Driving Risk Assessment Using Near-miss Events Based on Panel Poisson Regression and Panel Negative Binomial Regression

# Abstract

This study proposes a method to identify and evaluate driving risk as the primary step to calculate premiums in the newly emerging context of usage-based insurance. Telematics data obtained from Internet of vehicles contains a large number of near-miss events, which can be regarded as an alternative to modeling claims or accidents, to estimate a driving risk score for each vehicle. Poisson regression and Negative binomial regression are applied to a summary data set with one record per vehicle and to a panel data set of daily vehicle data containing near-miss events; i.e. counts of excess speed, high speed brake, harsh acceleration or deceleration, and additional driving behavior parameters not including accidents. Negative binomial regression performs better than Poisson regression. Vehicles are classified with a driving risk score computed from individual effects of the panel model. This study provides a research basis for actuarial insurance premium calculations even if no accident information is available and enables a precise supervision of dangerous driving behaviors based on driving risk scores.

# Keywords

driving risk assessment; usage-based insurance; driving risk score; telematics; near-miss event; driving behavior; panel data regression; count data model; econometrics

# Introduction

Near-miss events are incidents that denote the existence of danger, even if no accident occurs. Reporting of near-miss event is an established error reduction technique that has been used by many industries to manage risk and reduce accidents. In the auto insurance industry, insurers traditionally calculate premiums by analyzing the claims the insured policy holders reported in the past and reward with discounts those drivers that do not report accidents. However, this may be a rather incorrect approach to assess accident risk, when the insured has suffered accidents but has not claimed to avoid losing a discount. Fortunately, the advent of internet of vehicles has given an improved solution to this problem, using near-miss events to identify driving risk. Near-miss events ultimately provide information that can lead to actuarial premium calculations in the auto insurance industry (see, for example, Guillen et al. 2020).

This study purposes to explore how to evaluate driving risks and score drivers in the short term without claims and accidents, but based on information on near-miss counts in a short period of time. Dealing with the absence of claims combined with a short period of observation of the drivers using telematics sensors is one of the main novelties of our approach. The model obtained in this study has important significance for driving risk identification. Not only can the model reflect risk factors that influence each near-miss event, but the coefficients can also help us evaluate drivers’ risks and fixed-effects panel count data models can be used to rank drivers according to their individual effects. The modeling method and results are valuable for insurance companies to develop usage-based insurance (UBI) to personalize premiums. In addition, they are also interesting for traffic regulatory authorities to promote safe driving and prevent accidents.

Near-miss events are incidents that need to be defined and extracted from the original raw data files for further processing and analysis. Because the original telematics data in this study does not contain claims or accidents, the extraction of near-miss events that are highly relevant to identify driving patterns is critical. This study was carried out both on a per driver summary data set and on a panel data set where each driver has a daily sum-mary. Our data contain counts of the four near-miss events in our study. Here, over speed, high speed braking, harsh acceleration and harsh deceleration, have been defined based on actual driving conditions and local laws and regulations. Some other high-risk events, e.g. sharp turning, dangerous lane changing and unexpected maneuver, that have been proved by previous studies to be related to driving risk were not included in this study due to the dimension and precision limitations of the original data set. Since the extracted frequency of near-miss events is an unbounded non-negative integer, Poisson regression and Negative binomial regression are suitable for modelization.

Poisson regression, Negative binomial regression, Zero-inflated Poisson regression and Zero-inflated Negative binomial regression were respectively applied to the summary data set. Average speed, brake times, accelerator pedal position, engine fuel rate etc., were selected as independent variables. In particular, either mileage or fuel consumption could be chosen as exposure variable to offset the model. In order to have a clear understanding of risky factors of different near-miss events, each near-miss event was individually used as a dependent variable. However, no matter which one was selected as the dependent variable, Negative binomial regression provided the best fit in the summary data in this study.

Negative binomial regression also performed better than Poisson regression on the panel data sets. Individual effects and time effects were estimated using panel Poisson regression and panel Negative binomial regression on our short panel data set of 6 days in length. The regression results not only confirmed the existence of individual effects and time effects but allowed the driving risk of each vehicle to be ranked. Then, according to the individual effects converted into scores, the driving risk level of vehicles could be classified, providing an important reference for further accurate calculation of premiums.

The rest of this article is organized as follows. The development of UBI and previous efforts on driving risk assessment are summarized in Section 2. Section 3 describes the data and introduces the key parameters used in modeling. Section 4 presents the model expression of Poisson regression and Negative binomial regression in this study. Negative binomial regression results on summary data set and panel data set are reported and analyzed in Section 5. The results are discussed and the conclusions are presented in Section 6.

# Literature Review

The auto insurance industry has never stopped pursuing new ways to calculate more accurate actuarial premiums. However, traditional auto insurance business has been limited by the difficulty of obtaining information on policy holders, so classical ratemaking uses simple information of drivers (age gender,), vehicles (type of car, model and brand) and driving sections (Litman 2007). With the continuous progress of information technology, a new type of insurance business, UBI, based on multi-source data and personalized premium calculation is becoming the mainstream. Pay-as-you-drive (PAYD) mode of charging premiums depends on the driving mileage or fuel consumption and is based on the premise that mileage or fuel consumption correlatives with the probability of suffering an accident (Tselentis, Yannis, and Vlahogianni 2016). Then, PAYD has evolved into a newer scheme, called the pay-how-you-drive (PHYD) ratemaking mode, which is based on multiple sources of data including driving behavior data (Paefgen, Staake, and Thiesse 2013). After the development of 5G communication technology, it may be possible to implement an even more sophisticated monitoring and pricing strategy known as the manage-how-you-drive (MHYD) principle, i.e. real-time calculation of premiums based on multi-source data and providing real-time information to drivers to restrain bad driving behavior(Litman 2007; Tselentis, Yannis, and Vlahogianni 2017). However, due to various reasons such as technological, regulatory and other issues regarding privacy(Troncoso et al. 2010), there is still no mature PHYD product on the market at present(Pesantez-Narvaez, Guillen, and Alcañiz 2019; Guillen et al. 2019) and in terms of MHYD driving risk needs to be further studied to produce products that are more suitable for meeting the demand (Sun et al. 2020).

Traffic accidents all over the world cause a large number of casualties every year, and high risk driving is one of the main factors that cause traffic accidents (Litman 2007). Therefore, the research on driving risk has been a hot topic in recent decades. Fundamentally, simulation experiments have beeb designed in the laboratory setting to identify driving risk factors (Diego et al. 2013; Siordia et al. 2014; Charlton et al. 2014; Peng and Shao 2018). Further, real vehicle experiments on real road environments have been conducted to evaluate driving risk (Wang et al. 2015; Yan et al. 2016; Liao et al. 2018; Jiang et al. 2019; Yan et al. 2019). In addition, questionnaire surveys for driving risk assessment have also been studied (Lu, Xie, and Zhang 2013; J. Wang et al. 2020). In fact, the naturalistic type of driving data collected by the Internet of vehicles or smart phones, telematics data, can effectively reduce the influence of subjective factors and unreasonable assumptions in producing effective risk mitigating actions (Handel et al. 2014; Joubert, De Beer, and De Koker 2016; Verbelen, Antonio, and Claeskens 2018; Ma et al. 2018; Jiang et al. 2020).

In the research of driving risk assessment in the auto insurance industry, machine learning and generalized linear models coexist. With its strong ability to process big data efficiently, machine learning is increasingly entering the auto insurance business. Logistic regression (Jin et al. 2018), cluster analysis (Carfora et al. 2019), decision tree (Paefgen, Staake, and Thiesse 2013), support vector machine (Burton et al. 2016), neural network (Baecke and Bocca 2017) and other machine learning models (Guelman 2012; Bian et al. 2018; Jafarnejad, Castignani, and Engel 2017) have been widely studied in the field of driving risk assessment, and the results also show that machine learning is a powerful tool (Paefgen, Staake, and Fleisch 2014). However, since most machine learning procedures as black box algorithms do not have good interpretability, they cannot completely replace the conventional generalized linear models implemented for decades in the auto insurance industry (Pesantez-Narvaez, Guillen, and Alcañiz 2019).

Conventional generalized linear models pay attention to the correlation between influencing factors and claims or accidents in frequency and severty models (Boucher, Pérez-Marín, and Santolino 2013; Verbelen, Antonio, and Claeskens 2018; Ma et al. 2018; Guillen et al. 2019). But the study of near-miss events even when there is a lack of information on claims and accidents should not be ignored (Wang et al. 2015; Guillen et al. 2020), on the contrary, since near-misses are more frequent than accidents and they are positively associated with them, near-misses can be considered good alternatives for risk modeling for driving risk assessment.

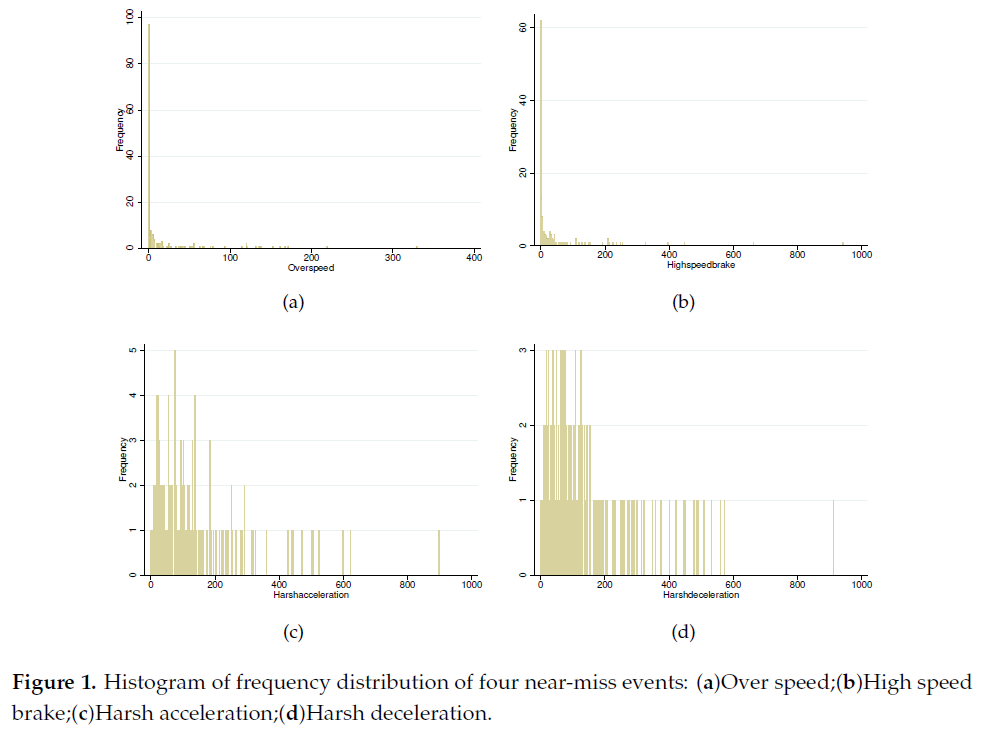
# Data Description

The telematics data used in this study is collected from an internet-of-vehicle information service provider in China. The original data set contains 182 data files representing sensor data for 182 vehicles observed from July 3, 2018 to July 8, 2018 (Sun et al. 2020). Each data file contains 62 different measurements, but after data processing (Sun et al. 2019), less than one-third of them could be retained due to recording errors and inconsistencies. The original data were transformed for modeling into the summary data set, with information on each driver (see details in Table 1).

**Table 1.** Descriptive statistics of the summary data set for 182 drivers observed from July 3 to July 8 2018.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Mean | Standard Deviation | Minimum | Maximum | Definition |
| Overspeed | 19.19 | 45.37 | 0 | 330 | Frequency of driving speed greater than 100km/h |
| Highspeedbrake | 44.23 | 108.3 | 0 | 942 | Frequency of braking when the driving speed is greater than 90km/h |
| harshacceleration | 139.0 | 134.7 | 0 | 899 | Frequency of cases when acceleration is greater than 6*m*/*s*2 |
| harshdeceleration | 141.9 | 137.8 | 1 | 913 | Frequency of cases when the acceleration is less than -6*m*/*s*2 |
| kilo | 2,223 | 1,674 | 3.73 | 7,164 | Total driving distance (km) |
| fuel | 621.7 | 470.9 | 10.25 | 2,018 | Total fuel consumption (L) |
| brakes | 1,588 | 1,426 | 6 | 9,243 | Total number of brakes |
| range | 5.201 | 5.021 | 0.027 | 26.78 | Range of driving (geographical units) |
| speed | 36.88 | 16.37 | 0.297 | 67.84 | Mean of speed (km/h) |
| rpm | 1,028 | 188.3 | 233.1 | 1,620 | Mean of revolutions per minute (r/min) |
| acceleratorpedalposition | 21.05 | 7.110 | 0.187 | 39.29 | Mean of acceleration pedal position (%) |
| enginefuelrate | 11.52 | 4.464 | 1.868 | 22.01 | Mean of engine fuel rate (%) |
| *a* The number of observations is 182. |  |  |  |  |  |

In particular, , , and are individually filtered by combining the rules of traffic law and driving code. Firstly, previous studies have confirmed that over speed is a dangerous driving behavior that is likely to cause traffic accidents. And China’s traffic safety regulations stipulate a maximum speed for the each type of vehicles on all types of roads. The maximum speed limit of the vehicles in this study is 90 km/h, and it is not illegal to exceed the speed limit by less than ten percent. Therefore, 100 km/h is taken as the threshold value of the overspeed near-miss event. Secondly, if the emergency braking of a car running at a high speed is operated improperly or subjected to lateral force, it is prone to side-slip or even cartwheel, thus high-speed (>90km/h) braking is a risky near-miss event worthy of study. Thirdly, both harsh acceleration and harsh deceleration are near-miss events that need to be avoided in terms of driving safety and fuel economy. Based on the previous research experience and the filter analysis of the extreme values of this data set by box graph method, is determined as the filtering threshold value of harsh acceleration and harsh deceleration. It can be seen from Figure [1](#frequency) that near-miss events are all non-negative integers. Combined with the relationship between expectation and variance shown in Table [1](#summary), the four near-miss events are suitable as dependent variables of a Poisson regression or a Negative binomial regression.



The panel data set has one summary per day for each driver. The statistics of panel data set are shown in the Table 2.

**Table 2.** Descriptive statistics of a panel data set for 182 drivers observed over six days (total cases 1092).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | N | Mean | Standard Deviation | Minimum | Maximum |
| overspeed | 1,092 | 3.199 | 14.37 | 0 | 315 |
| highspeedbrake | 1,092 | 7.435 | 21.74 | 0 | 215 |
| harshacceleration | 1,092 | 23.37 | 29.78 | 0 | 223 |
| harshdeceleration | 1,092 | 23.86 | 30.16 | 0 | 233 |
| kilo | 1,092 | 372.6 | 373.2 | 0 | 1,739 |
| fuel | 1,092 | 104.1 | 105.7 | 0 | 565.8 |
| brakes | 1,092 | 264.7 | 291.0 | 0 | 1,940 |
| range | 1,092 | 2.406 | 2.963 | 0 | 14.07 |
| speed | 1,092 | 31.96 | 21.58 | 0 | 77.74 |
| rpm | 1,092 | 894.3 | 346.9 | 0 | 1,731 |
| acceleratorpedalposition | 1,092 | 17.51 | 10.19 | 0 | 45.74 |
| enginefuelrate | 1,092 | 9.794 | 5.835 | 0 | 26.18 |

# Methods

Poisson regression is a generalized linear model. Generally speaking, Negative binomial regression can be considered as a generalization of Poisson regression with over-dispersion of the dependent variable where subindex *i* refers to the i-th observation in the data set. The probability density function of the Poisson distribution is:

where is the Poisson arrival rate and is determined by explanatory variable in Poisson regression to represent the average number of events, which is equal to the expectation and variance of the explained variable .

The Negative binomial distribution is a mixture of a Poisson() and a Gamma(,) distributions. The probability density function of the Negative binomial distribution is:

where and .

The zero-inflated model is applicable when the counting data contains a large number of zero values. Theoretically, it is a two-stage decision. First, it decides whether to choose zero or a positive integer, and then it determines which positive integer to choose. Therefore, the probability distribution of y is a mixed distribution:

where is the probability of an extra zero value, can follow a Poisson distribution or a Negative binomial distribution depending on the characteristics of the dependent variable.

The conditional expectation function of a Negative binomial regression model depends on a vector of explanatory variables () and similar to Poisson, is usually defined by a log-link as:

where is the number of the observation, depends on the number of independent variables, denotes the offset varables (so in our application it is or as the exposure variable), … represent the independent variables such as , , , , and , and … are unknown parameters that need to be estimated.

The two-way fixed effect model of panel Poisson regression and panel Negative binomial regression is specified as:

where is the number of the observation, is the time reference, is the offset and it equals or as the exposure variable in our application, represent the individual effect and represent the time effect. To avoid identification problems in the model specification, .

This study has gone through data preparation, modeling, risk scoring of driving risk, etc. The whole technical process is shown in the Figure [2](#flow). As the basic research of telematics data application, the result of this study has a good application prospect, such as driving behavior supervision and personalized premium calculation. Data processing in the preparation and Poisson regression and Negative binomial regression on different data set in the modeling can be implemented with data tools including, but not limited to, Stata, Python, R, etc.



Figure 2 Technique flow chart. Data preparation, modeling and risk scoring of driving risk.

# Results

Both Poisson regression and Negative binomial regression were applicable to this study, and the Zero-inflated model was taken as a consideration for the large number of zero values of dependent variables. In order to determine the most suitable model for this study, the performance of models on different dependent variables was compared.

## Results of summary data set

In summary data set, four near-miss events were respectively treated as dependent variables. The independent variables were , , , and where was chosen as the exposure variable or offset. Poisson regression, Zero-inflated Poisson regression, Negative binomial regression and Zero-inflated Negative binomial regression were estimated (see Table 3). No matter which near-miss event is the dependent variable, Negative binomial regression has maximum log-likelihood value, and minimum AIC value and BIC value. That is, Negative binomial regression has the best performance in this data set.

**Table 3.** Model performances of Poisson, Zero-inflated Poisson, Negative binomial and Zero-inflated Negative binomial in summary data set.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable Model | N | log-likelihood | df | AIC | BIC |
| POS | 182 | -3518.92 | 7 | 7051.846 | 7074.274 |
| overspeed ZIP | 182 | -2369.82 | 8 | 4755.64 | 4781.272 |
| NB | 182 | -490.517 | 8 | 997.0338 | 1022.666 |
| ZINB | 182 | -490.516 | 9 | 999.0315 | 1027.868 |
| POS | 182 | -2830.75 | 7 | 5675.498 | 5697.926 |
| highspeedbrake ZIP | 182 | -2667.02 | 8 | 5350.034 | 5375.666 |
| NB | 182 | -627.422 | 8 | 1270.843 | 1296.476 |
| ZINB | 182 | -627.422 | 9 | 1272.843 | 1301.68 |
| POS | 182 | -5857.26 | 7 | 11728.51 | 11750.94 |
| harshacceleration ZIP | 182 | -5857.26 | 8 | 11730.51 | 11756.14 |
| NB | 182 | -1032.81 | 8 | 2081.623 | 2107.255 |
| ZINB | 182 | -1032.81 | 9 | 2083.623 | 2112.459 |
| POS | 182 | -6269.47 | 7 | 12552.93 | 12575.36 |
| harshdeceleration ZIP | 182 | -6269.47 | 8 | 12554.93 | 12580.56 |
| NB | 182 | -1037.14 | 8 | 2090.285 | 2115.917 |
| ZINB | 182 | -1037.14 | 9 | 2092.285 | 2121.121 |

According to the results of Negative binomial regression in different dependent variables (see Table 4 and Figure 3(a)), different near-miss events are affected by different driving risk factors with different influences. Relatively speaking, the number of braking has the most obvious influence on near-miss events, it has a significant positive effect on high speed braking(0.000191), harsh acceleration(0.000133) and harsh deceleration(0.000126). The impact of average speed on near-miss events is also significant. The higher the average driving speed, the less rapid acceleration(-0.0474) and rapid deceleration(-0.0402) occur. In addition, average RPM is positively correlated with harsh acceleration(0.000947), and average accelerator pedal position is positively correlated with harsh acceleration(0.0214) and harsh deceleration(0.0330). Interestingly, some influencing factors have opposite effects on different dependent variables. Range of driving has positive effect on high speed brake(0.0541) but negative effect on harsh deceleration(-0.0305). And average engine fuel rate has a significant positive effect on high speed braking(0.158) but a negative effect on sharp deceleration(-0.0351). What’s more, the significance of the constant term indicates that in addition to the factors considered in this study, there are other factors that also influence near-miss events.

**Table 4.** Negative binomial regression results for four near-miss events in the summary data set of drivers.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Overspeed | highspeedbrake | harshacceleration | harshdeceleration |
| Constant | -7.536\*\*\* | -8.456\*\*\* | -2.101\*\*\* | -1.903\*\*\* |
|  | (-3.363) | (-7.526) | (-4.006) | (-3.933) |
| brakes | 0.000185 | 0.000191\*\*\* | 0.000133\*\*\* | 0.000126\*\*\* |
|  | (1.293) | (2.601) | (3.384) | (3.450) |
| range | 0.0369 | 0.0541\*\* | -0.0200 | -0.0305\* |
|  | (0.791) | (2.052) | (-1.287) | (-1.942) |
| speed | -0.00690 | 0.0152 | -0.0474\*\*\* | -0.0402\*\*\* |
|  | (-0.200) | (1.277) | (-8.810) | (-7.201) |
| rpm | 0.000666 | -0.000128 | 0.000947\* | 0.000515 |
|  | (0.431) | (-0.113) | (1.896) | (1.072) |
| acceleratorpedalposition | 0.0407 | 0.0241 | 0.0214\* | 0.0330\*\*\* |
|  | (1.130) | (1.028) | (1.872) | (2.815) |
| enginefuelrate | 0.0508 | 0.158\*\*\* | -0.0198 | -0.0351\*\* |
|  | (0.987) | (4.493) | (-1.116) | (-2.073) |
| log-likelihood | -490.5169 | -627.4217 | -1032.811 | -1037.142 |
| AIC | 997.0338 | 1270.843 | 2081.623 | 2090.285 |
| BIC | 1022.666 | 1296.476 | 2107.255 | 2115.917 |
| Observations | 182 | 182 | 182 | 182 |
| *a* Robust z-statistics in parentheses | *b* \*\*\* p<0.01, \*\* p<0.05, \* p<0.1 |  |  |  |
|  |  |  |  |  |

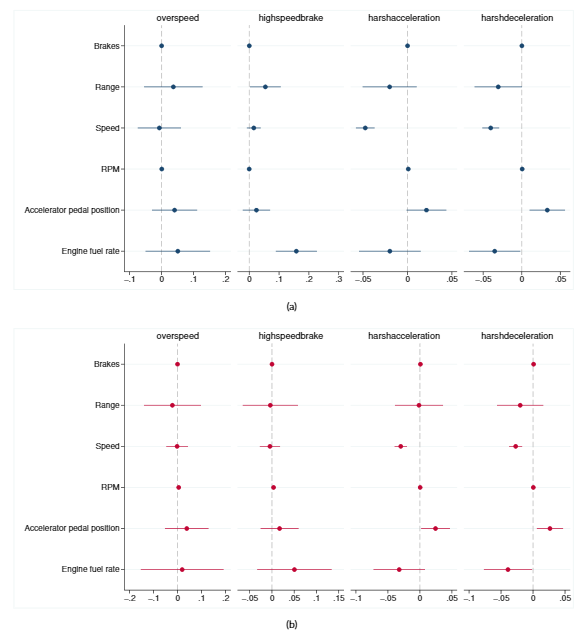


Figure 3. Partial coefficient estimation results of (a) Negative binomial regression; (b) Panel Negative binomial regression.

## Results of panel data set

As shown in Table 5, the evaluation index(log-likelihood, AIC and BIC) of Negative binomial regression is lower than that of Poisson regression under each dependent variable. Therefore, Negative binomial regression is better than Poisson regression on panel data.

**Table 5.** Model performances of Poisson and Negative binomial in the panel data set of drivers with six observations per driver..

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable Model | N | log-likelihood | df | AIC | BIC |
| overspeed XTPOS | 1092 | -1926.78 | 188 | 4229.559 | 5168.763 |
| XTNB | 1092 | -957.497 | 189 | 2292.993 | 3237.193 |
| highspeedbrake XTPOS | 1092 | -2594.37 | 188 | 5564.733 | 6503.937 |
| XTNB | 1092 | -1527.05 | 189 | 3432.105 | 4376.305 |
| harshacceleration XTPOS | 1092 | -6117.44 | 188 | 12610.89 | 13550.09 |
| XTNB | 1092 | -3526.09 | 189 | 7430.186 | 8374.386 |
| harshdeceleration XTPOS | 1092 | -6042.02 | 188 | 12460.03 | 13399.24 |
| XTNB | 1092 | -3547.66 | 189 | 7473.311 | 8417.51 |

The panel Negative binomial regression was used to estimate the two-way fixed effect model considering both individual effect and time effect on four dependent variables. The influencing factors reflected by it (seeing Table A1 and Figure 3(b)) are not all the same as the results of summary data. What remains is that rapid acceleration and rapid deceleration are positively affected by the number of brakes(0.000845&0.000869) and average accelerator pedal position(0.0244&0.0265) but negatively affected by the average speed(-0.0299&-0.0272) and average engine fuel rate(-0.0323&-0.0392). However, RPM which is not significant in the summary data is significantly positive for over speed(0.00485) and high speed braking(0.00371).

The advantage of panel data over summary data is that fixed effects can be estimated and thus individual effects and time effects can be interpreted. The time effect are significant in most cases for high speed braking, rapid acceleration and rapid deceleration, which indicates that these three near-miss events are greatly influenced by time. The time effect of the over speed event is significant for only one day, suggesting that it is less influenced by time. Most importantly, the individual effects of the four near-miss events can be used to score each observation. It should be noted that the first individual has been omitted in the regression to avoid complete multicollinearity, and its value is expected to be zero in the subsequent driving risk score.

# Discussions and Conclusions

The results obtained by panel regression were more reliable than those obtained by pooled regression. Table [4](#summary-nb), Table A[1](#panel-nb) and Figure [3](#coef) show that some coefficient are not significant in the pooled Negative binomial regression become significant in the panel Negative binomial regression, while some significant parameters in the pooled Negative binomial regression become not significant in the panel Negative binomial regression. It means that the dependent variables are affected by individual effects and time effects. Most of the individual and time coefficients in the panel Negative binomial regression are significant, which indicates the effectiveness of the panel negative binomial regression.

Driving risks can be evaluated by the regression coefficients of Negative binomial models on panel data. The value of the individual coefficients within a regression indicates the individual’s deviance from the level of the expected number of such a near-miss event, given the information on all the other explanatory variables. In other words, the individual effect coefficient can be understood as the effect utility of each vehicle on the occurrence of the corresponding near-miss event. Geometrically, the effect coefficient of each individual is a change in the intercept.

Four near-miss events have been used as dependent variables to obtain four sets of regression coefficients. Given the influencing factors and generating mechanisms of different near-miss events are different, it is not recommended to combine the four groups of regression coefficients into one group. However, sharp acceleration and sharp deceleration show very similar characteristics in terms of data description before regression (Table [1](#summary),[2](#summary-nb)), results after regression (Figure [3](#coef) and Table 4,A[1](#panel-nb)) and distribution of driving risk score (Figure [4](#score)), so it is feasible to combine them into a single near-miss event for further research.

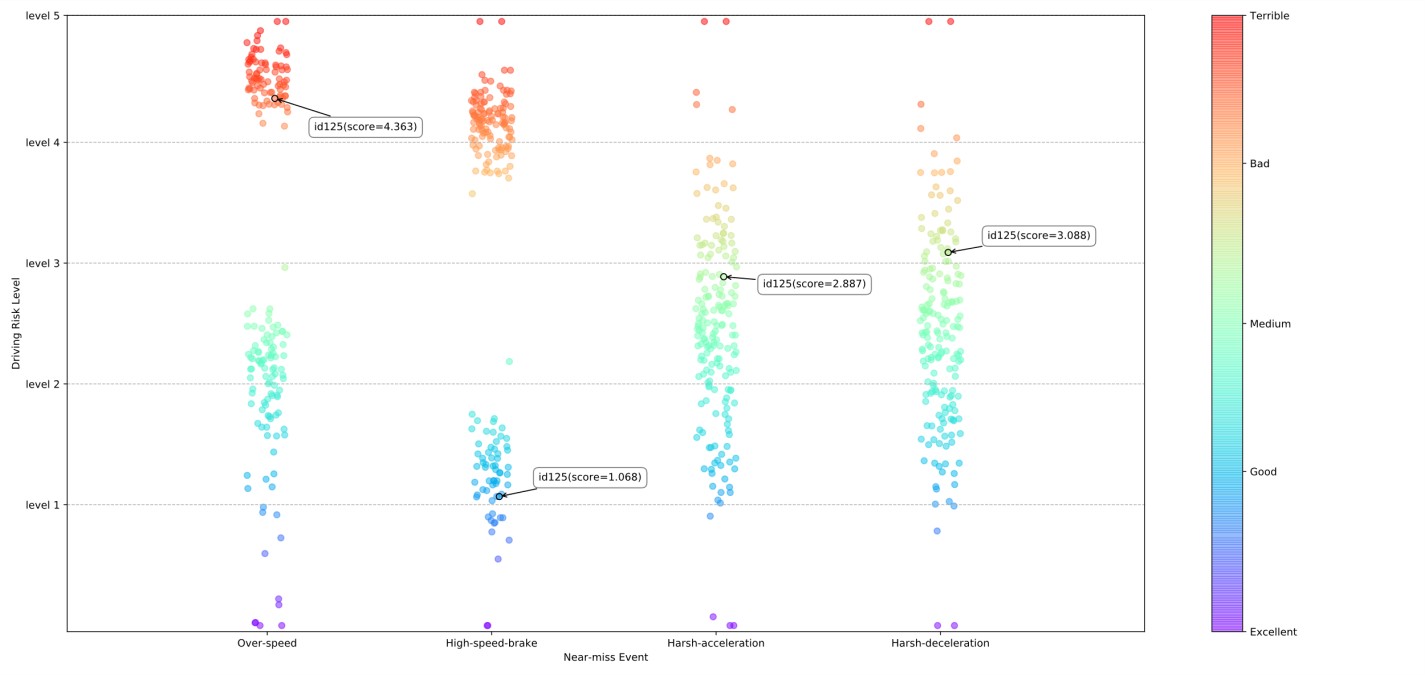
In order to transform individual effect estimates of near-miss models into a driving risk grading, several steps need to be done. Firstly, winsorization avoids the influence of possibly spurious outliers (the double tail was winsorized with the threshold 0.01 in this study). Secondly, the regression coefficient can be compressed to the interval of [0,1] through normalization. Then, each group of coefficients is mapped into an interval of [0,5] (see Table A[2](#score)), each observation then gets a driving risk level from 1 to 5, i.e. excellent, good, medium, bad and terrible (see Figure [4](#rank)). To be clear, the values of exactly 0 and 5 are because the corresponding observations are the minimum and the maximum values in their group and are Min-Max scaled. In and groups, two types of observations with high risk or low risk can be clearly seen. It indicates that these two near-miss events are more sensitive to driving behavior than and and can be considered with higher priority and weight in subsequent studies. Note that the same observation (id125) has different risk levels for different near-miss events, which also explains why multiple near-miss events cannot be analyzed together. Ultimately, the premium will be charged individually according to the driving risk level of the insured one.

The number and type of dependent variables and independent variables selected in this study are limited by the size and quality of the original data. With the promotion and innovation of IoV and of new energy vehicles, the amount and dimension of data will be greatly increased. Therefore, near-miss events as dependent variables could be increased or decreased flexibly according to needs. For example, it is recommended to include sharp turn as a near-miss event if possible, because sharp turn is highly studied and accident-proven patterns of high driving risk. For the same reason, more driving behavior indicators such as steering wheel angle speed, brake pedal position and so on could be used as independent variables in the regression model. In addition, traditional auto insurance factors such as driver information, vehicle information, road information, environment information and the health status of batteries (of new energy vehicles) should be considered to provide more optional independent variables for the model.

Econometrics and machine learning complement each other. The generalized linear model established in this study reveals the relationship between driving behavior factors and near-miss events, and gives a driving risk score for each observation. This model has strong explanatory power, but its generalization degree and robustness need to be further tested, especially when the data volume and data dimension are particularly large. The successful application of machine learning methods in many fields also shows that they are often effective in dealing with big data problems, but the biggest problem is that machine learning can not be explained well, which is exactly what the insurance field values. Therefore, it is a new research direction of telematics data application to find a balance between econometrics and machine learning, so as to have both good explanability, good generalization ability, quick response ability, etc..

In practical applications, near-miss events can be combined with claims and accidents to accurately evaluate driving risks. This study proves that near-miss events can be used as driving risk scores when there is no claims and accidents. However, when claims or accidents exist, the driving risk score obtained from claims or accidents can be used as the basis for premium calculation, while the driving risk rating obtained from near-miss events can be used to remind and warn drivers to reduce the corresponding dangerous driving habits.

In general, near-miss events can provide insurers with effective risk information in the absence of claims and accident data. Negative binomial regression is the most suitable modeling method for near-miss events as dependent variables in our real case study. This study provides a technical reference for the promotion and development of PHYD ratemaking schemes.



**Figure 2.** Driving risk rank of four near-miss events.

# Appendix A

**Table A1.** Panel Negative binomial regression results for four near-miss events.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | overspeed | highspeedbrake | harshacceleration | harshdeceleration |
| Constant | -8.820\*\*\* | -8.364\*\*\* | -2.029\*\*\* | -2.035\*\*\* |
| brakes | -0.000138 | 0.000174 | 0.000845\*\*\* | 0.000869\*\*\* |
| range | -0.0215 | -0.00365 | -0.00139 | -0.0201 |
| speed | -0.00188 | -0.00447 | -0.0299\*\*\* | -0.0272\*\*\* |
| rpm | 0.00485\*\* | 0.00371\*\*\* | 0.000412 | 0.000417 |
| acceleratorpedalposition | 0.0384 | 0.0172 | 0.0244\*\* | 0.0265\*\* |
| enginefuelrate | 0.0193 | 0.0505 | -0.0323 | -0.0392\*\* |
| 2018-07-04 | 0.273 | 0.216\* | -0.111\*\* | -0.216\*\*\* |
| 2018-07-05 | -0.168 | -0.0572 | -0.206\*\*\* | -0.317\*\*\* |
| 2018-07-06 | -0.00718 | -0.228\*\* | -0.257\*\*\* | -0.370\*\*\* |
| 2018-07-07 | -0.477\*\* | -0.200\* | -0.485\*\*\* | -0.600\*\*\* |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 2018-07-08 | 0.206 | 0.117 | -0.694\*\*\* | -0.784\*\*\* |
| id2 | -29.70\*\*\* | -2.001\*\* | 1.266\*\*\* | 1.342\*\*\* |
| id3 | -19.47\*\*\* | -17.47\*\*\* | 2.004\*\* | 1.740\*\*\* |
| id4 | -18.62\*\*\* | -16.69\*\*\* | 1.891\*\*\* | 1.960\*\*\* |
| id5 | -30.60\*\*\* | -4.956\*\*\* | -1.193\*\*\* | -1.072\*\*\* |
| id6 | -1.478\*\* | -0.554\* | 1.067\*\*\* | 0.935\*\*\* |
| id7 | -3.237\*\*\* | -0.645 | 0.656\*\*\* | 0.835\*\*\* |
| id8 | -21.39\*\*\* | -2.368\*\*\* | -0.190 | 0.124 |
| id9 | -1.156 | -0.0679 | -0.251 | -0.109 |
| id10 | -3.110\*\*\* | -1.527\*\*\* | -0.345\*\* | -0.256 |
| id11 | -2.026\*\* | -1.163\*\*\* | -0.162 | -0.272 |
| id12 | -1.342\*\* | -0.772\*\* | 0.0781 | 0.0981 |
| id13 | -2.344\*\*\* | -0.808\*\* | -0.138 | -0.129 |
| id14 | -3.178\*\*\* | 0.442 | -0.629\*\*\* | -0.365\*\* |
| id15 | -1.254\*\* | 0.167 | -0.0894 | 0.0270 |
| id16 | -23.00\*\*\* | -20.31\*\*\* | 0.271 | 0.439\*\* |
| id17 | -22.41\*\*\* | -2.102\*\*\* | -0.200 | 0.0983 |
| id18 | -21.61\*\*\* | -0.805 | -1.124\*\*\* | -1.267\*\*\* |
| id19 | -0.998 | 0.380 | 0.587\*\*\* | 0.586\*\*\* |
| id20 | -24.78\*\*\* | -3.749\*\*\* | 0.292 | 0.0926 |
| id21 | -22.39\*\*\* | -2.577\*\*\* | 0.322 | 0.458\*\*\* |
| id22 | -2.642\*\*\* | -0.229 | 0.496\*\*\* | 0.538\*\*\* |
| id23 | -0.792 | 0.00111 | -0.474 | -0.409\* |
| id24 | -24.05\*\*\* | -21.10\*\*\* | -0.329 | -0.103 |
| id25 | -21.70\*\*\* | -19.47\*\*\* | -0.882\*\*\* | -0.731\*\* |
| id26 | -2.739\*\*\* | -1.000\*\*\* | -0.440\* | -0.667\*\*\* |
| id27 | -23.77\*\*\* | -20.99\*\*\* | -0.0464 | 0.0656 |
| id28 | -18.27\*\*\* | -17.04\*\*\* | 0.0432 | 0.309 |
| id29 | -1.137 | -0.872\*\* | 0.591\*\*\* | 0.625\*\*\* |
| id30 | -21.14\*\*\* | -18.81\*\*\* | -0.223 | -0.102 |
| id31 | -0.407 | -0.632\*\* | -1.148\*\*\* | -0.949\*\*\* |
| id32 | -3.255\*\*\* | -2.923\*\* | -0.110 | 0.143 |
| id33 | -19.47\*\*\* | -18.27\*\*\* | -0.177 | -0.153 |
| id34 | -2.431\*\*\* | -1.547\*\*\* | -0.00573 | -0.0439 |
| id35 | -3.832\*\*\* | -1.041\*\* | -0.607\*\*\* | -0.552\*\*\* |
| id36 | -4.135\*\*\* | -2.411\*\*\* | -0.285 | -0.343\* |
| id37 | -39.82\*\*\* | -1.232\* | -0.480 | -0.218 |
| id38 | -20.79\*\*\* | -1.364\*\* | -1.484\*\*\* | -1.121\*\*\* |
| id39 | -39.80\*\*\* | 10.89\*\*\* | 11.65\*\*\* | 11.77\*\*\* |
| id40 | -1.325 | -0.416 | -0.278 | 0.0791 |
| id41 | -2.443\*\*\* | -1.020\*\* | 0.180 | 0.155 |
| id42 | -0.467 | 0.442 | 0.607 | 0.398 |
| id43 | -2.164\*\* | 0.219 | -0.0359 | 0.0900 |
| id44 | -2.465\*\*\* | -0.156 | 0.336 | 0.468\* |
| id45 | -2.110\*\*\* | -1.315\*\*\* | 0.105 | 0.282 |
| id46 | 0.132 | -0.480 | -0.312\*\*\* | -0.235\* |
| id47 | -2.957\*\*\* | -0.975 | -0.853\*\*\* | -0.656\*\*\* |
| id48 | 0.486 | 1.381\*\*\* | 0.829\*\*\* | 0.787\*\*\* |
| id49 | -26.13\*\*\* | -1.575\*\*\* | -0.568\*\*\* | -0.353\* |
| id50 | -2.556\*\*\* | -1.907\*\*\* | -0.413\*\* | -0.331\* |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| id51 | -21.19\*\*\* | -19.04\*\*\* | 1.123\*\*\* | 1.140\*\*\* |
| id52 | -21.82\*\*\* | -20.71\*\*\* | -0.354 | -0.952\*\*\* |
| id53 | -21.26\*\*\* | -19.27\*\*\* | -0.133 | 0.200 |
| id54 | -4.881\*\*\* | -1.082\*\*\* | -0.686\*\*\* | -0.639\*\*\* |
| id55 | -4.290\*\*\* | -1.731\*\*\* | 0.472\* | 0.476 |
| id56 | -2.462\*\*\* | -0.0866 | 0.119 | 0.377 |
| id57 | -21.86\*\*\* | -0.700 | 0.110 | 0.719\*\* |
| id58 | -1.877\* | -0.692 | -0.344 | 0.0660 |
| id59 | -40.00\*\*\* | -0.0709 | -0.726\*\* | -0.587\* |
| id60 | -3.117\*\*\* | -3.813\*\*\* | -0.711\*\* | -0.565\* |
| id61 | 0.821 | 1.078\* | -1.288\*\*\* | -1.076\*\* |
| id62 | -0.465 | 0.546 | -0.670 | -0.473 |
| id63 | -22.05\*\*\* | -19.52\*\*\* | 1.393\*\*\* | 1.513\*\*\* |
| id64 | -2.529 | -1.707 | 1.334\*\*\* | 1.339\*\*\* |
| id65 | -22.00\*\*\* | -19.36\*\*\* | -1.923\*\*\* | -1.288\*\*\* |
| id66 | -1.389 | -1.510\*\*\* | 0.504\*\*\* | 0.971\*\*\* |
| id67 | -26.39\*\*\* | -3.400\*\*\* | -0.371\*\* | -0.304\* |
| id68 | -19.61\*\*\* | -17.60\*\*\* | -1.286\*\*\* | -1.660\*\*\* |
| id69 | -25.19\*\*\* | -20.76\*\*\* | -0.589\*\*\* | -0.625\*\* |
| id70 | -21.81\*\*\* | -3.693\*\*\* | -1.489\*\*\* | -1.501\*\*\* |
| id71 | -32.23\*\*\* | -28.28\*\*\* | 0.587\*\*\* | 1.212\*\*\* |
| id72 | -5.534\*\*\* | -1.058\* | -0.516 | -0.643\* |
| id73 | -4.323\*\*\* | -2.863\*\*\* | -1.527\*\*\* | -1.523\*\*\* |
| id74 | -31.88\*\*\* | -27.94\*\*\* | 0.299 | 0.765\*\*\* |
| id75 | -2.868\*\*\* | -1.677\*\*\* | -0.267 | -0.0911 |
| id76 | -21.77\*\*\* | -22.16\*\*\* | -1.646\*\*\* | -1.903\*\*\* |
| id77 | -20.38\*\*\* | -18.72\*\*\* | 0.835\*\*\* | 0.729\*\*\* |
| id78 | -24.70\*\*\* | -3.260\*\*\* | -2.855\*\*\* | -2.759\*\*\* |
| id79 | -3.449\*\*\* | -0.618 | -0.232 | -0.110 |
| id80 | -22.34\*\*\* | -20.24\*\*\* | -0.0149 | 0.0509 |
| id81 | -35.06\*\*\* | -1.132\*\* | -0.341\*\* | -0.336\*\* |
| id82 | -1.391 | -0.541 | -0.312 | -0.326 |
| id83 | -1.516\*\*\* | 0.157 | -0.123 | -0.242 |
| id84 | -24.88\*\*\* | -1.866\*\* | -0.750\*\*\* | -0.855\*\*\* |
| id85 | -22.91\*\*\* | -3.843\*\*\* | -1.430\*\*\* | -1.318\*\*\* |
| id86 | -29.96\*\*\* | -2.036\*\*\* | -1.272\*\*\* | -1.111\*\*\* |
| id87 | -1.851\*\* | 1.034\*\*\* | 0.196 | 0.425\*\* |
| id88 | -20.59\*\*\* | -18.45\*\*\* | -0.208 | -0.165 |
| id89 | -26.39\*\*\* | -22.35\*\*\* | 1.100\*\* | 1.135\*\* |
| id90 | -4.008\*\*\* | -0.841 | -0.972\*\*\* | -0.982\*\*\* |
| id91 | -20.05\*\*\* | -19.02\*\*\* | 0.676\*\*\* | 0.818\*\*\* |
| id92 | -26.97\*\*\* | -22.96\*\*\* | 0.848\*\* | 0.663\*\* |
| id93 | -24.47\*\*\* | -21.29\*\*\* | -0.290 | -0.300 |
| id94 | -2.684\*\*\* | -1.034\*\*\* | -0.157 | 0.0139 |
| id95 | -25.60\*\*\* | -21.99\*\*\* | -0.503 | -0.670 |
| id96 | -23.42\*\*\* | -20.46\*\*\* | 1.374\*\*\* | 1.343\*\*\* |
| id97 | -21.44\*\*\* | -19.45\*\*\* | -0.464\*\* | -0.282 |
| id98 | -19.05\*\*\* | -17.65\*\*\* | -1.405\*\*\* | -0.887\*\* |
| id99 | -18.58\*\*\* | -17.09\*\*\* | -1.774\*\*\* | -1.369\*\*\* |
| id100 | -4.226\*\*\* | -20.22\*\*\* | 0.802\*\* | 0.824\*\* |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| id101 | -23.30\*\*\* | -20.24\*\*\* | 0.955\*\* | 0.814\* |
| id102 | -25.66\*\*\* | -22.49\*\*\* | 0.0308 | -0.0294 |
| id103 | -18.28\*\*\* | -16.93\*\*\* | 0.542\*\* | 0.606\*\*\* |
| id104 | -20.60\*\*\* | -18.55\*\*\* | 0.131 | 0.262\*\* |
| id105 | -3.426\*\*\* | -0.430 | -0.464 | -0.925\*\* |
| id106 | -25.81\*\*\* | -22.46\*\*\* | 0.317\* | 0.252 |
| id107 | -21.63\*\*\* | -19.42\*\*\* | 0.0144 | 0.147 |
| id108 | -24.10\*\*\* | -2.647\*\*\* | -0.532\*\* | -0.635\*\*\* |
| id109 | -21.46\*\*\* | -19.64\*\*\* | -0.347\*\*\* | -0.782\*\*\* |
| id110 | -21.03\*\*\* | -20.38\*\*\* | -1.801\*\*\* | -1.044\*\*\* |
| id111 | -3.405\*\*\* | -1.277\*\*\* | 0.173 | 0.198 |
| id112 | -20.18\*\*\* | -18.15\*\*\* | -1.453\*\*\* | -0.831\*\*\* |
| id113 | -30.49\*\*\* | -2.997\*\*\* | -1.703\*\*\* | -1.296\*\*\* |
| id114 | -24.22\*\*\* | -21.07\*\*\* | 0.637\*\*\* | 0.537\*\*\* |
| id115 | -22.90\*\*\* | -20.24\*\*\* | -0.0179 | -0.109 |
| id116 | -22.43\*\*\* | -3.753\*\*\* | -1.349\*\*\* | -1.135\*\*\* |
| id117 | -21.32\*\*\* | -19.05\*\*\* | -0.156 | -0.273\*\* |
| id118 | -19.53\*\*\* | -0.705 | 0.116 | 0.00337 |
| id119 | -20.89\*\*\* | -18.80\*\*\* | -0.145 | -0.143 |
| id120 | -28.10\*\*\* | -24.40\*\*\* | -0.0170 | 0.133 |
| id121 | -29.59\*\*\* | -0.687\* | 0.239 | 0.387\*\* |
| id122 | -22.31\*\*\* | -2.515\*\* | 0.623\*\* | 0.653\*\* |
| id123 | -23.52\*\*\* | -3.892\*\*\* | 0.698 | 0.886\*\* |
| id124 | -4.268\*\* | -2.612\*\* | 0.698\*\*\* | 0.361 |
| id125 | -3.828\*\* | -21.08\*\*\* | 0.296 | 0.619\* |
| id126 | -2.023 | -2.183\*\* | 0.576\* | 0.539\* |
| id127 | -22.73\*\*\* | -19.80\*\*\* | 1.158\*\*\* | 1.010\*\*\* |
| id128 | -21.55\*\*\* | -19.82\*\*\* | 0.762\*\*\* | 0.618\*\* |
| id129 | -1.540\*\* | 0.777\*\* | 0.0280 | 0.165 |
| id130 | -25.56\*\*\* | -22.20\*\*\* | -1.578\*\*\* | -1.635\*\*\* |
| id131 | -1.659\*\* | -0.403 | -0.980\*\*\* | -0.794\*\*\* |
| id132 | -19.92\*\*\* | -17.86\*\*\* | -0.863\*\*\* | -0.435\* |
| id133 | -27.00\*\*\* | -2.904\*\*\* | -0.622\*\*\* | -0.691\*\*\* |
| id134 | -32.40\*\*\* | -2.618\*\*\* | 0.488\*\* | 1.176\*\*\* |
| id135 | -24.19\*\*\* | -20.95\*\*\* | 0.930\*\*\* | 1.350\*\*\* |
| id136 | 3.358\*\*\* | 4.212\*\*\* | 2.661\*\*\* | 2.709\*\*\* |
| id137 | -24.30\*\*\* | -2.508\*\*\* | 0.0440 | 0.804\*\*\* |
| id138 | -19.39\*\*\* | -17.42\*\*\* | -0.827\*\*\* | -0.890\*\*\* |
| id139 | -4.105\*\*\* | -1.187\*\* | -0.922\*\*\* | -0.677 |
| id140 | -2.970\*\*\* | -0.615 | -1.276\*\*\* | -1.035\*\*\* |
| id141 | -25.41\*\*\* | -22.20\*\*\* | -1.071\*\*\* | -1.100\*\*\* |
| id142 | -38.18\*\*\* | -0.873\* | 0.0500 | 0.175 |
| id143 | -38.58\*\*\* | -0.397 | -0.368 | -0.157 |
| id144 | -0.585 | 0.551 | 0.0261 | 0.167 |
| id145 | -2.485\*\* | -1.273\*\* | -0.750 | -0.631 |
| id146 | -23.85\*\*\* | -1.250\*\*\* | -1.130\*\*\* | -0.758\*\* |
| id147 | -2.851\*\*\* | -0.0796 | -1.021\*\*\* | -0.896\*\*\* |
| id148 | -3.737\*\*\* | 1.617\*\*\* | -0.0483 | -0.0520 |
| id149 | -3.202\*\*\* | -1.184\*\* | -0.554\*\*\* | -0.343 |
| id150 | -3.616\*\*\* | -0.905\*\* | -1.167\*\*\* | -0.905\*\*\* |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| id151 | -0.362 | -1.167\*\* | -1.654\*\*\* | -1.677\*\*\* |
| id152 | -33.99\*\*\* | -3.751\*\*\* | -1.421\*\*\* | -1.382\*\*\* |
| id153 | -1.598\*\* | -0.169 | -2.936\*\*\* | -3.067\*\*\* |
| id154 | -22.42\*\*\* | -2.716\*\*\* | -1.703\*\*\* | -1.483\*\*\* |
| id155 | -4.238\*\*\* | -2.441\*\* | -0.759\*\*\* | -0.814\*\*\* |
| id156 | -44.40\*\*\* | -1.456\*\*\* | -0.590\*\*\* | -0.429\*\* |
| id157 | -1.868\*\* | 0.337 | -0.753\*\*\* | -0.502\*\* |
| id158 | -19.82\*\*\* | -17.98\*\*\* | 0.678\*\*\* | 0.744\*\*\* |
| id159 | -19.82\*\*\* | -18.42\*\*\* | 0.827\*\*\* | 0.715\*\*\* |
| id160 | -3.790\*\*\* | 0.550 | 0.148 | 0.337\* |
| id161 | -22.82\*\*\* | -19.90\*\*\* | 0.608\*\*\* | 0.494\*\*\* |
| id162 | -20.72\*\*\* | -18.61\*\*\* | 0.431\* | 0.176 |
| id163 | -23.06\*\*\* | -20.45\*\*\* | 1.844\*\*\* | 1.656\*\*\* |
| id164 | -2.923\*\*\* | -2.557\*\*\* | -0.245\* | -0.301\* |
| id165 | -21.48\*\*\* | -19.51\*\*\* | 1.341\*\*\* | 1.447\*\*\* |
| id166 | -26.53\*\*\* | -2.439\*\*\* | -0.158 | -0.0534 |
| id167 | -2.696\*\* | -4.124\*\*\* | 1.119\*\*\* | 1.089\*\*\* |
| id168 | -5.731\*\*\* | -1.940\*\*\* | 0.0447 | 0.0115 |
| id169 | -26.92\*\*\* | -23.39\*\*\* | 0.473\*\* | 0.422\* |
| id170 | -15.44\*\*\* | -13.89\*\*\* | -19.55\*\*\* | -0.684 |
| id171 | -3.650\*\*\* | -1.497\*\*\* | -0.344 | -0.313 |
| id172 | -3.659\*\*\* | -1.951\*\*\* | -0.427\* | -0.367 |
| id173 | -3.036\*\*\* | -3.500\*\*\* | -0.874\*\*\* | -0.888\*\*\* |
| id174 | 1.453 | 0.361 | -1.484\*\*\* | -1.288\*\*\* |
| id175 | -0.688 | 1.615\*\*\* | 0.114 | 0.333 |
| id176 | -1.666\* | -0.313 | 0.530 | -0.0614 |
| id177 | -2.576\*\*\* | -1.675\*\*\* | -0.245 | 0.187 |
| id178 | -0.823 | 0.510 | 0.213 | 0.0436 |
| id179 | -20.05\*\*\* | -1.071 | -1.386\*\*\* | -1.021\* |
| id180 | -4.457\*\*\* | -2.934\*\*\* | -0.402\*\* | -0.277 |
| id181 | -1.850\*\* | -0.909\*\* | -0.573\* | -0.354 |
| id182 | -4.755\*\*\* | -2.082\*\*\* | 0.387 | 0.409 |
| log-likelihood | -952.2391 | -1519.954 | -3479.969 | -3488.38 |
| AIC | 2292.478 | 3427.908 | 7347.937 | 7364.76 |
| BIC | 3261.657 | 4397.086 | 8317.116 | 8333.939 |
| Observations | 1,092 | 1,092 | 1,092 | 1,092 |
| *a* \*\*\* p<0.01, \*\* p<0.05, \* p<0.1 |  |  |  |  |

**Table A2.** Driving risk scores for four near-miss events after winsorizing and Min-Max scaling on regression coefficients.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| VARIABLES | overspeed | highspeedbrake | harshacceleration | harshdeceleration |
| id1 | 4.824741 | 4.344986 | 2.622834 | 2.52286 |
| id2 | 1.242371 | 4.033808 | 3.753797 | 3.75 |
| id3 | 2.476298 | 1.628204 | 4.413078 | 4.113936 |
| id4 | 2.578824 | 1.749502 | 4.312131 | 4.315106 |
| id5 | 1.133814 | 3.574272 | 1.557084 | 1.542612 |
| id6 | 4.646467 | 4.258833 | 3.576023 | 3.377835 |
| id7 | 4.434299 | 4.244682 | 3.208862 | 3.286394 |
| id8 | 2.244711 | 3.976736 | 2.4531 | 2.636247 |
| id9 | 4.685306 | 4.334427 | 2.398606 | 2.423189 |
| id10 | 4.449618 | 4.107521 | 2.314633 | 2.288771 |
| id11 | 4.580368 | 4.164127 | 2.478113 | 2.27414 |
| id12 | 4.662871 | 4.224932 | 2.692603 | 2.612564 |
| id13 | 4.542011 | 4.219333 | 2.499553 | 2.404901 |
| id14 | 4.441416 | 4.413722 | 2.060925 | 2.1891 |
| id15 | 4.673486 | 4.370957 | 2.542969 | 2.547549 |
| id16 | 2.050515 | 1.186551 | 2.864928 | 2.924287 |
| id17 | 2.12168 | 4.018102 | 2.444167 | 2.612747 |
| id18 | 2.218175 | 4.2198 | 1.618724 | 1.364301 |
| id19 | 4.704364 | 4.404081 | 3.147222 | 3.058705 |
| id20 | 1.835814 | 3.761974 | 2.883688 | 2.607535 |
| id21 | 2.124092 | 3.944234 | 2.910488 | 2.941661 |
| id22 | 4.506067 | 4.309374 | 3.065928 | 3.014813 |
| id23 | 4.729211 | 4.345159 | 2.199393 | 2.148866 |
| id24 | 1.923866 | 1.063697 | 2.328926 | 2.428676 |
| id25 | 2.207319 | 1.317181 | 1.834912 | 1.854426 |
| id26 | 4.494367 | 4.189475 | 2.229766 | 1.912948 |
| id27 | 1.957639 | 1.080804 | 2.581383 | 2.582846 |
| id28 | 2.621041 | 1.695073 | 2.661426 | 2.805413 |
| id29 | 4.687598 | 4.20938 | 3.150795 | 3.094367 |
| id30 | 2.274866 | 1.419818 | 2.42362 | 2.42959 |
| id31 | 4.77565 | 4.246703 | 1.597284 | 1.655084 |
| id32 | 4.432128 | 3.890427 | 2.524567 | 2.653621 |
| id33 | 2.476298 | 1.503794 | 2.464713 | 2.382955 |
| id34 | 4.531518 | 4.10441 | 2.617715 | 2.482718 |
| id35 | 4.362531 | 4.183099 | 2.080579 | 2.018105 |
| id36 | 4.325984 | 3.970049 | 2.368233 | 2.209217 |
| id37 | 0.021711 | 4.153396 | 2.194033 | 2.323519 |
| id38 | 2.317082 | 4.132869 | 1.297123 | 1.497805 |
| id39 | 0.024124 | 5 | 5 | 5 |
| id40 | 4.664922 | 4.280294 | 2.374486 | 2.59519 |
| id41 | 4.53007 | 4.186365 | 2.783634 | 2.664594 |
| id42 | 4.768412 | 4.413722 | 3.165088 | 2.886796 |
| id43 | 4.563723 | 4.379043 | 2.590763 | 2.605157 |
| id44 | 4.527417 | 4.320727 | 2.922994 | 2.950805 |
| id45 | 4.570236 | 4.140489 | 2.716634 | 2.780724 |
| id46 | 4.840663 | 4.270341 | 2.344113 | 2.307974 |
| id47 | 4.468072 | 4.193363 | 1.860818 | 1.923007 |
| id48 | 4.883362 | 4.559747 | 3.363409 | 3.242502 |
| id49 | 1.672979 | 4.100056 | 2.115419 | 2.200073 |
| id50 | 4.51644 | 4.048426 | 2.253886 | 2.22019 |
| id51 | 2.268835 | 1.384051 | 3.62605 | 3.565289 |
| id52 | 2.192845 | 1.124347 | 2.306593 | 1.652341 |
| id53 | 2.260391 | 1.348283 | 2.50402 | 2.705743 |
| id54 | 4.236002 | 4.176723 | 2.010005 | 1.938552 |
| id55 | 4.307288 | 4.075796 | 3.044488 | 2.95812 |
| id56 | 4.527778 | 4.331519 | 2.729141 | 2.867593 |
| id57 | 2.18802 | 4.236128 | 2.721101 | 3.180322 |
| id58 | 4.59834 | 4.237372 | 2.315526 | 2.583211 |
| id59 | 0 | 4.333961 | 1.974272 | 1.986101 |
| id60 | 4.448773 | 3.752022 | 1.987672 | 2.006218 |
| id61 | 4.923769 | 4.512628 | 1.472217 | 1.538954 |
| id62 | 4.768654 | 4.429895 | 2.024299 | 2.090344 |
| id63 | 2.165103 | 1.309405 | 3.86725 | 3.906364 |
| id64 | 4.519697 | 4.079528 | 3.814544 | 3.747257 |
| id65 | 2.171134 | 1.334287 | 0.904949 | 1.345099 |
| id66 | 4.657202 | 4.110164 | 3.073075 | 3.410753 |
| id67 | 1.641618 | 3.816248 | 2.291406 | 2.244879 |
| id68 | 2.459412 | 1.607987 | 1.474004 | 1.004938 |
| id69 | 1.78636 | 1.116571 | 2.096659 | 1.951353 |
| id70 | 2.194051 | 3.770683 | 1.292657 | 1.150329 |
| id71 | 0.937206 | 0 | 3.147222 | 3.631127 |
| id72 | 4.157238 | 4.180455 | 2.161872 | 1.934894 |
| id73 | 4.303307 | 3.899757 | 1.25871 | 1.130212 |
| id74 | 0.979422 | 0 | 2.889941 | 3.222385 |
| id75 | 4.478807 | 4.084194 | 2.384313 | 2.439557 |
| id76 | 2.198876 | 0.898855 | 1.152403 | 0.782736 |
| id77 | 2.366536 | 1.433814 | 3.368769 | 3.189466 |
| id78 | 1.845464 | 3.838019 | 0.07236 | 0 |
| id79 | 4.408728 | 4.24888 | 2.41558 | 2.422275 |
| id80 | 2.130123 | 1.197437 | 2.609523 | 2.569404 |
| id81 | 0.595856 | 4.168947 | 2.318206 | 2.215618 |
| id82 | 4.656961 | 4.260855 | 2.344113 | 2.224762 |
| id83 | 4.641884 | 4.369402 | 2.512953 | 2.301573 |
| id84 | 1.823752 | 4.054802 | 1.952832 | 1.741039 |
| id85 | 2.061371 | 3.747356 | 1.345364 | 1.317666 |
| id86 | 1.21101 | 4.028365 | 1.486511 | 1.50695 |
| id87 | 4.601476 | 4.505785 | 2.797927 | 2.911485 |
| id88 | 2.341206 | 1.475802 | 2.43702 | 2.371982 |
| id89 | 1.641618 | 0.869308 | 3.605503 | 3.560717 |
| id90 | 4.341302 | 4.214201 | 1.754511 | 1.624909 |
| id91 | 2.40634 | 1.387161 | 3.226729 | 3.270849 |
| id92 | 1.571659 | 0.774446 | 3.380382 | 3.129115 |
| id93 | 1.873206 | 1.03415 | 2.363766 | 2.248537 |
| id94 | 4.501001 | 4.184188 | 2.48258 | 2.535571 |
| id95 | 1.736907 | 0.925292 | 2.173486 | 1.910205 |
| id96 | 1.999855 | 1.163225 | 3.850277 | 3.750914 |
| id97 | 2.23868 | 1.320291 | 2.208326 | 2.264996 |
| id98 | 2.526958 | 1.600211 | 1.367697 | 1.711778 |
| id99 | 2.583649 | 1.687298 | 1.038056 | 1.271031 |
| id100 | 4.315007 | 1.200547 | 3.339289 | 3.276335 |
| id101 | 2.014329 | 1.197437 | 3.475969 | 3.267191 |
| id102 | 1.72967 | 0.847537 | 2.650348 | 2.495977 |
| id103 | 2.619835 | 1.71218 | 3.107022 | 3.076993 |
| id104 | 2.34 | 1.460251 | 2.739861 | 2.762436 |
| id105 | 4.411502 | 4.278116 | 2.208326 | 1.67703 |
| id106 | 1.711577 | 0.852202 | 2.906021 | 2.753292 |
| id107 | 2.215762 | 1.324956 | 2.635698 | 2.657279 |
| id108 | 1.917835 | 3.933348 | 2.147579 | 1.942209 |
| id109 | 2.236268 | 1.290744 | 2.312846 | 1.807791 |
| id110 | 2.288134 | 1.175666 | 1.013936 | 1.568215 |
| id111 | 4.414035 | 4.146398 | 2.777381 | 2.703914 |
| id112 | 2.390659 | 1.522456 | 1.324817 | 1.762985 |
| id113 | 1.147082 | 3.878919 | 1.101483 | 1.337783 |
| id114 | 1.90336 | 1.068363 | 3.191889 | 3.013899 |
| id115 | 2.062577 | 1.197437 | 2.606843 | 2.423189 |
| id116 | 2.119268 | 3.761352 | 1.417724 | 1.485004 |
| id117 | 2.253154 | 1.382496 | 2.483473 | 2.273226 |
| id118 | 2.469061 | 4.235351 | 2.726461 | 2.525942 |
| id119 | 2.30502 | 1.421373 | 2.4933 | 2.392099 |
| id120 | 1.435361 | 0.55051 | 2.607647 | 2.644477 |
| id121 | 1.255639 | 4.23815 | 2.836341 | 2.876737 |
| id122 | 2.133742 | 3.953875 | 3.179382 | 3.119971 |
| id123 | 1.987793 | 3.739736 | 3.246382 | 3.333029 |
| id124 | 4.309941 | 3.938791 | 3.246382 | 2.852963 |
| id125 | 4.363014 | 1.066808 | 2.887261 | 3.088881 |
| id126 | 4.58073 | 4.005505 | 3.137395 | 3.015728 |
| id127 | 2.083082 | 1.265862 | 3.657316 | 3.446416 |
| id128 | 2.225412 | 1.262752 | 3.303555 | 3.087966 |
| id129 | 4.638989 | 4.465819 | 2.647847 | 2.673738 |
| id130 | 1.741732 | 0.892635 | 1.21315 | 1.027798 |
| id131 | 4.624635 | 4.282315 | 1.747365 | 1.796818 |
| id132 | 2.42202 | 1.567554 | 1.851885 | 2.125091 |
| id133 | 1.568041 | 3.893381 | 2.067179 | 1.891002 |
| id134 | 0.916701 | 3.937858 | 3.058781 | 3.598208 |
| id135 | 1.906979 | 1.087024 | 3.453636 | 3.757315 |
| id136 | 5 | 5 | 5 | 5 |
| id137 | 1.893711 | 3.954964 | 2.66214 | 3.258047 |
| id138 | 2.485948 | 1.635979 | 1.884045 | 1.709034 |
| id139 | 4.329602 | 4.160394 | 1.799178 | 1.903804 |
| id140 | 4.466504 | 4.249347 | 1.482937 | 1.576445 |
| id141 | 1.759824 | 0.892635 | 1.666071 | 1.517008 |
| id142 | 0.219526 | 4.209225 | 2.6675 | 2.682882 |
| id143 | 0.171278 | 4.283248 | 2.294086 | 2.379298 |
| id144 | 4.754179 | 4.430673 | 2.64615 | 2.675567 |
| id145 | 4.525004 | 4.14702 | 1.952832 | 1.945867 |
| id146 | 1.947989 | 4.150597 | 1.613364 | 1.829737 |
| id147 | 4.480858 | 4.332608 | 1.710738 | 1.703548 |
| id148 | 4.37399 | 4.596448 | 2.579686 | 2.475311 |
| id149 | 4.438521 | 4.160861 | 2.127926 | 2.209217 |
| id150 | 4.388585 | 4.204249 | 1.580311 | 1.695318 |
| id151 | 4.781077 | 4.163505 | 1.145256 | 0.989393 |
| id152 | 0.724917 | 3.761663 | 1.353404 | 1.259144 |
| id153 | 4.631993 | 4.318705 | 0 | 0 |
| id154 | 2.120474 | 3.922618 | 1.101483 | 1.166789 |
| id155 | 4.31356 | 3.965383 | 1.944792 | 1.77853 |
| id156 | 0 | 4.118562 | 2.095766 | 2.130578 |
| id157 | 4.599426 | 4.397394 | 1.950152 | 2.063826 |
| id158 | 2.434082 | 1.548893 | 3.228515 | 3.203182 |
| id159 | 2.434082 | 1.480468 | 3.361622 | 3.176664 |
| id160 | 4.367597 | 4.430518 | 2.755047 | 2.831017 |
| id161 | 2.072226 | 1.250311 | 3.165982 | 2.974579 |
| id162 | 2.325525 | 1.450921 | 3.007861 | 2.683797 |
| id163 | 2.043278 | 1.16478 | 4.270145 | 4.037125 |
| id164 | 4.472173 | 3.947344 | 2.403966 | 2.247623 |
| id165 | 2.233855 | 1.31096 | 3.820797 | 3.846013 |
| id166 | 1.624732 | 3.965694 | 2.481687 | 2.474031 |
| id167 | 4.499554 | 3.703658 | 3.622476 | 3.518654 |
| id168 | 4.133476 | 4.043294 | 2.662766 | 2.533376 |
| id169 | 1.57769 | 0.707577 | 3.045381 | 2.908742 |
| id170 | 2.962391 | 2.184934 | 0 | 1.897403 |
| id171 | 4.384484 | 4.112186 | 2.315526 | 2.23665 |
| id172 | 4.383398 | 4.041584 | 2.241379 | 2.187271 |
| id173 | 4.458543 | 3.800697 | 1.842058 | 1.710863 |
| id174 | 5 | 4.401126 | 1.297123 | 1.345099 |
| id175 | 4.741756 | 4.596137 | 2.724674 | 2.827359 |
| id176 | 4.623791 | 4.296311 | 3.096302 | 2.466715 |
| id177 | 4.514028 | 4.084505 | 2.403966 | 2.693855 |
| id178 | 4.725472 | 4.424297 | 2.813114 | 2.562729 |
| id179 | 2.40634 | 4.178434 | 1.38467 | 1.589247 |
| id180 | 4.287144 | 3.888716 | 2.263713 | 2.269568 |
| id181 | 4.601597 | 4.203627 | 2.110952 | 2.199159 |
| id182 | 4.2512 | 4.021212 | 2.968555 | 2.896854 |

# References

Baecke, Philippe, and Lorenzo Bocca. 2017. “The Value of Vehicle Telematics Data in Insurance Risk Selection Processes.” *Decision Support Systems* 98. Elsevier: 69–79.

Bian, Yiyang, Chen Yang, J Leon Zhao, and Liang Liang. 2018. “Good Drivers Pay Less: A Study of Usage-Based Vehicle Insurance Models.” *Transportation Research Part A: Policy and Practice* 107. Elsevier: 20–34.

Boucher, Jean-Philippe, Ana Maria Pérez-Marín, and Miguel Santolino. 2013. “Pay-as-You-Drive Insurance: The Effect of the Kilometers on the Risk of Accident.” In *Anales Del Instituto de Actuarios Españoles*, 19:135–54. Instituto de Actuarios Españoles.

Burton, Angela, Tapan Parikh, Shannon Mascarenhas, Jue Zhang, Jonathan Voris, N Sertac Artan, and Wenjia Li. 2016. “Driver Identification and Authentication with Active Behavior Modeling.” In *2016 12th International Conference on Network and Service Management (Cnsm)*, 388–93. IEEE.

Carfora, Maria Francesca, Fabio Martinelli, Francesco Mercaldo, Vittoria Nardone, Albina Orlando, Antonella Santone, and Gigliola Vaglini. 2019. “A ‘Pay-How-You-Drive’ Car Insurance Approach Through Cluster Analysis.” *Soft Computing* 23 (9). Springer: 2863–75.

Charlton, Samuel G, Nicola J Starkey, John A Perrone, and Robert B Isler. 2014. “What’s the Risk? A Comparison of Actual and Perceived Driving Risk.” *Transportation Research Part F: Traffic Psychology and Behaviour* 25. Elsevier: 50–64.

Diego, Isaac Martín de, Oscar S Siordia, Raúl Crespo, Cristina Conde, and Enrique Cabello. 2013. “Analysis of Hands Activity for Automatic Driving Risk Detection.” *Transportation Research Part C: Emerging Technologies* 26. Elsevier: 380–95.

Guelman, Leo. 2012. “Gradient Boosting Trees for Auto Insurance Loss Cost Modeling and Prediction.” *Expert Systems with Applications* 39 (3). Elsevier: 3659–67.

Guillen, Montserrat, Jens Perch Nielsen, Mercedes Ayuso, and Ana M Pérez-Marín. 2019. “The Use of Telematics Devices to Improve Automobile Insurance Rates.” *Risk Analysis* 39 (3). Wiley Online Library: 662–72.

Guillen, Montserrat, Jens Perch Nielsen, Ana M Pérez-Marín, and Valandis Elpidorou. 2020. “Can Automobile Insurance Telematics Predict the Risk of Near-Miss Events?” *North American Actuarial Journal* 24 (1). Taylor & Francis: 141–52.

Handel, Peter, Isaac Skog, Johan Wahlstrom, Farid Bonawiede, Richard Welch, Jens Ohlsson, and Martin Ohlsson. 2014. “Insurance Telematics: Opportunities and Challenges with the Smartphone Solution.” *IEEE Intelligent Transportation Systems Magazine* 6 (4). IEEE: 57–70.

Jafarnejad, Sasan, German Castignani, and Thomas Engel. 2017. “Towards a Real-Time Driver Identification Mechanism Based on Driving Sensing Data.” In *2017 Ieee 20th International Conference on Intelligent Transportation Systems (Itsc)*, 1–7. IEEE.

Jiang, Kun, Diange Yang, Shichao Xie, Zhongyang Xiao, Alessandro Corrêa Victorino, and Ali Charara. 2019. “Real-Time Estimation and Prediction of Tire Forces Using Digital Map for Driving Risk Assessment.” *Transportation Research Part C: Emerging Technologies* 107. Elsevier: 463–89.

Jiang, Ying, Junyi Zhang, Yinhai Wang, and Wenyuan Wang. 2020. “Drivers’ Behavioral Responses to Driving Risk Diagnosis and Real-Time Warning Information Provision on Expressways: A Smartphone App–based Driving Experiment.” *Journal of Transportation Safety & Security* 12 (3). Taylor & Francis: 329–57.

Jin, Wen, Yinglu Deng, Hai Jiang, Qianyan Xie, Wei Shen, and Weijian Han. 2018. “Latent Class Analysis of Accident Risks in Usage-Based Insurance: Evidence from Beijing.” *Accident Analysis & Prevention* 115. Elsevier: 79–88.

Joubert, Johan W, Dirk De Beer, and Nico De Koker. 2016. “Combining Accelerometer Data and Contextual Variables to Evaluate the Risk of Driver Behaviour.” *Transportation Research Part F: Traffic Psychology and Behaviour* 41. Elsevier: 80–96.

Liao, Yuan, Minjuan Wang, Lian Duan, and Fang Chen. 2018. “Cross-Regional Driver–vehicle Interaction Design: An Interview Study on Driving Risk Perceptions, Decisions, and Adas Function Preferences.” *IET Intelligent Transport Systems* 12 (8). IET: 801–8.

Litman, Todd. 2007. “Distance-Based Vehicle Insurance Feasibility, Costs and Benefits.” *Victoria* 11.

Lu, Jingyi, Xiaofei Xie, and Ruogu Zhang. 2013. “Focusing on Appraisals: How and Why Anger and Fear Influence Driving Risk Perception.” *Journal of Safety Research* 45. Elsevier: 65–73.

Ma, Yu-Luen, Xiaoyu Zhu, Xianbiao Hu, and Yi-Chang Chiu. 2018. “The Use of Context-Sensitive Insurance Telematics Data in Auto Insurance Rate Making.” *Transportation Research Part A: Policy and Practice* 113. Elsevier: 243–58.

Paefgen, Johannes, Thorsten Staake, and Elgar Fleisch. 2014. “Multivariate Exposure Modeling of Accident Risk: Insights from Pay-as-You-Drive Insurance Data.” *Transportation Research Part A: Policy and Practice* 61. Elsevier: 27–40.

Paefgen, Johannes, Thorsten Staake, and Frédéric Thiesse. 2013. “Evaluation and Aggregation of Pay-as-You-Drive Insurance Rate Factors: A Classification Analysis Approach.” *Decision Support Systems* 56. Elsevier: 192–201.

Peng, Jinshuan, and Yiming Shao. 2018. “Intelligent Method for Identifying Driving Risk Based on V2v Multisource Big Data.” *Complexity* 2018. Hindawi.

Pesantez-Narvaez, Jessica, Montserrat Guillen, and Manuela Alcañiz. 2019. “Predicting Motor Insurance Claims Using Telematics Data—XGBoost Versus Logistic Regression.” *Risks* 7 (2). Multidisciplinary Digital Publishing Institute: 70.

Siordia, Oscar S, Isaac Martín de Diego, Cristina Conde, and Enrique Cabello. 2014. “Subjective Traffic Safety Experts’ Knowledge for Driving-Risk Definition.” *IEEE Transactions on Intelligent Transportation Systems* 15 (4). IEEE: 1823–34.

Sun, Shuai, Jun Bi, and Cong Ding. 2019. “Cleaning and Processing on the Electric Vehicle Telematics Data.” In *INFORMS International Conference on Service Science*, 1–6. Springer.

Sun, Shuai, Jun Bi, Montserrat Guillen, and Ana M Pérez-Marín. 2020. “Assessing Driving Risk Using Internet of Vehicles Data: An Analysis Based on Generalized Linear Models.” *Sensors* 20 (9). Multidisciplinary Digital Publishing Institute: 2712.

Troncoso, Carmela, George Danezis, Eleni Kosta, Josep Balasch, and Bart Preneel. 2010. “Pripayd: Privacy-Friendly Pay-as-You-Drive Insurance.” *IEEE Transactions on Dependable and Secure Computing* 8 (5). IEEE: 742–55.

Tselentis, Dimitrios I, George Yannis, and Eleni I Vlahogianni. 2016. “Innovative Insurance Schemes: Pay as/How You Drive.” *Transportation Research Procedia* 14. Elsevier: 362–71.

———. 2017. “Innovative Motor Insurance Schemes: A Review of Current Practices and Emerging Challenges.” *Accident Analysis & Prevention* 98. Elsevier: 139–48.

Verbelen, Roel, Katrien Antonio, and Gerda Claeskens. 2018. “Unravelling the Predictive Power of Telematics Data in Car Insurance Pricing.” *Journal of the Royal Statistical Society: Series C (Applied Statistics)* 67 (5). Wiley Online Library: 1275–1304.

Wang, Jianqiang, Heye Huang, Yang Li, Hanchu Zhou, Jinxin Liu, and Qing Xu. 2020. “Driving Risk Assessment Based on Naturalistic Driving Study and Driver Attitude Questionnaire Analysis.” *Accident Analysis & Prevention* 145. Elsevier: 105680.

Wang, Jianqiang, Yang Zheng, Xiaofei Li, Chenfei Yu, Kenji Kodaka, and Keqiang Li. 2015. “Driving Risk Assessment Using Near-Crash Database Through Data Mining of Tree-Based Model.” *Accident Analysis & Prevention* 84. Elsevier: 54–64.

Yan, Lixin, Yishi Zhang, Yi He, Song Gao, Dunyao Zhu, Bin Ran, and Qing Wu. 2016. “Hazardous Traffic Event Detection Using Markov Blanket and Sequential Minimal Optimization (Mb-Smo).” *Sensors* 16 (7). Multidisciplinary Digital Publishing Institute: 1084.

Yan, Ying, Youhua Dai, Xiaodong Li, Jinjun Tang, and Zhongyin Guo. 2019. “Driving Risk Assessment Using Driving Behavior Data Under Continuous Tunnel Environment.” *Traffic Injury Prevention* 20 (8). Taylor & Francis: 807–12.