

# Predicting Conflict Severity and Safety Impacts of Automated Vehicles in Simulated Urban Networks

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**Abstract.** This study investigates how conflict severity and Time-To-Collision (TTC) in urban traffic environments are affected by vehicle dynamics and the introduction of automated shuttle services. Microscopic simulation data from five European pilot sites were analysed using two statistical models. A binomial logistic regression was employed to classify conflicts as high or low severity, considering variables such as the maximum change in velocity (MaxDeltaV), the maximum deceleration of the second vehicle, conflict type (rear-end, lane change, or crossing), and the presence of automated vehicles. The results indicate that higher MaxDeltaV increases the probability of severe conflicts, while greater deceleration reduces it. Importantly, automated vehicle deployment is associated with a statistically significant reduction in severity. In parallel, a loglinear regression model was applied to TTC, showing that larger velocity changes shorten TTC, whereas stronger braking and the introduction of AVs extend it. Overall, the findings suggest that automated shuttles enhance traffic safety by lowering the likelihood of severe conflicts and providing additional time for evasive action across the network.

**Keywords:** Automated Vehicles, Conflict severity, Traffic safety, Urban mobility, Microscopic simulation.

## 1 Introduction

Road safety assessment is a foundation of sustainable transport planning, providing the basis for identifying risks and developing strategies to mitigate them. Human error remains the leading cause of road accidents [1, 2], and reducing this factor through automation is considered one of the major opportunities for improving safety. Automated Vehicles (AVs), by reducing direct human involvement in driving tasks, have the potential to minimize errors and enhance overall traffic safety. This potential is particularly critical in public transport services, where safe operations are essential.

The SHOW project is a large-scale EU initiative designed to test and evaluate AV-based mobility services in real-world conditions. A key element of SHOW is its network of pilot sites across Europe, where automated shuttles have been deployed. To complement these real-world deployments, simulation studies have been carried out,

providing an essential supplement to pilot testing. The use of microscopic simulation has become increasingly feasible for safety studies, supported by methods that quantify Surrogate Safety Measures (SSMs) such as Time-to-Collision (TTC) and traffic conflicts are now widely applied. Previous studies demonstrate the value of this approach. [3] found that AVs improve safety at higher penetration levels, even when operating with shorter headways; [4] reported a 35% reduction in conflicts and [5] also confirmed safety improvements. Complementary studies [6, 7, 8, 9] have also highlighted the potential of SSMs in evaluating AV impacts.

The simulation studies within the SHOW project were conducted at the pilot sites of Graz, Trikala, Madrid and Linköping. The Graz site focused on analysing the impacts of AVs in interaction with vulnerable road users and the wider traffic system. In Trikala, the main objective was to assess the effects of automated shuttles operating on a peri-urban route. The Madrid sites pursued two complementary objectives: in Carabanchel, refining simulations to incorporate realistic prevailing traffic data and AV shuttles and in Villaverde, integrating pilot data and exploring the effects of AV shuttles. Finally, the Linköping site investigated improving the realism of shared-space simulations, analysing potential impacts and developing models to integrate charging-related constraints into the simulations.

Microscopic simulations across SHOW pilot sites were conducted using different platforms. Graz, Linköping and Trikala primarily used SUMO, while Madrid simulations were developed in AIMSUN. Despite the use of different simulation platforms, all vehicle trajectory outputs were processed using the Surrogate Safety Assessment Model (SSAM), ensuring a comparable framework for conflict detection across all sites. The SSAM is a tool that analyses vehicle trajectory data to identify potential conflicts based on proximity and relative motion indicators such as TTC.

Together, these sites and simulations provide a comprehensive testing ground for assessing the broader impacts of AV integration across different European traffic environments. Within this framework, an essential aspect is the evaluation of safety. This paper addresses that need by analysing simulated AV operations across several cities, applying SSMs and regression modelling to assess conflict frequency, severity and contributing factors.

## 2 Methodology

Binary logistic regression is commonly applied to estimate the probability of an event, such as the occurrence of a crash (yes/no), as a function of explanatory variables. The dependent variable takes values of 0 or 1. The model is defined as:

$$y = \text{logit}(p) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (1)$$

where  $p$  is the probability of the event occurring,  $\beta_0$  is the intercept,  $\beta_1, \dots, \beta_n$  are the coefficients, and  $X_1, \dots, X_n$  are the predictor variables.

In this study, the method is used to analyze simulation data to investigate how traffic conditions, the presence of AVs and conflict type influence conflict severity (low vs. high).

Loglinear regression, also known as Poisson regression, when applied to count data, is a generalized linear model with a logarithmic link function. It is suitable for modeling non-negative outcomes such as event counts. The model is expressed as:

$$y = \log(p) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (2)$$

where  $p$  the expected count of events,  $\beta_0$  is the intercept,  $\beta_1, \dots, \beta_n$  are the coefficients, and  $X_1, \dots, X_n$  are the predictor variables.

In this study, loglinear regression is applied to simulation data to examine how traffic conditions, AV presence and conflict types influence TTC.

Conflict severity classification was performed only on simulation datasets with disaggregated trajectory data, using the SSAM [10]. SSAM outputs were categorized following [11]: low-severity conflict:  $TTC > 1$  s and high-severity conflict:  $TTC \leq 1$  s.

### 3 Descriptive statistics

#### 3.1 Conflicts per vehicle-kilometre

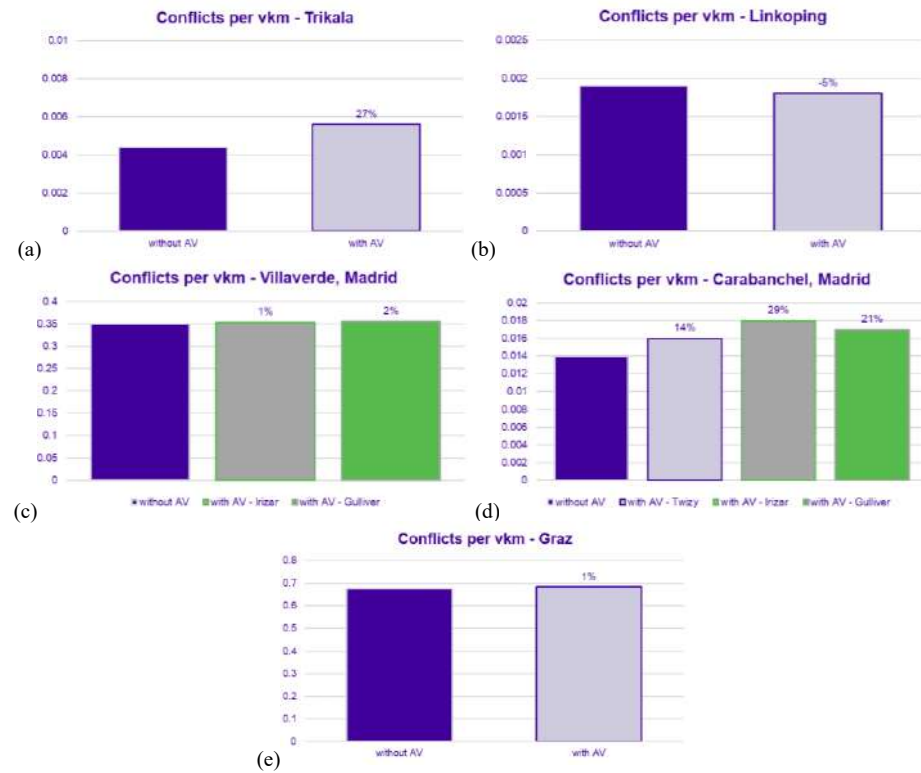


Fig. 1. Conflicts per vehicle-kilometer covered within pilot sites

Conflicts were identified using SSMs derived from SSAM outputs, with rates calculated as total conflicts divided by vehicle-kilometres (vkm). To ensure accuracy, conflicts with  $TTC \leq 0.1$  s were excluded, as these are typically artifacts caused by

simulation or SSAM software limitations [12]-[13]. Fig. 1 (a-e) illustrates the distribution of conflicts per vkm across the pilot sites.

- Trikala: Conflicts increased by 27%, reflecting the challenges of AV operation at low speeds within mixed traffic.
- Linköping: Conflicts decreased by 5%, likely due to the safer and more controlled campus environment, which supports smoother AV integration.
- Madrid sites: Results varied. Villaverde showed a minor 1-2% increase, while Carabanchel experienced larger increases (14-29%), depending on the AV type, suggesting that local traffic composition and operational speeds are key factors.
- Graz: A marginal increase of  $\sim 1\%$  was observed, indicating stable AV integration.

### 3.2 Conflict severity

Fig. 2 presents a histogram of conflict distributions, distinguishing high- and low-severity categories. Low-severity conflicts dominate across all sites, suggesting that most interactions are not critical. High-severity conflicts, while less frequent, remain non-negligible, indicating persistent near-crash risks.

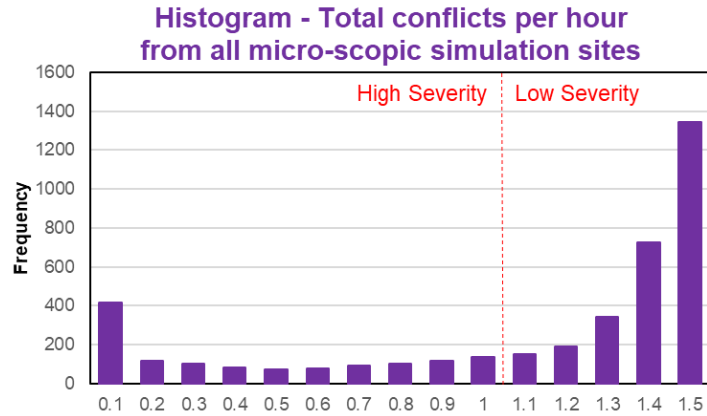


Fig. 2. Histogram for simulation conflicts and their categorization

Table 1 provides aggregated counts of simulated conflicts per vkm under AV operation scenarios. Results show that 67.3% of conflicts were low severity, compared to 32.7% classified as high severity.

Table 1. Simulated low- and high-severity conflicts per vkm

	Low-severity conflicts	High-severity conflicts
Graz, Austria	0.287	0.397
Villaverde, Madrid, Spain	0.251	0.103
Trikala, Greece	0.005	0.000
Linköping, Sweden	0.004	0.000
Carabanchel, Madrid, Spain	0.004	0.013
Proportion of conflicts by severity	67.3%	32.7%

- Graz: Balanced distribution, indicating diverse traffic dynamics with both minor and critical events.
- Villaverde (Madrid): Predominantly low-severity conflicts, suggesting frequent but less critical interactions.
- Trikala: Mostly low-severity conflicts, consistent with increased interactions but limited severity.
- Linköping: Very low conflict counts overall, reflecting the safety advantages of the controlled campus context.
- Carabanchel (Madrid): Few conflicts overall, with most of them low-severity, consistent with its nature as a protected parking depot.

## 4 Results and discussion

### 4.1 Binomial logistic regression for conflict severity

To distinguish between critical and non-critical interactions, a binary logistic regression model was developed with conflict severity as the dependent variable (0 = low severity, 1 = high severity). The explanatory variables included:

- MaxDeltaV is the maximum change in velocity during a conflict,
- MaxD is the maximum deceleration of the second vehicle,
- Scenario is baseline without AV operation (0) versus AV deployment (1),
- Conflict Type is categorized as Crossing (reference), Lane Change, or Rear-End.

The regression was applied to conflict records from all microscopic simulation datasets, covering Graz, Linköping, Trikala, Carabanchel (Madrid), and Villaverde (Madrid). In total, the dataset comprised 62,142 observations. Results for the binary Logistic Regression model appear on Table 2.

**Table 2.** Binomial logistic regression for conflict severity

	Estimate	Std. Error	t value	Pr(> t )	Sig.
(Intercept)	-0.663	0.051	-13.014	<2e-16	***
MaxDeltaV	0.292	0.005	54.697	<2e-16	***
MaxD	-0.026	0.001	-19.54	<2e-16	***
Scenario	-0.099	0.020	-5.051	4.39e-07	***
Conflict Type: Lane Change (Ref: crossing)	-0.270	0.050	-5.43	5.64e-08	***
Conflict Type: Rear End (Ref: crossing)	-0.837	0.046	-18.117	<2e-16	***

*Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1*  
*Null deviance: 78733 on 62141 degrees of freedom*  
*Residual deviance: 68154 on 62136 degrees of freedom*  
*AIC: 68166*

The results indicate that higher MaxDeltaV values significantly increase the probability of high-severity conflicts. This outcome reflects the intuitive expectation that larger velocity changes in a potential collision raise the likelihood of severe consequences, since the relative kinetic energy exchanged during impact is greater. In

contrast, the coefficient for MaxD is negative, showing that stronger deceleration reduces the chance of severe conflicts.

The Scenario variable also carries a negative coefficient, implying that the introduction of AVs decreases the probability of high-severity conflicts. Although the model could not directly isolate the specific involvement of AVs in conflicts due to simulation limitations, the result nevertheless suggests a safety benefit from AV deployment, given that all other network and vehicle conditions were held constant. Finally, the coefficients for Lane Change and Rear-End interactions are both negative compared to Crossing conflicts, which served as the reference category. This means that lane-change and rear-end conflicts are statistically less likely to result in severe outcomes than crossing events. The finding is consistent with expectations, as crossing movements inherently involve higher risk due to intersecting trajectories, whereas in lane-change and rear-end situations, vehicles generally move in the same direction, reducing relative speed differences and the resulting severity.

#### 4.2 Loglinear regression for TTC

To further explore AV impacts on traffic safety, a loglinear regression model was estimated with TTC (in seconds) as the dependent variable. TTC represents the time remaining before a potential crash if trajectories are maintained. Explanatory variables included the same set as in the logistic regression: MaxDeltaV, MaxD, Scenario and Conflict Type. The analysis used conflicts extracted from microscopic simulations across all pilot sites (Graz, Linköping, Trikala, Carabanchel, and Villaverde, Madrid). Results for the Loglinear Regression model appear on Table 3.

**Table 3.** Loglinear regression for TTC during conflicts in sec

	Estimate	Std. Error	t value	Pr(> t )	Sig.
(Intercept)	-0.579	0.018	-31.652	<2e-16	***
MaxDeltaV	-0.063	0.002	-39.379	<2e-16	***
MaxD	0.012	0.000	27.880	<2e-16	***
Scenario	0.013	0.007	1.881	0.0599	
Conflict Type: Lane Change (Ref: crossing)	0.328	0.017	18.791	<2e-16	***
Conflict Type: Rear End (Ref: crossing)	0.681	0.017	41.082	<2e-16	***

*Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1*  
*Residual standard error: 0.792 on 62136 degrees of freedom*  
*Multiple R-squared: 0.1674, Adjusted R-squared: 0.1673*  
*F-statistic: 2498 on 5 and 62136 DF, p-value: < 2.2e-16*

The results show that MaxDeltaV has a negative coefficient, indicating that larger velocity changes are associated with shorter TTC values, making conflicts more critical. Conversely, MaxD has a positive coefficient, suggesting that stronger deceleration leads to longer TTC values. This means that when a vehicle brakes more intensely, it effectively creates more time to avoid a collision, thereby reducing immediate risk.

The coefficient for Scenario is positive, though only marginally significant, indicating a non-statistically significant trend toward increased TTC under AV deployment. As for conflict types, both Lane Change and Rear-End interactions display positive and

significant coefficients compared to Crossing conflicts. This indicates that these types of events generally result in longer TTC values, meaning they allow more reaction time and are less instantly dangerous.

## 5 Conclusions

The integration of AVs into traffic networks reveals several safety implications. Simulations show that the lower operating speeds of AVs increase the frequency of interactions with other road users, which leads to higher conflict rates. However, the majority of these conflicts are of low severity, suggesting that while AVs may generate more frequent close encounters, they rarely escalate into critical situations. Controlled environments such as campuses or depots consistently display fewer and less severe conflicts, emphasizing the role of operating context in shaping outcomes.

The reduction in traffic speeds with AV deployment has mixed effects. On one hand, slower speeds produce more conflicts; on the other, they also lower the potential severity of incidents, reducing the likelihood of serious crashes. Logistic regression analysis confirms that automated shuttles reduce the probability of severe conflicts, while greater speed differentials between vehicles increase severity and higher deceleration mitigates it. Conflict type also matters crossing conflicts are consistently the most hazardous, whereas lane-change and rear-end interactions tend to result in less severe outcomes. The loglinear regression analysis supports these findings, showing that AV deployment extends TTC, giving drivers and systems more time to respond and reducing the immediacy of risk. Greater braking effort further lengthens TTC, while higher velocity differences shorten it, indicating more critical situations.

In summary, the simulations suggest that although AVs may raise the number of interactions within traffic, these are predominantly low severity. Automation contributes to improved safety by reducing the likelihood of severe outcomes and extending reaction times. The overall implications of AV integration depend strongly on network conditions, operational speeds, and traffic environments, with controlled settings offering the most favourable results. These insights can help guide policymakers, transport authorities, and urban planners in designing deployment strategies that maximize the safety benefits of AVs while mitigating their potential drawbacks. However, the analysis is based on aggregated simulation outputs and does not explicitly capture detailed vehicle behaviour parameters, which may influence surrogate safety measures such as TTC and conflict severity.

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