Estimating traffic conflict severity for Connected and Automated vehicles using simulation-based surrogate safety indicators

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ABSTRACT

The evolution of Connected and Automated Vehicles (CAV) will undeniably change the dynamics of traffic flow and affect traffic safety. Even with the promising accompanying reduction in the total volume of conflicts, there is still a need to test the severity of these anticipated conflicts. This study aims to examine the severity of conflicts arising out of CAV, by analyzing the vehicle trajectories resulting from microsimulation scenarios of several sharing percentages (0%, 25%, 50%, 75%, and 100% CAV). Besides time-to-collision severity indicator, two indirect surrogate safety measures (the velocity vector after conflict, Delta-*v*; and the maximum speed in the conflict, MaxS) were used to estimate potential serious conflicts. The results showed that when CAVs fully occupy the road, with shorter reaction times and smoother dynamics, will significantly reduce conflict severity and crash probability, while intermediate scenarios of CAV penetration rates derive different conclusions respect the severity indicators analyzed.

Keywords: CAV, traffic safety, conflict severity, microsimulation

1. INTRODUCTION

The forthcoming introduction of connected and automated vehicles (CAV) on the roads is a reality (NHTSA, 2008; ATKINS, 2016; Rahman et al. 2019). Penetration rates of CAV will not reach 100% immediately, however, penetration will steadily increase. Many studies have shown that increasing the penetration rates of CAV can significantly reduce the potential road conflicts (Papadoulis et al., 2019; Gueriau & Dusparic, 2020; Zhang et al., 2020). As a next step, it is worth investigating how severe these conflicts will be. Due to the lack of real operational data on the CAV, a technique based on microsimulation is used to model several CAV introduction scenarios followed by measuring the conflicts through surrogate safety indicators. For this purpose, researchers usually use the Surrogate Safety Assessment Model (SSAM) developed by the Federal Highway Administration (FHWA). Later, vehicles trajectories from the microsimulation are the inputs to SSAM to measure the potential conflicts and their severity.

FHWA has modeled SSAM to identify many indicators that can be measures of the likelihood of conflict in addition to the severity of that conflict. For instance, time to collision (TTC), post encroachment time (PET), and deceleration rate (DR) calculate how close vehicles are to each other, and thus they could be considered as "closeness" measures that indicate the collision proximity. Meanwhile, the maximum speed (MaxS), or the difference in vehicles speeds (DeltaS) could be considered as measures of "severity" for the resulting conflicts (Gettman & Head, 2003; Saunier et al., 2007; Svensson, 2010).

Since the safety investigation of CAV is a recent topic, most previous studies have concentrated on "closeness" measures. Papadoulis et al. (2019), Gueriau & Dusparic (2020), and Zhang et al. (2020) used the TTC indicator to quantify the resulted conflicts from CAV penetration within several segment types and traffic conditions and compared these amounts of conflicts to the baseline scenario (i.e., the human-driven only scenario). Ye and Yamamoto (2019) proposed three rules of space-time relationship to assess road safety based on the frequency of unsafe situations that occurred during the simulation using 0.5 seconds and 1.1 seconds as TTC thresholds.

Furthermore, Rahman et al. (2019) used derived measures from TTC (e.g., Time Exposed Time-to-Collision, and Time Integrated Time-to-Collision) as indicators of conflict severity besides evasive action indicators (e.g., number of critical jerks) that consider both maneuvering and nearness behavior. As mentioned previously, all of these studies were consistent with the result that CAV penetration will reduce traffic conflict or the possible serious conflicts using the proximity indicators (i.e., TTC, PET) or their derivatives. In contrast, as far as the authors know, there are no studies that explicitly discussed the extent of severity.

This study envisages the severity of traffic conflicts resulting from CAV penetration. In the explanation, proximity measures are considered in addition to vehicle speed and speed vectors to conclude the safety condition after the conflict event, rather than just the intensity of the event for nearby vehicles. Three SSAM indicators (TTC, MaxS, and Delta-*v*) are used to provide an explicit estimation of the severity of conflicts resulting from different CAV penetration scenarios for further comparison.

The paper is structured as follows: The next section shows a description of the motorway segment, modeling of CAV behavior in the microsimulation platform, and the conflict severity indicators used in the study. The third section of the paper presents the conflict severity results obtained from the microsimulation-SSAM method and discusses them. The last section summarizes the conclusions, presents the limitations of this study and suggests future directions for CAV simulation research.

2. METHODOLOGY

This research aims to generate new knowledge about the impact of CAV on the potential conflict severity. Given this objective, several measures have been chosen and will be described in this section.

2.1. Simulated Segment

As a test corridor, a study area of motorway segment (4.57 km of GR-30 Granada, Spain) was built in Aimsun Next platform. Geometry configurations including road alignment, curves, and lanes detailing were specified using Open Street Map and Google map of the segment. The chosen segment presents three lanes, fourteen on and off-ramps, and two major entry points. The next step was to enter the traffic flow parameters. To this purpose, the vehicles' speed and traffic volumes (pc/hr) were attained by General Traffic Directorate (Dirección General de Tráfico (DGT)) detectors in Granada and used for the microsimulation scenarios.

2.2. CAV Calibration

To simulate CAV it is necessary to connect the traffic within a network besides performing their autonomous behavior which is predicted to be different from human driver behavior (for example, CAV is predicted to be with lower reaction times, accepting shorter gaps, cooperate in lane change, etc.). CAV connection network with its elements was conducted on the V2X Aimsun Next extension. The main element in the connection network is channel design. Channels with their radio hardware and protocols perform the communication process between vehicles. Many studies (Teixeira et al., 2014; Mir and Filali, 2014; Ahmadvand et al., 2016; Chen et al.,

2019) have shown the effect of the number of probable CAV in the channel range, CAV speed on the road, and the reliability of the channel on its design. Based on the GR-30 motorway segment traffic data, with an average speed limit of 100 km/h, it would be expected more than 125 connected vehicles in the range of the channel. So, it was chosen the type IEEE 802.11p (250 m range) channel with 2,100 ms latency and 0.75 packet loss.

On the other hand, autonomous behavior was represented by replacing all human driver behavior that can end as a crash cause (i.e., human errors) with a behavior that affects the control, reaction, and cooperation generated by technology. This aforementioned behavior (human or technological) within longitudinal and lateral movements is following traffic flow theory, specifically Gipp's car-following and lane change models (1981; 1986a; 1986b) when operating in Aimsun Next API. Appendix A shows all the parameters proposed to be affected by automation in Gipp's "Car-Following" and "Lane-Changing" models based on previous research and logic. The definitions of the parameters are summarized from the Aimsun user manual. The values in the table are the inputs for the microsimulation models. They are provided as the mean and the standard deviation and follow a normal distribution as suggested by Gipp's model.

2.3. Microsimulation Scenarios

To estimate the traffic conflict severity of CAV, it is suggested to simulate several penetration rates to represent the market CAV introduction scenarios. Five scenarios were considered in traffic microsimulation with different CAV penetration rates (0%, 25%, 50%, 75%, and 100%). Those scenarios were calibrated with real traffic data; between 10:00 and 12:00 (off-peak morning hours) on a normal day. The number of runs for each scenario was determined using the equation of Shahdah et al. (2015) (Equation 1) and 15 replications were considered a sufficient sample (with a 90% confidence level).

$$N = \left(\frac{t_{(1-\alpha/2),N-1} * \sigma}{E} \right)^2 \qquad (1)$$

Where, N equals the required number of simulation runs, σ equals the sample standard deviation of the simulation output, t is the student's t-statistic for two-sided error of a $\alpha/2$ with $N-1$ degree of freedom and E equals the allowed error range, where $E = \varepsilon * \mu$; μ is the mean of the number of simulated conflicts based on the initial set of simulations runs and ε is the allowable error specified as a fraction of the mean For example in 100% CAV scenario we tested a 15 runs trial(with σ = 28.06, t = 2.14 (with α = 0.05 and degree of freedom =14), E = (0.10*305) and it was a sufficient sample. In addition, 50 runs were also considered for each scenario and the results have not changed significantly, indicating that 15 runs is a representative sample.

2.4. Conflict Severity Indicators

Traffic conflict are the evident instances in which two or more road users or vehicles near each other in space and time to the point that there is a risk of collision if their movements do not change. In simulation, traffic conflicts can be determined by modeling the traffic flow tracking with the goal of extracting vehicle pathways over time and evaluate their closeness, so that the closer ones the higher severe conflicts. To assess conflict severity in this study, with 0.2 s time step simulation runs, vehicle trajectories resulted from Aimsun microsimulation are examined to identify the resulting traffic conflicts. The following three SSAM output indicators were used to calculate the severity for each scenario:

- **TTC less than 1.0 s**

Time-to-collision is an important indicator that has been used to assess traffic safety in various studies (Gueriau & Dusparic,2020; Papadoulis et al.,2019; Rahman et al., 2019; Zhang et al., 2020). It is defined as "the time that remains until a collision could occur if two successive vehicles maintain a speed difference" (Hayward, 1972). According to the recommendation of Papadoulis et al. (2019), and after a sensitivity analysis we have done, the proposed threshold of SSAM analysis for time to collision (TTC) was 1.5 seconds. Thus, it is clear that any situation in which TTC is below this threshold is a conflict. After that, based on previous studies (Sayed, 1992; Shelpy, 2011), the conflict is assumed a "serious" conflict if TTC for this conflict is below 1.0 s.

- **Delta-*v* and severity probabilities**

Delta-*v* refers to the change in speed between pre-collision and post-collision trajectories of a vehicle throughout the considered conflict (see Figure 1). The indicator MaxDelta-*v* in SSAM represents the maximum vector magnitude between colliding vehicles.

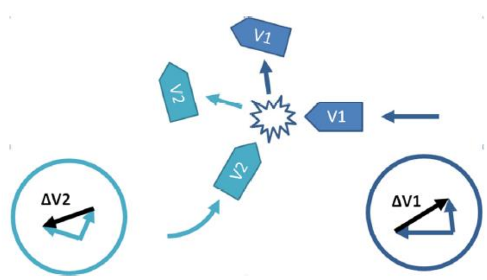

Fig. 1- Illustration of Delta-*v* for two colliding vehicles (Shelpy, 2011)

This proxy (MaxDelta-v) for the conflict's severity is estimated in SSAM based on a hypothetical collision between the two conflicting vehicles. FirstDeltaV and SecondDeltaV are calculated based on the difference between conflict velocity (provided by speed FirstVMinTTC and heading FirstHeading) and post-collision velocity (supplied by speed PostCrashV and heading

PostCrashHeading). Then, the higher value between FirstDeltaV and SecondDeltaV is known as MaxDelta-v, where:

- FirstVMinTTC (SecondVMinTTC): is the speed of the first (second) vehicle at tMinTTC which is the simulation time where the minimum TTC value for this conflict was observed.
- FirstHeading (SecondHeading): is the heading of the first (second) vehicle during the conflict. This heading is approximated by the change in position from the start of the conflict to the end of the conflict.
- PostCrashV: is an estimate of the post collision velocity of both vehicles. This estimate assumes that the vehicles did crash, at the estimated conflict angle, at velocities observed at the tMinTTC, and assuming an inelastic collision between the center of mass of both vehicles, where both vehicles subsequently deflect in the same direction and at the same velocity.
- PostCrashHeading: is the estimated heading of both vehicles following a hypothetical collision.

In the 1970s, researchers developed models to predict the likelihood that an incident would result in injuries or fatalities based on variables such as impact speed and vehicle mass, and began to investigate the use of Delta-*v* to predict injuries and fatalities. It became clear that Delta-*v* was a strong predictor of conflict severity (Carlson, 1979). After multiple improvements to the equations for Delta-*v* severity probabilities, Evan (1994) generalized two models for predicting injury and fatality probabilities based on the assumption of inelastic collision dynamics, and simply used the scalar value of Delta-*v* and using SI units (see Equations 2 and 3). Since conflict severity should be related to the probability of serious injury, these two models were used in this study to predict the probability for injury and fatal conflicts:

$$P_{(\text{jnj.})} = \left(\frac{\text{Delta}-v}{67.4}\right)^{2.62} \qquad (2)$$

$$P_{(\text{fat.})} = \left(\frac{\text{Delta}-v}{69.2}\right)^{4.57} \qquad (3)$$

- **MaxS and TTC diagram**

MaxS is the maximum speed registered in the microsimulation of either vehicle throughout the conflict. For example, if vehicle A has a Speed =100km/h and vehicle B has a speed=105 km/h, MaxS will be 105km/h. Archer (2005) and Svensson and Hyden (2006) discussed the MaxS/TTC severity indicator; the conflict which is closer to collision (low TTC) with higher speed will be a severe conflict. They created a severity hierarchy for traffic events so that an unknown event with a certain position in the severity hierarchy has a certain proximity to a severe conflict (i.e. how imminent the danger was). Figure 2 depicts the structure of the uniform severity zones used in this study following the aforementioned studies, where the bold red curve delineating severe conflicts from non-severe conflicts. Uniform severity zones are bands of equal severity.

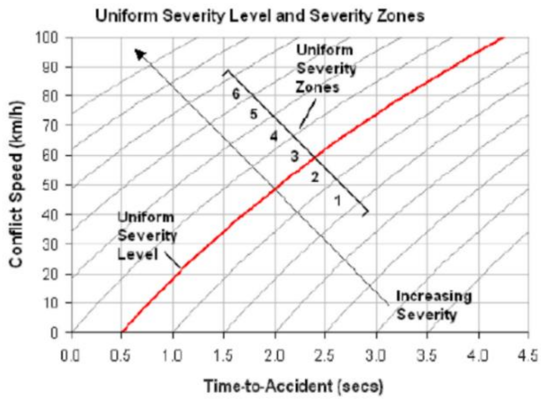

Fig. 2- Uniform severity levels defined by the MaxS/TTC (Archer, 2005)

3. RESULTS AND DISCUSSION

The results are presented for each scenario of CAV penetration rate. Since the number of conflicts resulting from each scenario varies (see Figure 3), the results were standardized by a ratio of each scenario's conflicts to the baseline scenario's conflicts (0% CAV) to obtain comparable results. The effect was measured calculating the percentage of serious conflicts reduction between each scenario and the base scenario (in Tables 1, 2 and 3).

3.1.TTC less than 1 s

To calculate the severe conflicts in this case, from the direct values of TTC in SSAM outputs, a ratio of conflicts with a TTC of less than 1.0 s (filtered out from all TTC resulted values) to the total conflicts was measured and standardized for each scenario.

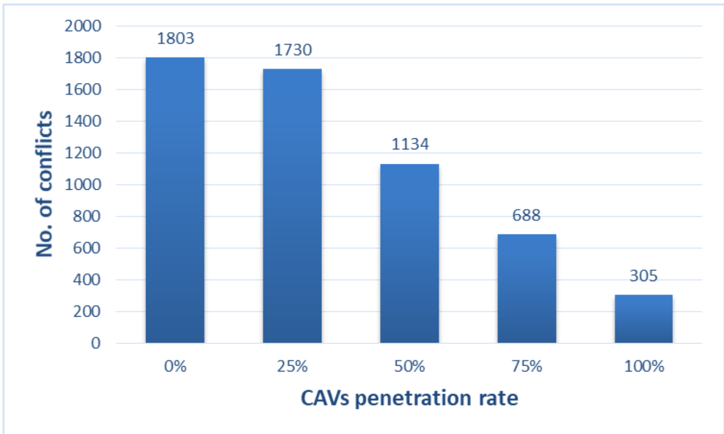

Fig. 3- Number of conflicts resulted by the proposed scenarios

The standardization was done by dividing the number of conflicts with TTC value lower than 1.0s of each scenario by the base scenario total number of conflicts (1,803 conflicts). Table 1 shows that increasing the CAV penetration rate reduces the percentage of severe conflicts (the conflicts with TTC less than 1.0s) compared to the base scenario. A low CAV penetration rate reduces the severe conflicts by more than 20%. High CAV penetration, on the other hand, reduces the severe conflicts by about 75%. Rahman et al. (2019) also showed less severe conflicts measured by their indicators that were derived from TTC (e.g., Time Exposed Time-to-Collision and Time Integrated Time-to-Collision) even with low level of automation.

Table.1: Percentages of conflicts of TTC <1 s

CAV penetration rate	Nº. of total conflicts	Nº. of severe conflicts (TTC<1s)	% of severe conflicts (standardized)	% of change of severe conflicts
0%	1,803	644	35.72	0
25%	1,730	507	28.12	-21.27
50%	1,134	413	22.91	-35.87
75%	688	319	17.69	-50.46
100%	305	162	8.98	-74.84

3.2.Delta-*v* and severity probabilities

Based on Evans (1994) equations (Equations 2 and 3) of the velocity vector (Delta-*v*) resulting from SSAM analysis under the name of MaxDeltaV, probabilities of injury and fatal conflicts were calculated and aggregated as severe conflicts. Then, the standardized ratio of severe conflicts was calculated by dividing the number of severe conflicts at each scenario by the total number of conflicts at the base scenario. Table 2 shows that under the low prevalence of CAV (25%), the likelihood of conflicts with casualties and fatalities decreases. This could be due to the enhancement related to the technology use and reduction in reaction time. The same is in the case of 100% CAV scenario, because of the smooth acceleration and deceleration on the road, the risk during the impact decreases. Meanwhile the effect could be different in the case of 50% and 75% scenarios. The probability of injured and fatal conflicts can be higher although with lower number of total conflicts (Figure 3). The main expected cause of this increasing is the high difference in the reaction time and headways between CAV and HDV that affect the impact (before and after) speeds.

Table.2: Probabilities of injury and fatal conflicts using Delta-*v* indicator

%CAVs	delta-*v* (m/s)	P(inj)	P(fat)	% of severe conflicts (standardized)	% of change of severe conflicts
0%	2.478	0.001437	9.765E-06	0.1447	0
25%	2.388	0.001304	8.246E-06	0.126	-12.95
50%	3.146	0.002686	2.906E-05	0.1708	18.01
75%	4.248	0.005902	0.0001147	0.2296	58.67
100%	4.632	0.007404	0.0001704	0.1281	-11.45

3.3.MaxS /TTC diagram

Following Archer (2005) in terms of Swedish Traffic Conflict Technique, conflicts distribution of TTC and MaxS has been used to determine the serious conflicts, the 0.5s red line delineates the serious conflicts from non-serious conflicts (see Figure 4). Considering all conflicts which their TTC value is below 5.0s, severe conflicts percentage in Table 3 is standardized and it is equal to the number of serious conflicts (above the red line) divided by the total number of conflicts in the base scenario. Table 3 also shows that increasing the CAV percentage generally reduces the volume of severe conflicts. Except in the 25% CAV scenario; the first introduction of CAV will change traffic behavior consistency that increased the number of total conflicts in this case and increased the serious conflicts slightly by about 8%. Whereas the benefits of using the connection and automation technologies started to affect with higher CAV penetration rates due to the higher homogeneity and flow smoothness. Thus, 50% and 75% CAV penetration rates have shown lower serious conflicts than the base scenario by 30.39% and 33.69% respectively. Afterward, when the road is fully occupied by CAV, serious conflicts can be reduced to 40.30% of serious conflicts between HDV.

Table.3: Serious conflicts ratio using MaxS/TTC diagram

CAV penetration rate	**Nº of severe conflicts**	**Nº. of total conflicts**	% of severe conflicts (Standardized)	% of change of severe conflicts
0%	1,392	5,206	26.74	0
25%	1,502	8,597	28.85	7.90
50%	969	5,538	18.61	-30.39
75%	923	3,652	17.73	-33.69
100%	831	2,500	15.96	-40.30

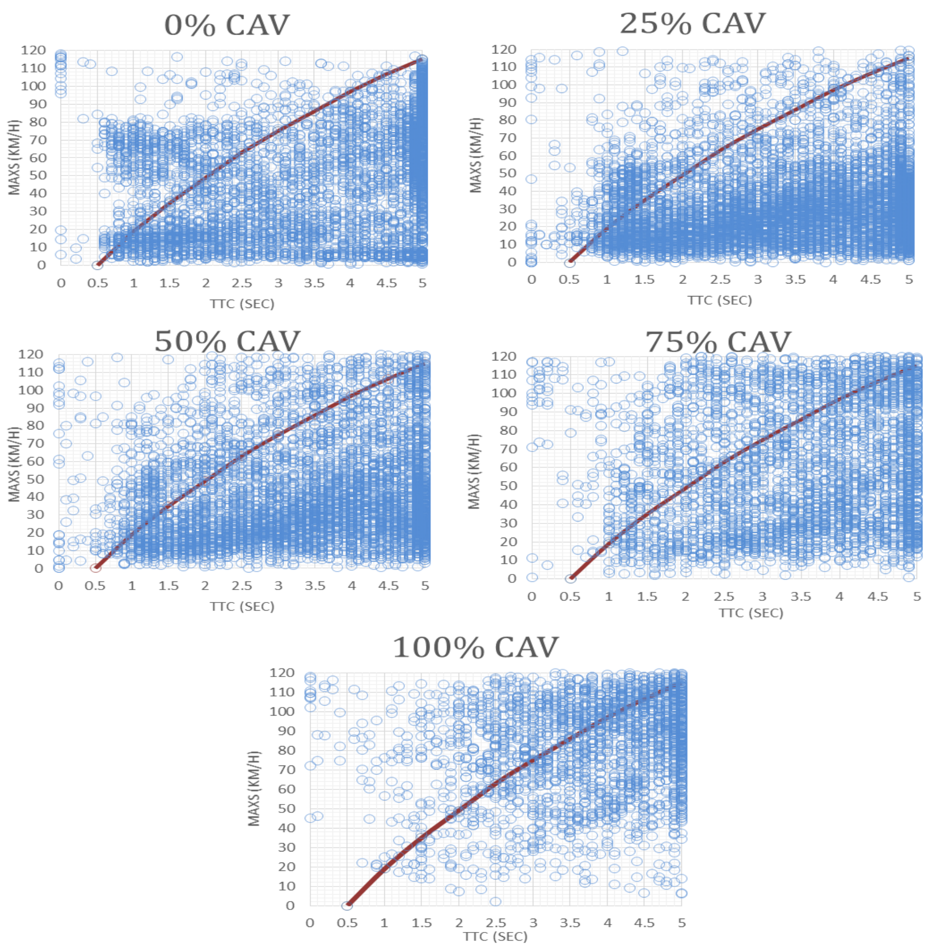

Fig. 4- Severe conflicts using MaxS/TTC diagram

3.4.TTC, Delta-*v*, and MaxS /TTC comparison

Table 4 summarizes the characteristics and the percentage of effect for each indicator used in this study. Most of traffic conflict indicators introduced in recent decades represent the severity of an incident as its proximity to a collision in terms of time or space (Zheng et al., 2014). Accordingly, TTC is the most prevalent indication family used in studying traffic accidents and conflict severity (Laureshyn et al., 2016). However, the early detecting and rating of safety-critical traffic conflict techniques depended mainly on human observer judgments (e.g. Hydén, 1987; Migletz et al., 1985). Thus, TTC point that used to define the potential traffic conflicts (threshold) or that point used to align the serious conflicts had several assumptions and validation. Further assumptions were used also in calibration of TTC values referring to CAV, but in this study the assumption was to keep both HDV and CAV values the same.

As the proximity to a collision is not the unique dimension of "severity". The potential consequences of the conflict should preferably be considered in predicting other dimension of severity (Laureshyn et al., 2017). Consequently, other two measures have been used in this study to estimate the potential conflicts' severity.

Table.4: Comparison of severity indicators

Indicator	TTC	Delta-*v*	MaxS /TTC
Popularity and quality	- Mostly used - The critical points are based on human judgments	- Less used - Clear reflect of severity with probability terms - Represents the kinematics of the conflict - The parameters are based on collisions validation	- Moderately used - Reflect both proximity to collision and the dynamics of the vehicle - Almost the same assumptions of the critical point among several studies
Size of effect on severe conflicts	(-) 21.3-75 %	(-)11.45 – 12.95% (+) 18.01 – 58.67	(-)30.39 – 40.3% (+) 7.9

Delta-*v* is a physics notation that denotes an object's change in velocity as a result of another object impact. Conflicts with greater Delta-*v* values indicate higher forces affecting the road user and likely result more injuries and fatalities (Johnson & Gabler, 2012; Evans, 1994). As Delta-*v* expresses the severity explicitly, its results are someway different than the other two indicators. On the other hand, Delta-*v* equations were validated using HDV behavior so they could have different values for CAV behavior. Furthermore, the validation has been done on data with different context and traffic characteristics (i.e., in the 1990s in USA) that could change the results definitely. But since this indicator was not used for traffic conflicts analysis until it was incorporated in the SSAM recently (Shelpy, 2011) there was not clear effort to develop new equations, thus the classical Evan models were used.

According to the Swedish Traffic Conflict Technique (Gårder, 1982; Hydén, 1987; Shbeeb, 2000; Svensson, 2010), distinguishing the serious conflicts from the rest of conflicts is the way to express the severity because serious conflicts have been found to have a higher likelihood of being an indicator of a breakdown in the interaction, which could correspond to the breakdown in the interaction preceding an accident (Laureshyn et al., 2016). The diagram (MaxS /TTC) chosen for this technique has been used in several studies (e.g., Svensson and Hyden, 2006; Sakshaug et al., 2010) but not with CAV context, but in general it was found to be a good indicator that represents many dimensions of severity. However, this indicator is not mandatory comparable with the other two indicators because its TTC threshold broadened to 5s (instead of 1.5s as in TTC and Delta-*v* indicators) in order to allow MaxS to reach 120 km/h as maximum speed of the motorway section analyzed.

Regarding the size of effect, a closer inspection of the Table 4 shows that there is a difference between the results of these indicators although they show the same tendency of the results that there will be a noticeable reduction of severe conflicts with 100% CAV penetration rate. There is a gradually increase of the effect of both TTC and MaxS /TTC with increasing the penetration rate of CAV. In contrast, the effect of Delta-*v* indicator has different results. The indicator showed a good effect (12.95% reduction) when introducing low penetration rates. Even though, the effect could be inverted with higher penetration rates as Delta-*v* values of CAV are higher. This could represent the reality someway, that even with the decrease of the total potential conflicts due to high technological aspects, the risk due to the behavior variety could still exist.

4. SUMMARY, CONCLUSIONS AND LIMITATIONS

This paper investigates the safety impact of CAV penetration by evaluating the resulting conflict severity with simulation-based surrogate safety indicators. Fully automated and connection features were calibrated in the Aimsun Next platform with its V2X extension and five penetration rates scenarios were simulated. The resulting trajectories were analyzed using SSAM under 1.5s TTC and 5s PET thresholds. Severe conflicts were then defined using three SSAM indicators: TTC, Delta-*v*, and MaxS/TTC. The percentage of severe conflicts reduction was calculated between each scenario and the human-driven scenario to determine the effect of CAV penetration.

Severe conflicts defined by a TTC of less than 1.0s or by the MaxS/TTC diagram showed a similar result, which can reach up to 75% and 40% respectively reduction of severe conflicts when the road is entirely driven by CAV. Meanwhile, the probability of conflicts with injuries and fatalities using Delta-*v* indicator showed a different effect of CAV penetration that could duplicate the conflicts with injuries or fatalities with high penetration rates of CAV.

Although this study is a contribution to the traffic safety evaluation of CAV, it has some limitations that should be considered in further research. First, the TTC threshold for CAV has not yet been defined and could be different from the HDV value, so a further assessment will be done in a next work. A sensitivity analysis could be also applied for some critical parameters of CAV behavior. In addition, active and passive vehicles in conflicts are not defined while it is important to identify the CAV behavior within the collision, so distinguishing the vehicle type that causes the severity in the resulting conflicts is a priority. Using Delta-*v*'s equations for severity probabilities is also a limitation as they were calibrated using HDV crashes, certainly the multiplier and power would be changed for CAV. Moreover, Delta-*v*'s equations need further research in order to be updated across different geographical contexts and considering recent changes on traffic characteristics. However, all three measures provide a clear indication of the reduction in severity resulting from the CAV penetration regardless to the level of uncertainty because of the lack of real data.

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APPENDIX A:

Gipp's models parameters affected by the type of driver:

Parameters	**Definition**	**Hints work**	**HDV**	**dev**	**CAV**	**dev**
Main parameters						
Speed acceptance	How much vehicles could take a speed greater than speed limit	Atkin (2016), Stanek et al. (2017), Ye and Yamamoto (2019).	1.1	0.1	1	0.05
Clearance (m)	Distance that vehicle keeps with the preceding one when stopped	Atkin (2016), Stanek et al. (2017).	1	0.3	0.2	0.2
Max give-way time (sec)	Give-way time at a Yield or stop junction or an on-ramp	Atkin (2016)	10	2.5	7.4	0.5
Guidance acceptance (%)	The probability that a vehicle will follow the recommendations	Stanek et al. (2017)	70	10	100	0
Reaction time (sec)	The time to react in general	Zhang et al., (2020)	0.8	-	0.6	-
Reaction time at stop	The time to react at stop	Zhang et al., (2020)	1.2	-	1	-
Reaction time at traffic light	The time to react at traffic light	-	1.6	-	1.45	-
Max acceleration (m/s^2)	The highest value that the vehicle can achieve under any circumstances	Atkin (2016), Stanek et al. (2017), Karjanto et al. (2017)	3.28	0.2	3.72	0.15

Normal deceleration. (m/s²)	The maximum deceleration that the vehicle can use under normal conditions	Atkin (2016), Naujoks et al. (2016), Karjanto et al. (2017) Zhang et al., (2020)	3.27	0.25	4.12	0.18
Max deceleration (m/s²)	The most severe braking can be applied under special circumstances	Atkin (2016), Naujoks et al. (2016), Karjanto et al. (2017) Zhang et al., (2020)	5.39	0.5	6.2	0.3
Car-following model						
Sensitivity factor	How much the vehicle could be sensitive to the deceleration of the leader	-	1	0	1.5	0.5
Gap (sec.)	How much override the headway calculated by car following model	Karjanto et al. (2017)	0	0	0.6	0.1
Headway aggressiveness	How much vehicles could enter with shorter gaps without forcing the rear vehicle to brake	Stanek et al. (2017)	0.8	0.2	0	0
Lane-changing model						
Overtake speed threshold	The threshold that delaminates an overtaking maneuver	Stanek et al. (2017)	90	-	95	-
Percentage staying in overtaking lane	The probability that a vehicle will stay in the faster lane instead of recovering to the slower lane after an overtake maneuvers	Naujoks et al. (2016)	40	-	20	-
Imprudent lane change	Defines whether a vehicle will still change lane after assessing an unsafe gap	Naujoks et al. (2016)	Ticked	-	Non ticke d	-
Cooperate in creating a gap	Vehicles can cooperate in creating a gap for a lane changing vehicle	Stanek et al. (2017)	non ticked	-	ticke d	-
Aggressiveness Level	The higher the level, the smaller the gap the vehicle will accept, being a level of 1 is the vehicle's own length	Stanek et al. (2017)	0-1	-	0-0.75	-
Distance Zone Factor	To modify the distance zones used in the Lane Changing Model to adjust where lane changes start to be considered and, if a range is given, to randomize behavior	Talebpour and Mahmassani (2016) Stanek et al. (2017),	0.8-1.2	-	0.6-1.5	-