. In parametric modelling, individual covariates can introduce variation in the impact of the effect of examined variables on crash probability and degree of severity. Several studies have concentrated on random parameter models to overcome these shortcomings (Chen et al. 2019a; Chen et al. 2019b; Chen, Saeed, and Labi 2017; Waseem, Ahmed, and Saeed 2019; Yamany et al. 2020); however, these approaches need distributional hypotheses and may face adversity while following groups of observations with shared unobserved heterogeneity (Mannering, Shankar, and Bhat 2016).

Correspondence analysis (CA) is an unsupervised machine learning technique. This method can examine two-way and multi-way tables that contain associations between the rows and columns from datasets with a wide range of nominal variables. In recent years, CA has become a popular unsupervised machine learning algorithm among transportation safety researchers (Das and Sun 2015; Das and Sun 2016; Das et al. 2018; Ali et al. 2018; Jalayer, Pour-Rouholamin, and Zhou 2018; Baireddy, Zhou, and Jalayer 2018; Das 2021;

Das, Mousavi, and Shirinzad 2021a; Das, Tran, and Theel 2020; Das et al. 2021b;Hossain et al. 2021a; Hosseini, Jalayer, and Das 2021). Cluster correspondence analysis is a variant of the CA framework. This method uses both dimension reduction and clustering for categorical data analysis. The ability to concurrently assign individuals to clusters and optimal scaling measures to the variable categories has made this method unique among all dimension reduction methods. Additionally, this method outperforms different CA techniques in determining the nature of the underlying cluster structures. Readers can consult Velden, D'Enza, and Palumbo (2017) for a complete theoretical concept of this method.

Consider a dataset with $n$entities (e.g. moped drivers associated with crashes) for p categorical variables (for example, utility pole as the most harmful event). This dataset can be expressed as a super indicator matrix $\mathbf{Z}$ with $n \times Q$ dimension, where $Q = \sum_{j=1}^{p} q_j$. By using an indicator matrix $\boldsymbol{Z}_K$, one can develop a table to cross-tabulate cluster memberships with the nominal or categorical variables such as $\boldsymbol{F} = \boldsymbol{Z'}_K\boldsymbol{Z}$, where $\boldsymbol{Z}_K$ is the $n \times K$indicator matrix indicating cluster membership. This method develops optimal scaling values for rows (as clusters) and columns (as categories). The clusters are optimally split regarding the distributions over the categorical variables in a two-dimensional space. Similarly, the categories differing distributions over the clusters can be expressed as*:*

$$max\emptyset_{clusca}(\boldsymbol{Z}_K, \boldsymbol{B}^*) = \frac{1}{p} trace\boldsymbol{B}^{*'}\boldsymbol{D}_z^{-1/2}\boldsymbol{Z}'\boldsymbol{M}\boldsymbol{Z}_K\boldsymbol{D}_Z^{-1}\boldsymbol{Z}_K'\boldsymbol{M}\boldsymbol{Z}\boldsymbol{D}_z^{-1/2}\boldsymbol{B}^* \tag{1}$$

Where,

$$\boldsymbol{M} = \boldsymbol{I}_n - 1_n 1_n'/n$$

$$\boldsymbol{B} = \sqrt{np}\boldsymbol{D}_z^{-\frac{1}{2}}\boldsymbol{B}^*$$

$\boldsymbol{D}_K = \boldsymbol{Z}_K'\boldsymbol{Z}_k$, a diagonal matrix with cluster sizes

$\boldsymbol{D}_z$ is a diagonal matrix so that $\boldsymbol{D}_z 1_Q = \boldsymbol{Z}' 1_n$

This study used R package *clustrd* (Markos, D'Enza, and Velden 2019) to perform the analysis. The Calinski–Harabasz measure (also known as the valence ratio criterion) provides the ratio of the sum of between-clusters dispersion and of inter-cluster dispersion for all clusters. This measure was used to determine the optimum number of clusters.

Results

This study randomly conducted the k-means runs multiple times to gain an optimal number of clustering. By following the procedure in Yamany et al. (2020), the soundness of the clusters was examined by comparing the root mean square (RMSE) outcomes. After conducting the optimisation technique, the final cluster was fixed at eight. Table 5 shows the key measures associated with the cluster centroids, including the sample size (i.e. number and percentage of crashes within each cluster) and coordinates.

Figure 2 is the biplot of the clustering results. The locations of the centroids of eight clusters are shown in blue ellipses. As the biplot shows the locations of all attributes, it is difficult to explore individual attributes. In this study, biplot visualisation serves as a common diagram to show the nature of the presence of all attributes and their locations in a

Table 5. Cluster parameters.

Cluster	Axis 1	Axis 2	Proportion	Within Cluster Sum of Squares
Cluster 1	0.0057	−0.0334	16.9%	0.0154
Cluster 2	0.0176	0.0129	16.7%	0.0118
Cluster 3	−0.0257	−0.0033	13.4%	0.0130
Cluster 4	−0.0008	−0.0095	13.1%	0.0130
Cluster 5	0.02	−0.0036	12.4%	0.0077
Cluster 6	0.0248	0.0287	10.9%	0.0116
Cluster 7	−0.0219	0.0141	10.5%	0.0077
Cluster 8	−0.0533	0.0167	6.1%	0.0073

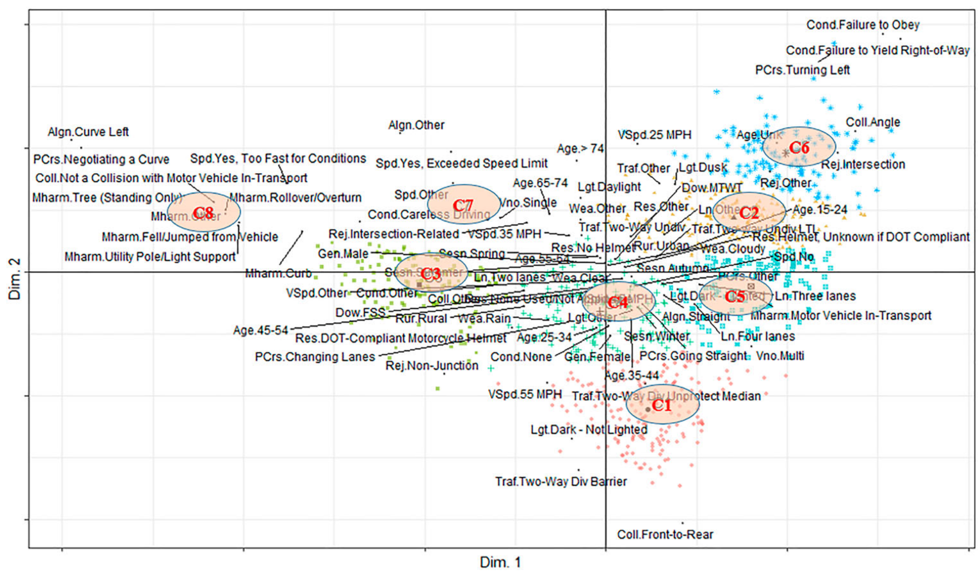

Figure 2. Biplot showing the clusters.

two-dimensional space. Additional cluster level bar plots are shown later and explained in detail (see Figures 3 and 4). Eight clusters were identified in this plot. The CCA algorithm performs the dimension reduction on the dataset and maximises the distance between the clusters and minimises the distance inside of the clusters. The results ended up with clusters that have a close relationship among the points inside of the same clusters and could be clearly distinguished from the other clusters. Table 5 above shows the amount of variation of the data explained by each cluster. Clusters 1–8 show 16.9%, 16.7%, 13.4%, 13.1%, 12.4%, 10.9%,10.5%, and 6.1% variation of the total dataset, respectively. The first six clusters contain information for more than 80% of the data. The least information is associated with Cluster 8 (only 6.1% of the data).

C1 – front-to-rear collision with the vehicle

In Cluster 1 (C1), the pattern (on the right-hand side with positive standard residuals) shows a group of categories that are closely associated with each other. These categories include front-to-rear collision type, no lighting during the dark condition, at non-junction locations, two-way traffic way divided by a barrier median or divided two-way traffic with unprotected median, vehicle speed at 55 mph, the most harmful event being the moving vehicle, and the rider not being in distracted or careless driving conditions. Out of these categories, the front-to-rear collision type has the longest bar on the positive side of cluster 1, which indicates that this category has the strongest association with other categories in this cluster. This type of collision often occurred in dark conditions without lighting. With the poor visibility in the no lighting conditions at night, riders' ability to react to emergencies is compromised, even if they are not distracted or careless at the moment (Miggins et al. 2011). In the cluster, two median types, divided with barrier and divided with unprotected median, are associated with a front-to-rear collision. It shows that this type of collision could occur on two-way roads with or without a barrier median. Moped riders often consider lane splitting as a safer option to quickly move through traffic, particularly at locations without barriers, when the other motorised vehicles are stopped or at a slow-moving speed (Blackman and Haworth 2010). Another combination worthy of mentioning is that this front-to-rear type of collision is highly associated with these non-junction locations and vehicles in the moving condition. The intersection is often where drivers and riders pay a lot of attention, and so the front-to-rear collision is less likely to happen. Furthermore, the majority of non-intersection roadways are relatively high-speed zones and pose additional safety hazards for moped and scooter riders when they collide with regular vehicles (Blackman and Haworth 2013).

C2 – angle collision with the vehicle

Cluster 2 (C2) depicts the pattern associated with the crashes with the angle collision type. Collisions that hit at angles often occur at intersections with moving vehicles at a relatively low speed (25 mph), and when the moped or seated scooter riders fail to obey traffic rules. Montella et al. (2020) showed that violation-related intersection crashes are likely to be angle collisions. This pattern explains the possible reasons for this type of collision. Collison at an angle caused by the rider violating the rules indicates that the rider may not fully check the driving environment and that the vehicle driver may not expect the violation (Wang et al. 2012). This pattern explains 16.7 percent of the variation in the dataset, making it the cluster with the second-highest percentage of the variation. This is a typical collision involving the moped or seated scooter riders. This finding suggests that law enforcement or traffic agencies should make more efforts for these intersections with this type of scooter rider-involved collisions.

C3 – collision with objects

Cluster 3 shows the pattern of moped or scooter rider-involved collisions with non-vehicle objects, such as utility poles, lighting support, trees, and other objects. This type of collision occurs at non-junction roadways under the dark and no lighting conditions and is associated with careless driving behaviour. The collision with objects leads to overturning or to riders jumping off of the scooters. Moskal et al. (2007) demonstrated a greater likelihood of severe injuries among riders involved in collisions with fixed objects. In the corresponding pattern, poor lighting conditions at non-junction locations and careless driving riders is the key combination that causes fatal collisions with objects. Under poor lighting conditions, if the traffic is not complex (especially in rural areas), riders may become less cautious and end up in fatal collisions (Montella et al. 2012).

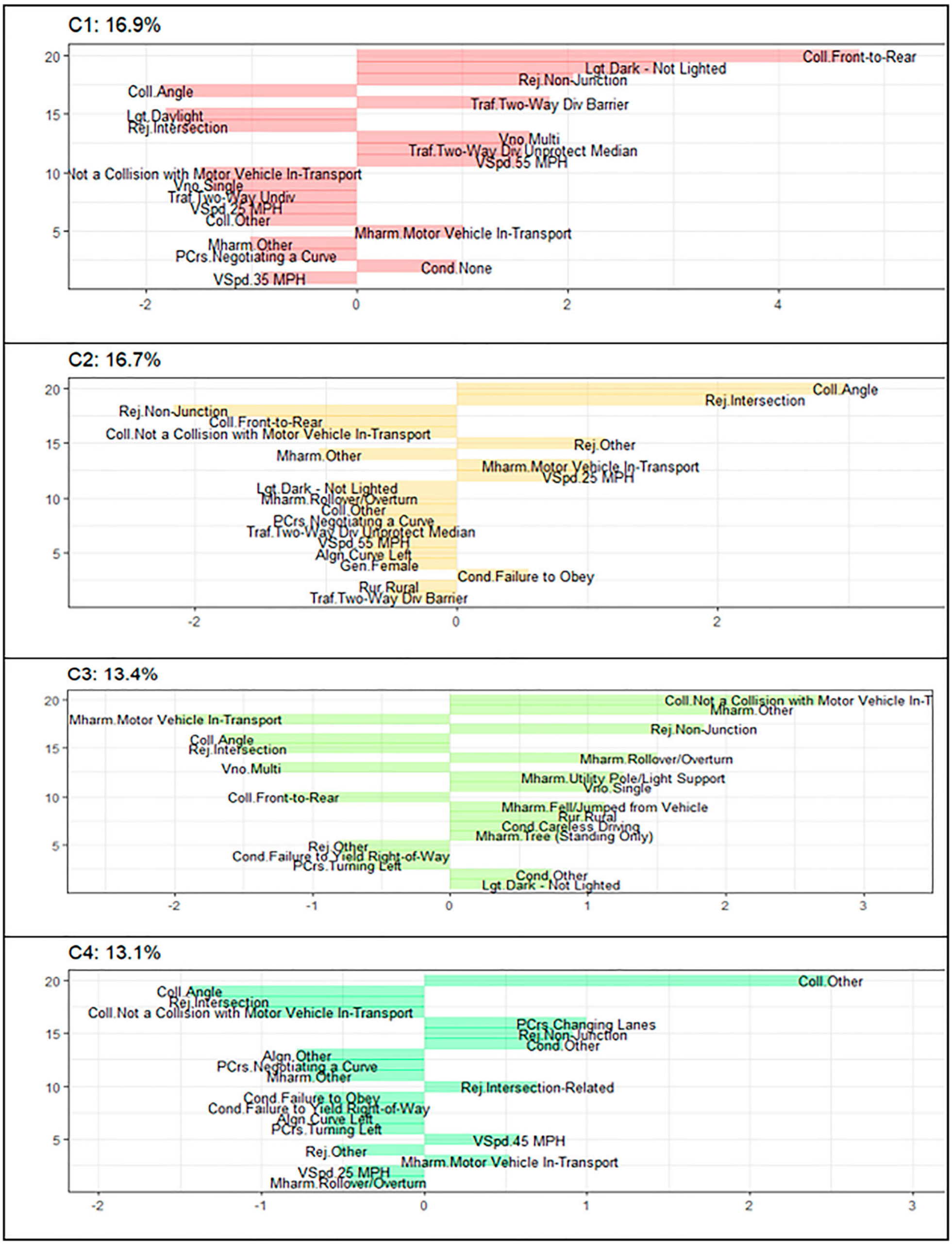

Figure 3. Cluster 1–4.

C4 – collision with vehicles due to lane-changing

Cluster 4 states that the collisions caused by changing lane behaviour are caused by colliding with moving vehicles under a relatively higher speed – 45mph. This type of crash could occur at intersections or non-intersections. As a scooter is a small size motor vehicle, changing lanes is relatively easy and could happen in a relatively short time compared with the changing lane manoeuvre of a vehicle. Several studies have highlighted moped and scooter riders' frequent lane-changing behaviour, which escalates the magnitude and degree of the related crash episodes (Guo, Sayed, and Zaki 2019; Lee 2015). In practice, the sign of turning from the scooter is not as obvious as from a normal vehicle. A careless changing lane manoeuvre of a scooter, such as improper signalling or the vehicle driver failing to respond to the scooter turning signal, are the hypothesised scenarios that lead to this type of fatal crashes.

C5 – collision at wide intersections (3–4 lanes)

Cluster 5 shows that the pattern of the crashes that happened at wide intersections with three or four lanes in the dark but lighted condition. Blackman and Haworth 2010 identified that more severe moped crashes have been significantly associated with nighttime during the weekend (Blackman and Haworth 2013). In this study, the crash type is angle collision with moving vehicles. The rider condition is often not distracted or careless. The collision of the scooter and vehicle is apparently not caused by careless driving behaviour. The potential reason explained by this pattern is that during the dark condition, even with the lighted intersection, the vehicle or scooter may not be visible to each other before both of them arrived at the lighted intersection. Due to the wide length of a three or four-lane intersection, completely crossing the intersection needs more time than narrower intersections. It is possible that the moped and seated scooters are still in the intersection while the vehicle is approaching the intersection. The reaction time for both sides may not be enough to respond. For this, the lighting condition should not be limited to the intersection area for these wide intersections, especially for unsignalized intersections. Expanding the lighting areas around the intersection to ensure vehicles and scooters from any direction can detect each other could help reduce the occurrence of this type of collision.

C6 – collision at intersections with failed-to-yield scooters

Cluster 6 demonstrates a pattern associated with the left turn or angle collisions involving failed-to-yield scooters at intersections. This type of collision often occurs during the daytime, when both scooters and vehicles have plenty of confidence about the driving environment, and when involved riders failed to yield to the vehicles with the right of way. Moped riders being at fault while taking left turns at intersections is one of the most serious types of moped crashes (Wang 2014). Low moped speed (speed around 25 mph) is associated with this type of fatal crash. Even if the vehicle speed is not fast, unexpected failed-to-yield moped or scooter riders could lead to fatal crashes. This is a new finding which was not identified in previous studies.

C7 – collision of speeding scooters

Cluster 7 is the pattern for the fatal collision involving speeding moped or seated scooter drivers. Speeding has been one of the most contributory factors for fatal vehicle-vehicle crashes. This pattern shows the same story for scooters. This type of collision may not involve other moving vehicles, but it is highly associated with intersections. This may suggest that the rider with the speeding scooter failed to stop when the rider wanted to and

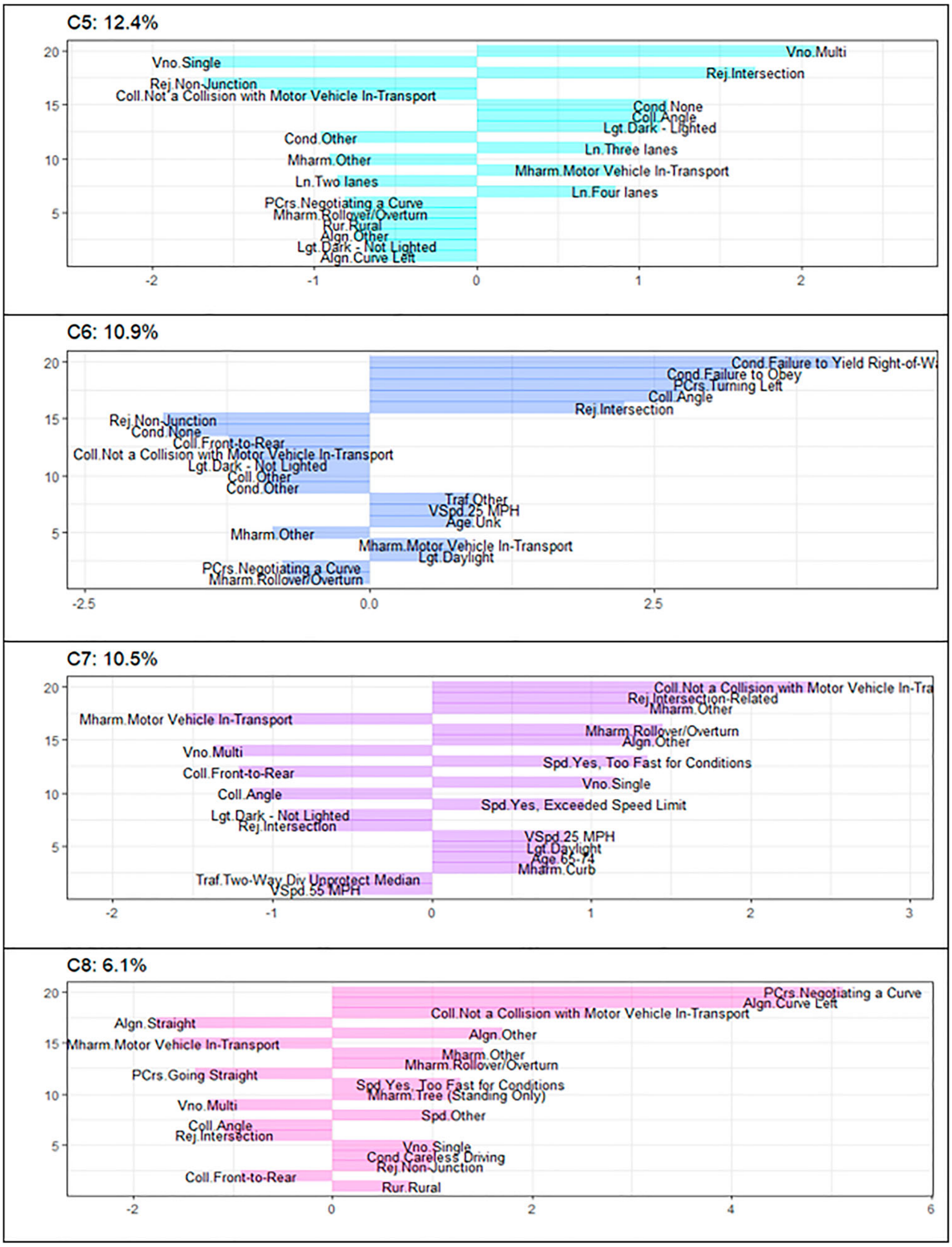

Figure 4. Cluster 5–8.

subsequently collided with a kerb. Riders in the 65–74 age group are also associated with fatal crashes with speeding riders. Compared with younger riders, elderly riders may get serious injuries when the speeding scooter fails to stop and then rolls over or overturns. This unique finding was not examined by previous studies.

C8 – collision of scooters with multiple violations (speeding, distracted)

Cluster 8 shows the pattern for fatal crashes that involved speeding and careless moped or scooter riders that occurred at non-junction locations and didn't involve other moving vehicles. Negotiating a curve at a rural and non-junction area is highly associated with this type of fatal collision. Riding in non-junction and rural areas means that the driving condition is often excellent without many complexities, which could be a dominant reason for riders speeding and becoming careless while driving. This finding is more in line with motorcycle crashes than moped crashes (Blackman and Haworth 2013). Fatal crashes occur at a combination of multiple conditions: speeding, carelessness, and negotiating a curve. The involved moped or seated scooter often rolls over or overturns and hits a tree. The scenario involved in this type of collision often leads to fatalities.

Key findings

For fatal crashes involving both scooters and vehicles, the collision types are front-to-rear and angle. Front-to-rear crashes often occur at non-junction-related locations in poor lighting conditions. A possible solution could be adding more lighting to these scooter-vehicle crash hot spots to reduce the crashes. Angle collision is highly associated with intersection-related locations and moped or scooter riders who violate traffic rules. For this type of collision, more obvious traffic signs and more strict law enforcement may be necessary for certain areas with high fatal crash occurrences. Angle collision could also happen to riders who do not violate traffic rules. This type of collision is most associated with wide intersections that have three or four lanes during night conditions. In these dark conditions, the intersection may be lighted. However, a wide intersection requires more time for a scooter to pass, and poor lighting conditions at these non-intersection roadway segments could compromise the scooter riders' judgment. Vehicles on road segments away from the intersection and without proper lighting conditions could be hard to detect by the scooters before they decide to cross the intersection. There is not enough reaction time for the riders when the vehicle approaches the intersection and becomes visible to them. To reduce this type of crash, extending the intersection lighting coverage to further road segments could help scooter riders detect incoming vehicles earlier and make better judgments.

Another type of fatal crash that involved both scooter and vehicle results from the scooters' lane-changing behaviour and a high-speed vehicle (45 mph). Mopeds or scooters are small 'vehicles' that can be easily manoeuvred. When a rider decides to perform lane-changing, this behaviour could occur faster than a vehicle normally takes. The turning light for scooters is typically not as obvious as vehicles. Thus, sudden lane-changing or distracted vehicle drivers could result in fatal crashes.

Fatal crashes from non-collision with vehicles often involve rollovers or overturns and hitting light supports, utility poles, trees, kerbs, and other things. This type of fatal crash that occurs at the intersection-related location is associated with elderly and speeding scooter riders. This type of crash happens at non-junction-related locations that are often in rural areas, which have less complicated traffic or traffic control devices. Poor light condition is a dominant factor for this type of crash at rural locations. Without proper lighting conditions, riders collide with unexpected objects, such as utility poles, resulting in fatal crashes. Proper lighting in these areas is highly recommended. This type of fatal crash could also take place in the daytime and often involves speeding and careless riders. Speeding and negotiating a curve is a combination strongly associated with this type of fatal crash. Targeted traffic safety education for these areas that have high occurrences of this type of crash could help to mitigate the situation. Traffic signs may be needed for curves on rural roadways that have frequent occurrences of this type of crash.

Conclusions

The presented national statistics describe the need to document the nature and extent of risk factors associated with moped and seated motor scooters. This study applied CCA to identify the significant risk factors and their associations that cause the related fatal collisions. In addition to depicting the clusters of individual crash attributes in a lower-dimension space, this innovative categorical data analysis method can estimate the relative contributions of categories for each cluster group. The findings indicated that associations among certain contributing factors, such as lighting, traffic way, road geometry, and settings, significantly influence the manner of moped and motor scooter-related fatal crashes. Angle crashes occurred at wide intersections in poor lighting conditions (C5), whereas front-to-rear collisions happened at high-speed non-junctions of two-way streets in dark without street lighting (C1). In similar visibility conditions, collisions with fixed objects turned into rollover crashes on rural non-junctions (C3). The outcomes also revealed risk-taking manoeuvres of moped riders with fatal consequences, including disregarding traffic rules at intersections (C2, C6, C7), lane changing with other vehicles travelling at high speed (C4), and speeding while negotiating curves (C8). The contextual understanding of these factors could guide authorities in developing data-driven interventions and countermeasures.

The findings of the research can be communicated to stakeholders by developing educational materials, licencing recommendations, and entry-level training requirements to mitigate risks. The research needs to call for several key tasks, including documentation of the extents and patterns of moped and seated motor scooter use and user profiles, documentation of moped definitions and safety rules and laws by the states of the U.S., data-driven summarisation of the significant risk factors, development of interactive tools to collect information from stakeholders from social media and other platforms, development of an information guide to provide information and potential mitigations for risk factors, and development of model licencing and training requirements for moped, seated motor scooter riders, and vehicles as a way to improve moped safety.

The findings suggest that preventive strategies should focus on reducing violations and increasing moped riders' anticipatory abilities as well as other road users' awareness of mopeds. Because of their youth, the impact of such measures could be amplified by infrastructure that allows for safe interaction between mopeds and other road users. Injury prevention measures aimed toward certain populations could increase moped safety. Future studies with large samples may help better understand the characteristics of moped-vehicle conflicts.

Acknowledgments

The authors like to thank three anonymous reviewers for their constructive suggestions and feedback.

Declaration of conflicting interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

Ahmad, N., A. Ahmed, B. Wali, and T. U. Saeed. 2019. Exploring factors associated with crash severity on motorways in Pakistan. Transport.

Ali, F., D. Dissanayake, M. Bell, and M. Farrow. 2018. "Investigating car Users' Attitudes to Climate Change Using Multiple Correspondence Analysis." *Journal of Transport Geography* 72: 237–247. doi:10.1016/j.jtrangeo.2018.09.007.

Baireddy, R., H. Zhou, and M. Jalayer. 2018. "Multiple Correspondence Analysis of Pedestrian Crashes in Rural Illinois." *Transportation Research Record* 2672 (38): 116–127. doi:10.1177/0361198118777088

Bandzar, S., S. Gupta, and H. Atallah. 2016. "Increase in Moped Injuries Requiring Emergency Care." *American Journal of Emergency Medicine* 34 (10): 2000–2002. doi:10.1016/j.ajem.2016.07.052.

Blackman, R. A., and N. L. Haworth. 2010. Implications for Safety and Planning of a Sharp Increase in Moped and Scooter Use. *Conference*, No. June, 2010.

Blackman, R., and N. Haworth. 2010. "A Qualitative Exploration of the Attitudes and Experiences of Moped and Scooter Riders." *Transportation Research Board 89th Annual Meeting Compendium of Papers*, Washington, DC, 1–16.

Blackman, R. A., and N. L. Haworth. 2013. "Comparison of Moped, Scooter and Motorcycle Crash Risk and Crash Severity." *Accident Analysis and Prevention* 57: 1–9. doi:10.1016/j.aap.2013.03.026.

Bonander, C., R. Andersson, and F. Nilson. 2015. "The Effect of Stricter Licensing on Road Traffic Injury Events Involving 15 to 17-Year-Old Moped Drivers in Sweden: A Time Series Intervention Study." *Accident Analysis and Prevention* 83: 154–161. doi:10.1016/j.aap.2015.07.022.

Boone, E. M., M. E. Rossheim, J. R. Krall, and R. M. Weiler. 2018. "State Helmet Laws and Helmet Use among Fatally Injured Moped Riders in the United States, 2011–2015." *Traffic Injury Prevention* 19 (3): 270–273. doi:10.1080/15389588.2017.1383604.

Brandau, H., F. Daghofer, M. Hofmann, and P. Spitzer. 2011. "Personality Subtypes of Young Moped Drivers, Their Relationship to Risk-Taking Behavior and Involvement in Road Crashes in an Austrian Sample." . *Accident Analysis and Prevention* 43 (5): 1713–1719. doi:10.1016/j.aap.2011.03.030.

Chen, S., T. U. Saeed, S. D. Alqadhi, and S. Labi. 2019a. "Safety Impacts of Pavement Condition at two-Lane and Multi-Lane Highways: Accounting for Heterogeneity and Seemingly Unrelated Correlation Across Crash Severities." *Transportmetrica A: Transport Science* 15 (1): 18–33.

Chen, S., T. U. Saeed, and S. Labi. 2017. "Impact of Road-Surface Condition on Rural Highway Safety: A Multivariate Random-Parameters Negative Binomial Approach." *Analytic Methods in Accident Research* 16: 75–89.

Chen, S., T. U. Saeed, S. Lavrenz, M. Alinizzi, and S. Labi. 2019b. "Safety Sensitivity to Roadway Characteristics: A Comparison Across Highway Classes." *Accident Analysis and Prevention* 123: 39–50.

Das, S. 2021. "Identifying key Patterns in Motorcycle Crashes: Findings from Taxicab Correspondence Analysis." *Transportmetrica A: Transport Science* 17: 593–614. doi:10.1080/23249935.2020.1802362.

Das, S., R. Avelar, K. K. Dixon, and X. Sun. 2018. "Investigation on the Wrong Way Driving Crash Patterns Using Multiple Correspondence Analysis." *Accident Analysis & Prevention* 111: 43–55. doi:10.1016/j.aap.2017.11.016.

Das, S., A. Dutta, and X. Sun. 2019. "Patterns of Rainy Weather Crashes: Applying Rules Mining." *Journal of Transportation Safety and Security* 12 (9): 1083–1105. doi:10.1080/19439962.2019.1572681.

Das, S., S. M. Mousavi, and M. Shirinzad. 2021a. "Pattern Recognition in Speeding Related Motorcycle Crashes." *Journal of Transportation Safety and Security*, doi:10.1080/19439962.2021.1877228.

Das, S., and X. Sun. 2015. "Factor Association with Multiple Correspondence Analysis in Vehicle–Pedestrian Crashes." *Transportation Research Record: Journal of the Transportation Research Board* 2519 (1): 95–103.

Das, S., and X. Sun. 2016. "Association Knowledge for Fatal Run-off-Road Crashes by Multiple Correspondence Analysis." *IATSS Research* 39: 146–155.

Das, S., X. Sun, B. Dadashova, M. A. Rahman, and M. Sun. 2021b. "Identifying Patterns of Key Factors in Sun Glare-Related Traffic Crashes." *Transportation Research Record*. doi:10.1177/03611981211037891.

Das, S., L. N. Tran, and M. Theel. 2020. "Understanding Patterns in Marijuana Impaired Traffic Crashes." *Journal of Substance Use* 26 (1): 21–29. doi:10.1080/14659891.2020.1760381.

Federal Highway Administration (FHWA). 2019. "Motorcycle Crash Causation Study: Final Report." DOT National Transportation Integrated Search - ROSA P, no. February. https://rosap.ntl.bts.gov/view/dot/40088.

Fonseca, C. N., and M. Okumura. 2010. "Research Review About Moped Accidents and the Necessity of Time Dimensional Management in University Campus Traffic." *Proceedings of the Conference on Traffic and Transportation Studies, ICTTS* 383: 627–637. doi:10.1061/41123(383)60.

Galanis, D. J., N. A. Castel, L. L. Wong, and S. Steinemann. 2016. "Impact of Helmet Use on Injury and Financial Burden of Motorcycle and Moped Crashes in Hawai'i: Analysis of a Linked Statewide Database." *Hawai'i Journal of Medicine & Public Health: A Journal of Asia Pacific Medicine & Public Health* 75 (12): 379–385. http://www.embase.com/search/results?subaction = viewrecord&from = export&id = L619645069.

Galanis, D. J., C. L. Ly, L. L. Wong, S. Steinemann, and L. Rosen. 2014. "Helmet Use among Motorcycle and Moped Riders Injured in Hawaii: Final Medical Dispositions from a Linked Database." *Journal of Trauma and Acute Care Surgery* 77 (5): 743–748. doi:10.1097/TA.0000000000000435.

Glaser, Yi G., Feng Guo, Youjia Fang, Bing Deng, and Jonathan Hankey. 2017. "Investigate Moped-Car Conflicts in China Using a Naturalistic Driving Study Approach." *Journal of Safety Research* 63: 171–175. doi:10.1016/j.jsr.2017.10.008.

Guo, Y., T. Sayed, and M. H. Zaki. 2019. "Evaluating the Safety Impacts of Powered Two Wheelers on a Shared Roadway in China Using Automated Video Analysis." *Journal of Transportation Safety and Security* 11 (4): 414–429. doi:10.1080/19439962.2018.1447058.

Haworth, N., K. Greig, and A. Nielson. 2009. "Comparison of Risk Taking in Moped and Motorcycle Crashes." *Transportation Research Record*. 2140 (1): 182–187. doi:10.3141/2140-20.

Haworth, N., A. Nielson, and K. Greig. 2008. "Moped Crashes in Queensland." *Journal of the Australasian College of Road Safety* 19 (3): 31–37.

Hossain, M. M., M. A. Rahman, X. Sun, and E. Mitran. 2021a. "Investigating Underage Alcohol-Intoxicated Driver Crash Patterns in Louisiana." *Transportation Research Record*. doi:10.1177/03611981211019742.

Hossain, M. M., X. Sun, E. Mitran, and M. A. Rahman. 2021b. "Investigating Underage Alcohol-Intoxicated Driver Crash Patterns in Louisiana." *IATSS Research*. doi:10.1016/j.iatssr.2021.07.002.

Hosseini, P., M. Jalayer, and S. Das. 2021. "A Multiple Correspondence Approach to Identify Contributing Factors Related to Work Zone Crashes." Transportation Research Board Annual meeting, Washington D.C.

Jalayer, M., M. Pour-Rouholamin, and H. Zhou. 2018. "Wrong-Way Driving Crashes: A Multiple Correspondence Approach to Identify Contributing Factors." *Traffic Injury Prevention* 19: 35–41. doi:10.1080/15389588.2017.1347260.

Johnson, N. K., B. M. Johnson, G. M. Denning, and C. A. Jennissen. 2017. "Pediatric Moped-Related Injuries in the U.S. from 2002-2014: Age-Related Comparisons of Mechanisms and Outcomes." *Journal of Trauma and Acute Care Surgery* 83 (5S): S201–S209. doi:10.1097/TA.0000000000001625.

Johnson, N. K., B. M. Johnson, G. M. Denning, and C. A. Jennissen. 2019. "Adult Moped-Related Injuries Treated in U.S. Emergency Departments." *Traffic Injury Prevention* 20 (8): 813–819. doi:10.1080/15389588.2019.1665650.

Lee, T. 2015. "Investigating the Heterogeneity in Driving Behavior of Powered Two-Wheelers Under Mixed Traffic Flow." *Transportation Research Board, 94th Annual Meeting* 918: 15–1165.

Mannering, Fred L., Venky Shankar, and Chandra R. Bhat. 2016. "Unobserved Heterogeneity and the Statistical Analysis of Highway Accident Data." *Analytic Methods in Accident Research* 11: 1–16. doi:10.1016/j.amar.2016.04.001.

Markos, M., A. D'Enza, and V. M. Velden. 2019. "Beyond Tandem Analysis: Joint Dimension Reduction and Clustering in R." *Journal of Statistical Software* 91 (10): 1–24.

Miggins, M., L. Lottenberg, H. Liu, L. Moldawer, P. Efron, and D. Ang. 2011. "Mopeds and Scooters: Crash Outcomes in a High Traffic State." *Journal of Trauma - Injury, Infection and Critical Care* 71 (1): 217–222. doi:10.1097/TA.0b013e318208f874.

Møller, M., S. K. Andersen, N. Bonde, and M. Hagenzieker. 2021. "Engagement in Violations among Young Moped Riders – Using a Qualitative Approach to Reveal Underlying Beliefs." *Journal of Transport and Health* 20: 101002. doi:10.1016/j.jth.2020.101002.

Montella, A., M. Aria, A. D'Ambrosio, and F. Mauriello. 2012. "Analysis of Powered Two-Wheeler Crashes in Italy by Classification Trees and Rules Discovery." *Accident Analysis and Prevention* 49: 58–72. doi:10.1016/j.aap.2011.04.025.

Montella, A., R. de Oña, F. Mauriello, M. Rella Riccardi, and G. Silvestro. 2020. "A Data Mining Approach to Investigate Patterns of Powered Two-Wheeler Crashes in Spain." *Accident Analysis and Prevention* 134. doi:10.1016/j.aap.2019.07.027.

Moskal, A., J. Martin, E. Lenguerrand, and B. Laumon. 2007. "Injuries Among Motorized Two-Wheelers in Relation To Vehicle and Crash Characteristics in Rhone, France." *Esv*, 1–10. https://www-esv.nhtsa.dot.gov/Proceedings/20/07-0232-O.pdf.

National Highway Traffic Safety Administration. 2021a. Traffic safety facts 2020: Annual Crash Statistics. National Center for Statistics and Analysis (NCSA).

National Highway Traffic Safety Administration. 2021b. Motorcycles: 2019 data (Traffic Safety Facts. Report No. DOT HS 813 112). National Center for Statistics and Analysis (NCSA).

National Highway Traffic Safety Administration. 2021c. Motorcycle Helmet Use in 2020 – Overall Results. (Traffic Safety Facts Research Note. Report No. DOT HS 813 143). National Center for Statistics and Analysis (NCSA).

Saeed, T. U., T. Hall, H. Baroud, and M. Volovski. 2020a. "Analyzing Road Crash Frequencies with Uncorrelated and Correlated Random Parameters Count Models: An Empirical Assessment of Multilane Highways." *Analytic Methods in Accident Research* 23: 100101.

Saeed, T. U., R. Nateghi, T. Hall, and B. Waldorf. 2020b. "Statistical Analysis of Area-Wide Alcohol-Related Driving Crashes: A Spatial Econometric Approach." *Geographical Analysis* 52 (3): 394–417.

Salatka, M., S. Arzemanian, J. F. Kraus, and C. L. Anderson. 1990. "Fatal and Severe Injury: Scooter and Moped Crashes in California, 1985." *American Journal of Public Health* 80 (9): 1122–1124.

Steg, L., and A. van Brussel. 2009. "Accidents, Aberrant Behaviours, and Speeding of Young Moped Riders." *Transportation Research Part F: Traffic Psychology and Behaviour* 12 (6): 503–511. doi:10.1016/j.trf.2009.09.001.

Tagliabue, M., and M. Sarlo. 2015. "Affective Components in Training to Ride Safely Using a Moped Simulator." *Transportation Research Part F: Traffic Psychology and Behaviour* 35: 132–138. doi:10.1016/j.trf.2015.10.018.

Theofilatos, A., and A. Ziakopoulos. 2018. "Examining Injury Severity of Moped and Motorcycle Occupants with Real-Time Traffic and Weather Data." *Journal of Transportation Engineering, Part A: Systems* 144 (11): 04018066. doi:10.1061/jtepbs.0000193.

Velden, M., A. D'Enza, and F. Palumbo. 2017. "Cluster Correspondence Analysis." *Psychometrika* 82 (1): 158–185.

Wang, B. 2014. "Analysis of Moped Crashes and Riders' Fault Involvement in Wisconsin." (Msc. Thesis).

Wang, X., Y. Xu, P. Tremont, and D. Yang. 2012. "Moped Rider Violation Behavior and Moped Safety at Intersections in China." *Transportation Research Record* 2281: 83–91. doi:10.3141/2281-11.

Waseem, M., A. Ahmed, and T. U. Saeed. 2019. "Factors Affecting Motorcyclists' Injury Severities: An Empirical Assessment Using Random Parameters Logit Model with Heterogeneity in Means and Variances." *Accident Analysis and Prevention* 123: 12–19.

Weaver, J. L., K. R. Miller, M. Benns, and B. G. Harbrecht. 2018. "Moped Crashes are Just as Dangerous as Motorcycle Crashes." *American Surgeon* 84 (6): 826–830. doi:10.1177/000313481808400626.

Yamany, M. S., T. U. Saeed, M. Volovski, and A. Ahmed. 2020. "Characterizing the Performance of Interstate Flexible Pavements Using Artificial Neural Networks and Random Parameters Regression." *Journal of Infrastructure Systems* 26 (2): 04020010.

Zhang, Xujun, Yaming Yang, Jie Yang, Jie Hu, Yang Li, Ming Wu, Lorann Stallones, and Henry Xiang. 2018. "Road Traffic Injuries among Riders of Electric Bike/Electric Moped in Southern China." *Traffic Injury Prevention* 19 (4): 417–422. doi:10.1080/15389588.2018.1423681.