Analysis of Injury Severities of Accidents Involving Low-Emission Vehicles

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Abstract. In recent years, there has been a significant increase in the use of electric and hybrid vehicles on roads worldwide, as governments and road users seek to reduce emissions and promote sustainable transportation. However, as the number of these low-emission vehicles on the roads continues to grow, so does the concern about how safe they truly are. Although electric and hybrid vehicles have been shown to produce lower rates of accidents than vehicles with conventional fuel combustion engines, there is limited evidence as to the factors that may affect the severity of crashes involving low-emission vehicles.

This research is conducted using evidence from crashes involving electric and hybrid vehicles in the United Kingdom. The study uses data from the STATS19 dataset to identify common patterns and trends underpinning the injury severity of occupants and other road users involved in crashes with electric and hybrid vehicles. Through inferential statistical tests and models, this analysis controls for factors, such as the accident location, road and driver characteristics, with a goal to identify the key factors contributing to the occurrence of accidents and quantify their impact on the severity of sustained injuries. Among others, the road speed limit, the road type, as well as weather conditions were identified to affect the likelihood of severe injury outcomes. The findings of this study can assist policymakers and local Authorities in designing and implementing appropriate mobility management systems targeted at the users of low-emission vehicles to enhance road safety and mitigate collision risk.

Keywords: electric vehicles · hybrid vehicles · accidents · injury severity · ordered regression

1 Introduction

According to the "Global Status Report on Road Safety 2023" published by the World Health Organization (WHO), almost 1.2 million lives are lost annually across the globe as a result of road rashes. Between 20 and 50 million people are involved in non-fatal crashes, with many victims facing some form of disability or permanent health problems, potentially significantly affecting their quality of life in the long term (Global status report on road safety, 2023). As such, road safety constitutes a major public health issue, which

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requires the implementation of effective interventions to eliminate the effects of road crashes on societies and economies.

The emergence and broad use of low-emission vehicles, and especially, electric and hybrid-electric vehicles may cause shifts in the determinants of road crashes, and consequently, on the countermeasures that need to be applied. Interestingly, by 2030, it is expected that 56% of vehicles will run on internal combustion engines, while 35% of the fleet will consist of hybrid vehicles and 9% will be electric. The corresponding percentages recorded in 2013 were 98% for gasoline or diesel vehicles, while hybrid and electric vehicles accounted for only 2%. The target for uptake of electrification signifies a complete transition to electric and hybrid vehicles, which are expected to comprise 100% of the fleet in circulation within 15–20 years (Telang et al., 2021). While the share of low emission vehicles into the automotive market is constantly growing, concerted efforts have been directed towards scrutinizing the safety ramifications of road accidents involving these emerging vehicle types.

At the core of robust decision-making frameworks in road safety is the need for a thorough investigation into the implications of electric and hybrid vehicles being involved in road accidents. Prior to the implementation of safety countermeasures and the delineation of pertinent strategies, a comprehensive understanding of the evolving landscape engendered by these novel vehicle technologies is essential. This underscores the necessity for an exhaustive appraisal of the safety landscape vis-à-vis the proliferation of electric and hybrid vehicles. Such an appraisal is critical for ensuring the efficacy and integrity of subsequent road safety interventions to national or international policies.

The key road safety issues stemming from the electric and hybrid-electric vehicles are associated with several operational and design factors. The use of lithium-ion batteries, which is quite frequent in EVs, may pose risks such as thermal runaway, fire, and explosion, especially following incidents of overcharging or crashes with other vehicles (Huang et al., 2021). The charging infrastructure of electric vehicles may serve as an additional source of accidents or safety incidents. Inadequate or poorly designed charging infrastructure can contribute to accidents, especially if charging cables induce safety hazards (Guzek et al., 2024) or other charging incidents that may result in more serious events, potentially fatal, such as overcharging, ignition, leaks, etc. (Wang et al., 2019).

Potential road safety issues may also emerge from the low-noise operation of electric and hybrid-electric vehicles. Electric and hybrid vehicles exhibit a distinctive feature - their almost silent operation, especially noticeable at speeds below 20-30 km/h despite emitting low-frequency sounds. This characteristic becomes even more pronounced in vehicles powered solely by electric energy, where the sound is 1-3 dB weaker compared to hybrids. As speed increases beyond 50 km/h, the friction sound generated by the tires on the road nullifies any difference in sound levels. This seemingly innocuous feature harbors potential risks for vulnerable road users, particularly pedestrians (especially those with visual impairments), and cyclists. Consequently, there is a growing need to identify appropriate countermeasures to mitigate these risks effectively (Verheijen and Jabben. 2010). Range anxiety is not only a barrier towards the adoption of electric vehicles (Coffman et al., 2017) but it can also impede the safety performance of these vehicles. Concerns over the limited battery range could prompt some groups of drivers (especially the most aggressive ones) to engage in aberrant driving behaviors, such as

speeding or traffic signal violations, in their efforts to conserve battery power (Yuan et al., 2018).

Overall, over the recent years, a number of studies (to name a few, Nitsche et al., 2014; Yang et al., 2020; Botton et al., 2021) have investigated the safety aspects of electric and hybrid vehicles in various road networks. Despite extensive research ad-dressing various safety concerns, such as accident-avoidance strategies related to electric vehicle batteries, risks of electrocution stemming from the electrical systems, and the impact of low-frequency noise emissions on other road users, a notable gap exists regarding the behavioral patterns of users of electric and hybrid vehicles and their contribution to traffic accidents. Moreover, there is a dearth of information regarding the socio-demographic profiles of the users and how such vehicles interact within the con-text of existing road infrastructure. Therefore, there is a need for more empirical evidence on the factors determining the multi-faceted dimensions of accidents involving electric and hybrid vehicles. The present study aims to explore all these factors that can potentially influence the injury severity of accidents involving electric and hybrid vehicles. The novelty of this study lies in its comprehensive approach, integrating accident, geometric, vehicle, environmental, and socio-demographic characteristics within a single dataset to investigate accidents involving low-emission vehicles. Due to the limited availability of such integrated data in safety literature, this study aims to offer new insights into the underlying mechanisms of accident generation, particularly in the context of advanced technological innovation expected to dominate future car fleets.

2 Data

To identify the severity determinants of accidents involving electric and hybrid vehicles, injury severity data was drawn from the STATS19 dataset of the United Kingdom (Department for Transport, 2023). STATS19 is a public database that contains rich information regarding the accidents occurred in Great Britain and recorded by the police, such as the date, time, location, vehicles involved, types of road users, severity of injuries, and contributing factors such as road conditions, vehicle maneuvers and weather. The STATS19 dataset has been extensively used in previous accident injury-severity studies (Lyons et al., 2008; Imprialou and Quddus, 2019; Fountas et al., 2022). For this study, data from accidents occurred in Scotland (part of the United Kingdom) between 2010 and 2018 has been processed and statistically analyzed. By the end of 2010, there were around 135,000 electric or hybrid-electric cars in the UK (Department for Transport, 2011), whereas by the end of 2018, more than 620,000 vehicles were in use on the UK roads (Fleet News, 2019) According to the typology of the STATS19 database, the severity of accidents is recorded in three distinct, injury levels: slight, serious, and fatal injury. Upon a preliminary analysis of the accident data over the aforementioned period, it was identified that in 216 accident records, electric or hybrid vehicles were involved.

As earlier stated, the data used for the preparation of Fig. 1 were drawn from the STATS19 database (Department for Transport, 2023). Hybrid vehicles (which mainly refer to hybrid-electric vehicles) represent 88.43% of the sample, whereas the rest 11.57% of the sample consists of accidents involving electric vehicles, as also shown in Fig. 1. The predominance of the hybrid vehicles in the pool of observed accidents is

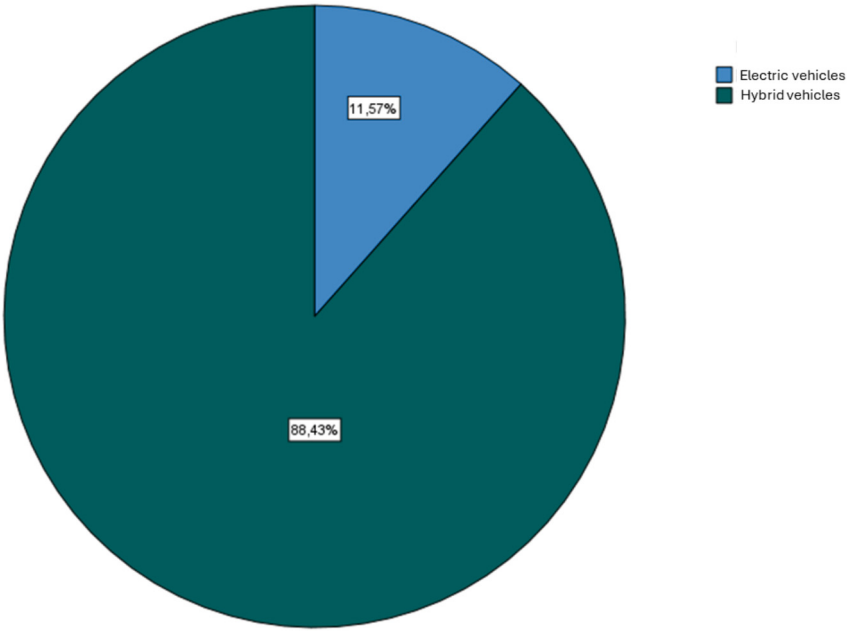

Fig. 1. Distribution of low-emission vehicles involved in accidents per their specific type

intuitive and can be attributed to their relative higher share in the car fleet compared to the fully electric vehicles (Department for Transport, 2011). As to the injury severities, the largest share of the sample is comprised of minor injuries (79.17% of accident records), followed by serious injuries at 19.44%, and fatal injuries with a very small percentage of approximately 1.39%. These injury severity statistics are in line with previous evidence from the same area (Fountas et al., 2020).

3 Methods

To identify the factors affecting the determinants of injury severities of accidents involving low-emission vehicles (i.e., electric and hybrid vehicles), a comprehensive data analysis was carried out comprising of three separate stages: (i) descriptive analysis; (ii) inferential statistical analysis and (iii) statistical modeling. The computation of descriptive statistics (e.g., mean, percentages, frequencies, etc.) is usually considered as the first step in data analysis and can assist in understanding the distribution of data and in preparing the data and variables for further statistical analysis (Fisher and Marshall, 2009).

The inferential statistical analysis refers to the process of inducing general conclusions or rules from a dataset and deal with the estimation, hypothesis, and generalization of results from a sample to a general population (Daniel and Cross, 2018; Basbas et al., 2020). Hypothesis testing is a key sub-category of inferential statistics. The selection of hypothesis test that will be leveraged to check whether there exists any statistically

significant association between a dependent and independent variable is subject to the type of the compared variables. In this study, the dependent variable is the injury severity outcome, which can take three categorical values (slight, serious, and fatal injury) and can be placed in an ordinal severity scale. As such, the dependent variable is ordinal and discrete in nature, therefore, only non-parametric tests can be considered. The independent variables (i.e., the variables representing potential determinants of injury severities) are either nominal or ordinal in nature. To that end, the chi-square and Friedman tests were carried out to identify any potential relationships. The chi-square test can help identify potential associations between categorical variables, whereas the Friedman test can provide even more specific insights when the compared variables are ordinal in nature.

Given that the inferential statistics can provide insights only about possible associations between pairs of variables, a statistical model is needed to gain a more comprehensive understanding of the factors affecting the injury severities of accidents involving electric or hybrid vehicles. In contrast to inferential statistics, the estimation of a statistical model entails recognizing the direct influence of each independent variable on the dependent variable, while concurrently accounting for the effects of all other variables considered within the model (Tsavdari et al., 2022). For the estimation of the injury severity model, the Generalized Linear Model (GLM) was selected as an appropriate modeling approach. The generalized linear model extends the traditional linear model, enabling the dependent variable to be associated with both categorical factors and independent continuous variables. Moreover, the model accommodates a non-normal distribution for the dependent variable. The GLMs encompass widely utilized statistical models, including linear regression for normally distributed responses, logistic models for binary data, log-linear models for count data, as well as various other statistical models through their highly flexible formulation. In this study, the sample and the dependent variable does not adhere to a normal distribution; as such and given the ordinal nature of the dependent variable, an ordered probit model was selected as an appropriate approach to identifying the injury-severity determinants (Washington et al., 2020). It should be noted that all the statistical analyses presented in this paper were carried out using the software package IBM SPSS Statistics 28.0.

4 Results

4.1 Key Descriptive Statistics

Starting with the socio-demographic characteristics of the vehicle drivers involved in the accidents, 68.06% of the drivers were males, whereas female drivers were observed in 31.48% of the cases. As to the age of the drivers, the mean age of the driver was 46.5 years old, with the majority of the drivers' ages ranging from 26 to 65 years old. 3 out of 4 accidents involving electric or hybrid vehicles occurred on a single carriageway (unseparated road with a single lane per direction), whereas almost 14% of the accidents were observed on dual carriageways (roads with directions separated through a central median). With respect to the accident location, the vast majority of accidents (67.59%) occurred in urban areas. Focusing on particular roadway features of the accident location, 4 out of 10 accidents were not located on or close to a junction, whereas almost 30% of the observations were associated with a T or a staggered junction. As to the road

surface conditions, most of the incidents (63.43%) took place on a dry pavement, and almost 34% of them were linked with a wet pavement surface. Considering the vehicle maneuver at the time of the accident, 43% of the accidents occurred while the vehicle was traveling straight ahead, whereas 17.6% of the sample consists of accidents during right-turn maneuvers. In 64.35% of the cases, the first point of impact in the course of the accident was at the front of the vehicle Another important vehicle characteristic is related to the engine capacity, with the descriptive statistics showing that 45% of the vehicles involved in the crashes had engine capacity greater than 1400 cc; however, it should be noted herein that for 11.5% of the cases, information about engine capacity was not available in the dataset. Finally, with regards to the prevailing environmental conditions at the time of the accident, approximately 3 out of 4 accidents occurred under fine weather and daylight conditions.

4.2 Inferential Statistical Analysis

Table 1 presents the results of the inferential statistical tests that were conducted to identify potential associations between the injury severities of accidents involving electric or hybrid vehicles and roadway-, vehicle-, driver- or environment-related factors. As shown in the Table, the p-value of all tests (both chi-square and Friedman tests) was lower than 0.01, thus suggesting the presence of statistically significant relationships between the accident injury severities and these factors at a minimum 99% level of confidence.

The relationships of other variables with the accident injury severity were also investigated through statistical tests, but they turned out to be statistically insignificant.

4.3 Ordered Probit Model

As earlier mentioned, while the inferential statistical tests can give some insights into the pair-wise comparisons of the injury severities with established safety determinants, they cannot account for the simultaneous impact of other factors on the dependent variable. Therefore, the inferences of such tests may be subject to bias. To gain a more comprehensive understanding of the concurrent effects of several factors on accident injury severities, an ordered probit model was estimated. The results of the model are presented in Table 2. All the independent variables are statistically significant at a minimum 90% level of confidence, as indicated by the corresponding p-values. For the model estimation, all the available and relevant variables were tested, but only those included in Table provided statistically significant results. The goodness-of-fit of the model was also thoroughly evaluated through Likelihood Ratio Tests (LRTs).

Overall, two characteristics related to road geometry (road type and speed limit) and one environmental attribute (weather conditions) were identified to exert a significant impact on accident injury severities. By comparing the parameters of all explanatory variables included in the model, it is evident that the two geometric characteristics have a stronger influence on injury outcomes. Driver characteristics (e.g., age, gender, and so on) were also tried as potential independent variables in the model, but their impact was identified as statistically insignificant.

Table 1. An overview of the results of the inferential statistical tests

Dependent Variable	Independent Variable	Statistical Test	p-value
Injury severity outcome (slight injury, serious injury, fatality)	Road type (One way street, dual carriageway, single carriageway, slip road, roundabout)	$\chi 2$ (chi-square)	$p < 0.01$
	Speed limit (20mph, 30mph, 40mph, 50mph, 60mph, 70mph)	$\chi 2$ (chi-square)	$p < 0.01$
	Junction type (Not at junction or within 20 m, roundabout, mini-roundabout, T or staggered junction, crossroads, more than 4 arms (not roundabout), private drive or entrance, other junction type)	$\chi 2$ (chi-square)	$p < 0.01$
	Lighting conditions (Daylight, darkness - lights lit, darkness - lights unlit, darkness - no lighting, darkness - lighting unknown)	$\chi 2$ (chi-square)	$p < 0.01$
	Weather conditions (Fine no high winds, raining no high winds, snowing no high winds, fine and high winds, raining and high winds, snowing and high winds, fog or mist, other)	$\chi 2$ (chi-square)	$p < 0.01$
	Road surface conditions (Dry, wet or damp, snow, frost or ice, flood over 3cm. Deep oil or diesel, mud)	$\chi 2$ (chi-square)	$p < 0.01$
	Pavement hazard	$\chi 2$ (chi-square)	$p < 0.01$
	Accident location (urban, small town, rural)	$\chi 2$ (chi-square)	$p < 0.01$
	Vehicle maneuver (Reversing, parked, slowing or stopping, U-turn, turning left, turning right, changing lane, overtaking, going ahead)	$\chi 2$ (chi-square)	$p < 0.01$
	Vehicle's point of impact (Did not impact, front, back, offside, nearside)	$\chi 2$ (chi-square)	$p < 0.01$
	Driver's gender (male, female)	$\chi 2$ (chi-square)	$p < 0.01$

(*continued*)

Table 1. (*continued*)

Dependent Variable	Independent Variable	Statistical Test	p-value
	Driver's age range (0 – 5, 6 – 10, 11 – 15, 16 – 20, 21 – 25, 26 – 35, 36 – 45, 46 – 55, 56 – 65, 66 – 75, Over 75)	Friedman	$p < 0.01$
	Vehicle's engine capacity (in cc)	Friedman	$p < 0.01$

Table 2. Estimation results of the ordered probit model.

Variable	Parameter (B)	Wald Chi-square	Degrees of freedom	p-value
Threshold 1	23.845	–	–	–
Threshold 2	26.179	–	–	–
Speed limit = 20 mph	−3.342	−6.123	1	0.035
Slip road	4.213	9.405	1	0.002
Fine weather with high winds	2.454	3.420	1	0.064

As shown in Table 2, accidents occurring on roads with 20mph speed limit are less likely to result in fatal injuries. The sign of the coefficient is negative, which implies a lower likelihood of fatal injuries. This result may reflect the effect of reduced speeds that are observed in roads with 20mph speed limits (Olowosegun et al., 2023). Furthermore, 20mph roads have been found to lead to the mitigation of severe road casualties (Cleland et al., 2020), which seems to be also confirmed in the case of electric and hybrid vehicles.

As shown in Fig. 2, the vast majority of accidents occurring on 20mph roads (almost 82%) resulted in a slight injury, whereas for higher speed limits, the proportion of serious and fatal injuries is significantly higher. Fatal injuries are observed on accidents occurring on roads with 30mph (which represent almost 60% of the accidents in the dataset) and 60mph speed limit (representing approximately 22% of the accident in the dataset). In fact, most accidents (approximately 82%) on 60mph roads result in fatal and serious injuries, which is a quite concerning finding as to the safety performance of low-emission vehicles on high-speeds roads (such as dual carriageways). Similar patterns are evident on 70 mph roads (typically motorways and dual carriageways), with 62% of accidents yielding serious injuries, but no fatalities. Accidents on 20mph roads account for a bit less than 10% of the sample, whereas it is notable than no fatal injuries were observed on these roads; this finding further highlights the crucial role of low speed limits for the implementation of the Safe Systems Approach, which puts emphasis on the elimination of serious and fatal injuries (Karndacharuk and McTiernan, 2019).

In contrast, the variables "slip road" and "fine weather with high winds" are associated with a higher likelihood of fatal injuries, as the corresponding sign of the coefficient is positive. That means that accidents that involve electric or hybrid vehicles and occur

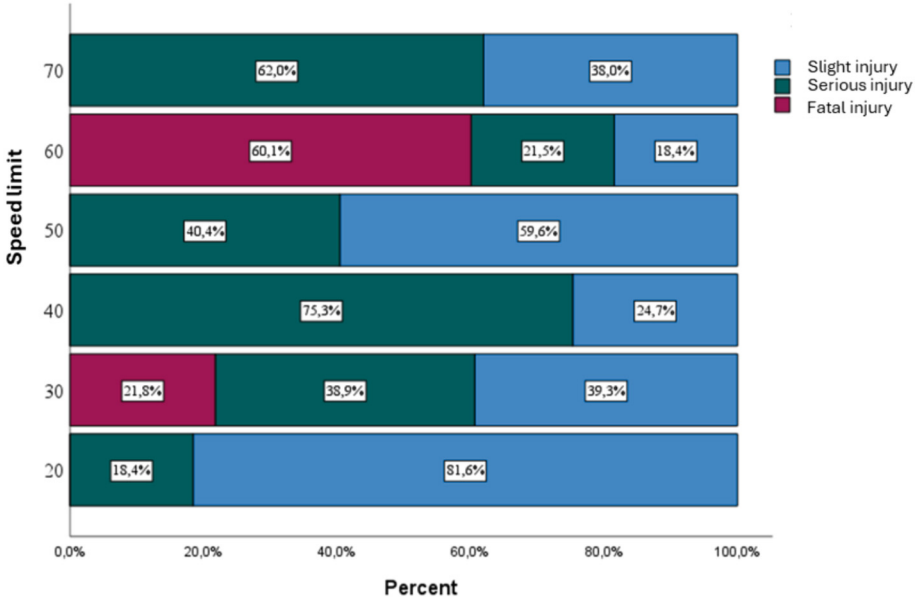

Fig. 2. Distribution of accident injury severities across roads with different speed limits (in miles per hour – mph)

on slip roads (e.g., exit or entrance ramps of highways) or under fine weather conditions but with high winds are associated with more severe injuries. Fine weather may induce risk-compensating effects, thus prompting drivers to indulge in more aggressive driving patterns, as also suggested by previous research (Mannering and Bhat, 2014). Lastly, the combination of limited space on slip roads and the complexity of maneuvers that are required due to merging and diverging traffic (to or from the highway) can make accidents on slip roads more likely to result in severe injuries compared to accidents on other types of roads.

5 Discussion and Conclusions

This study sought to deliver new empirical evidence on the injury severities of accidents involving electric or hybrid-electric vehicles and their determinants. Despite the small sample size, the analysis shows that the majority of accidents involving such low-emission vehicles resulted in slight injuries. The descriptive analysis showed that a significant proportion of accidents involve more male drivers compared to females, with a disparity of approximately 30%. Moreover, high proportions of drivers involved in accidents are evident within the age brackets of 26–35, 36–45, and 45–55. Given that drivers of such ages are more likely to use electric or hybrid vehicles, this finding highlights the necessity for informing and sensitizing drivers of these age groups to acquaint themselves not only with new vehicle types but also with updated road safety practices.

Furthermore, a considerable proportion of accidents are observed on unseparated roads featuring a single lane per direction; on such roads, traffic directions are distinguished through pavement markings rather than median strips. In addition, most accidents were identified in urban areas, which can be attributed to the high presence of electric and hybrid vehicles navigating within urban environments. This finding also serves as an alert for a more intensive infrastructure development for electric vehicles in urban areas as well as for a holistic integration of low-emission vehicles with the smart infrastructure of cities to enable better traffic management and accident prevention.

Regarding the vehicle maneuver characteristics, most accidents occurred when the vehicles were traveling straight ahead and not on or close to junctions. Hence, most accidents occurred when drivers did not have to undertake complex maneuvers, though other distractions (internal or external) might play a notable role. It is acknowledged that contemporary electric and hybrid vehicles may include features such as touch control panels or large screens facilitating camera usage, map navigation, or mobile phone connectivity, potentially diverting the driver's attention from the driving task. The incorporation of more disruptive Advanced Driving Assistance Systems (ADAS) within low-emission vehicles could also help tackle the safety implications of driving distractions.

The results of the inferential statistical analysis and the ordered probit model unveiled valuable insights into the interaction between several roadway- and environment-related variables and the injury severity of accidents. Notably, the posted speed limit, and particularly lower speed limits (20 mph or 30 km/h), emerged as significant influencing factors of accident severity. This finding highlights that electric and hybrid vehicles have a satisfactory safety performance in low-speed environments, as the likelihood of severe or fatal injuries reduces. A safety-related synergetic effect seems to underpin the use of low-emission vehicles in traffic calmed area; this potential implication warrants further investigation in the future, as, once confirmed, it can help local Authorities better co-ordinate their efforts in not only reducing vehicle emissions, but also improving the level of road safety, especially in built-up areas. Weather conditions were also identified as a major influencing factor with accidents occurring under fine weather and high winds favoring greater injury severity. This result suggests that the risk-compensating behaviors of drivers under varying environmental conditions, are not only important for drivers of conventional vehicles, as suggested by previous research (e.g., Fountas et al., 2020) but they can also affect the safety performance of drivers of electric or hybrid-electric vehicles.

This study is one of the first attempts to profoundly understand the relationship between electric and hybrid vehicles and key contributing factors of traffic safety. The expansion of research into new-age, low-emission vehicles stands to yield considerable benefits. As time progresses, it becomes increasingly apparent that the automotive fleet undergoes a continuous integration of novel electric and hybrid vehicles. Considering that this study was conducted on the basis of limited accident data, the use of a broader sample size in the future could enable the refinement of models tailored to address users' requirements for increased safety within road networks. Furthermore, the administration of surveys pertaining to perceptions of safety of electric and hybrid vehicles could furnish insights from the users' standpoint, thereby facilitating a more exhaustive investigation.

Disclosure of Interests. The authors have no competing interests to declare.

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