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Crash Severity and Rate Evaluation of Conventional Vehicles in Mixed Fleets with Connected and Automated Vehicles

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Abstract

Connected and Automated Vehicle (CAV) technology, although in the development stage, is quickly expanding its market but a full market penetration might not be rapid. The safety concern is the paramount challenge to widespread adoption of this disruptive technology. During the transition period, fleets will be composed of a combination of CAVs and conventional vehicles, and therefore it is germane to investigate the repercussions of CAVs on traffic safety at different penetration. Since crash severity and frequency in conjunction reflect the traffic safety, this study attempts to investigate the effect of CAVs on both crash severity and frequency. PTV VISSM microsimulation platform is used to simulate M1 Geelong Ring Road network (Princes Freeway) in Victoria, Australia, which is the testbed for this study. Network performance is evaluated using performance metrics (Total System Travel Time, Delay and instantaneous speed profiles). Surrogate safety measures (time to collision, post encroachment time, etc.) are examined to inspect the safety in the network. The results showed that CAVs would not inevitably decrease the crash severity and crash rate involving manual vehicles, despite the improvement in network performance, given the demand and the set of parameters used in our operational CAV algorithm are intact. Additionally, the study identifies that the safety benefits of CAVs are not proportional to CAV penetration, and a full-scale benefits CAVs can only be achieved at 100% CAV penetration. The results presented in this study provide an insight into the repercussion of CAVs on comprehensive traffic safety to the insurance companies and other industry participants, enabling safety-related services and more enterprising business models.

Keywords: Crash Rate; Crash Severity; Connected Automated Vehicles

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1. Introduction

Connected and Automated Vehicles (CAVs) have the potential to revolutionise the transport sector, by decreasing accidents, improving safety, alleviating congestion and improving road capacity. The introduction of CAVs into existing infrastructure is complicated because of the driving behaviour of human drivers. As a result, the penetration of CAVs in existing infrastructure will be long-drawn and scrutinising the network at different CAV penetration is requisite. Due to the diffusion of CAVs in automobile fleets, driving and its auxiliary industries, specifically the actuarial organisations, may become much less consumer-facing in the future. Unequivocally, it is a chief concern of actuarial organisations to anticipate not only the crash frequency but crash severity in a CAV deployed environment. Literature indicates the reduction of crash frequency in CAV deployed environment, but the aftermath of a crash is an unexplored theme. The overarching goal of this paper is the thorough investigation of the effect of CAVs on network safety. This study considered the potential crashes as well as actual collisions with a principal focus on gauging the crash severity. Assessment of network safety is accomplished using the following two steps. The first step is to scrutinise the network performance. The second step employs surrogate safety measures (SSM) to evaluate the frequency of potential and actual crashes and their corresponding severity. For modelling CAVs, the external driver model plugin of VISSIM is used, similar to the previous study[1].

Relevant literature is examined and discussed in section 2, followed by an outline of the simulation framework and testbed employed for the study. Subsequently, a run-through of the methodology followed by an intricate description of analysis and results are presented. Lastly, we present the conclusion in section 6.

2. Literature Review

For our study, we will be using microsimulation platforms approach for generating artificial data. Researchers use microsimulation platforms for traffic safety investigation on the grounds of data quality and modelling fidelity. Microsimulation studies, including CAVs, indirectly institute simulation of the vehicle sensor system and communication; these simplifications have a trivial effect on network-or corridor level results [2]. Furthermore, few studies deployed micro-simulation platforms in association with SSAM, safety evaluation platform provisioned by Federal Highway Administration (FHWA), to assess the network – or – corridor level safety. Safety in the traffic system is usually gauged by the frequency and severity of traffic crashes. Various micro-simulation studies exhibit that CAVs can predominately reduce the crash frequency [3-7], although the repercussion of CAVs on crash severity is arguable.

To better understand the safety impacts of CAVs, we utilise surrogate safety measures to investigate the crash severity. It is worth mentioning that there are two interpretations of the term severity since it is necessary to differentiate between the severity of the conflict and the severity of the resulting crash [8]. In the context of vehicle crashes, severity is the magnitude of adverse consequences which can be categorised as fatality, injury and property damage. In the case of traffic conflicts, nearness or proximity is used to express severity. In the case of a crash (conflict event resulting in a collision), the magnitude of Maximum speed of either vehicle throughout the conflict (MaxS) and Difference in vehicle speeds as observed at tMinTTC (DeltaS) are ideal indicators of severity. Higher MaxS and DeltaS values are indicators of higher severity. In the context of traffic conflicts, the magnitude of post encroachment time (PET) and time-to-collision (TTC are ideal indicators of the conflict severity, in other words, the probability of a collision as a sequel of conflict [8], Lower PET and TTC indicate a higher probability of a collision utilised these SSM to investigate the effect of CAVs on network safety at different penetration. Discussion is presented in section 5.3 and 5.4.

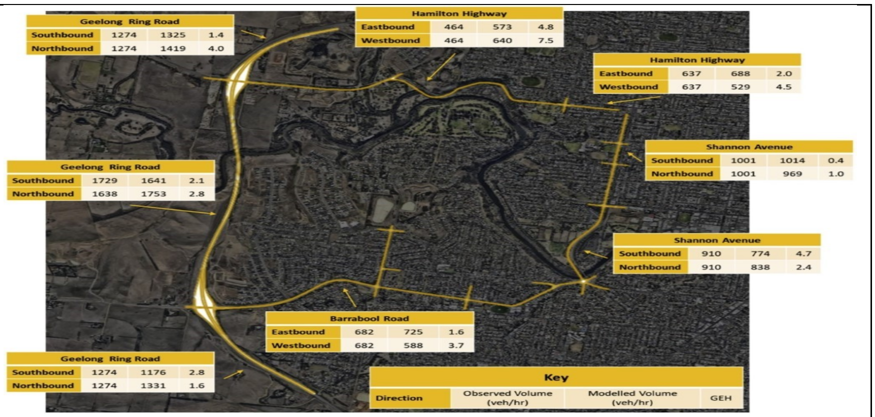
3. Simulation Testbed, Microsimulation Model and Analysis Tools

M1 Geelong Ring Road (Princes Freeway) in Victoria, Australia was utilised as a testbed for this study. The motorway consists of two lanes in each direction and can be accessed through a third tapered lane. The network contains one conventional four-way, one diverging diamond interchange (DDI), and an onramp and an offramp signalised intersection. Four roundabouts and seven give-away priority junctions are present in the network.

Additionally, DDI has been artificially appended to the network because of its increased popularity and safer impression. Network data (geometry and speed limits) is obtained from Google Maps, Bing Maps and OpenStreetMaps. Roads and Maritime Services traffic signal guidelines are used for phasing configuration of the traffic signals. The traffic data contains link volumes and 24-hour traffic profile data. Public platforms [9] provide link volume as annual average daily traffic (AADT). The peak-hour AM flow is obtained from AADT using “Typical Hourly Traffic Volume” Additionally, the typical hourly traffic volume is also employed to obtain AADT to the peak-hour volume conversion factor. This data was used to develop a calibrated origin-destination matrix for the base traffic model scenario.

Method	GEH
Sum of total volumes on links	1.05
Weight average of the GEH on individual links against the observed volume	2.65
Weighted average of the GEH on individual links against the measured volume	2.69

(a)



(b)

Fig. 1. (a) Network scale calibration results (GEH statistics); (b) Study area and GEH statistics for links in the network

Simulations were conducted in PTV VISSIM [12]. The simulator controls non-CAV driving behaviour, communicates with CAV driving behaviour algorithm, generate, store and forward real-time data. There is a total of 11 scenarios with 10% CAV penetration rate increments. 0% is designated as the base case with fully non-CAV fleet and 100% case is designated as fully CAV fleet. Each scenario uses three random seeds for modelling the variation. For the comparison of field volumes with simulation volumes, Geoffrey E. Heavers (GEH) static is utilised. Calibration is performed using RMS guidelines[10]. Default Wiedemann 74 and Wiedemann 99 models (psycho-physical perception models) are used for controlling non-CAV driving behaviour, for urban settings and freeway settings, respectively. Wiedemann-99 adds less stochastic noise and is simpler when compared to Wiedmann-74 model, but the latter facilitates cooperative lane changes with greater ease. For CAV driving behaviour, a CAV control algorithm was developed using the PTV VISSIM application programming interface and integrated with the micro simulator using a dynamic linking library. The non-CAVs standstill at a distance of 2 meters and drive with a significantly higher headway, whereas CAVs use a headway of 0.5 meters. It is worth mentioning that the CAV control algorithm is flexible and can accommodate different values of headways. A detailed and comprehensive explanation of external CAV control algorithm can be found in this study [1]. Microsimulation software is incompetent of directly identifying crashes or estimate network safety. Therefore, surrogate safety assessment is a prevalent technique adopted to assess network safety in the transportation research community. For our study we will be employing the Surrogate Safety Assessment Model (SSAM) provisioned by the Federal Highway Administration (FHWA), US Department of Transportation to extract surrogate measures including time-to-collision (TTC), post-encroachment time (PET), relative speed during at T_{ttc}. A comprehensive description of SSAM can be found on the FHWA website [13].

4. Methodology

The underlying theme of investigation is to inspect the effect of CAVs on network safety, prospecting both crash frequency and severity. Traffic network is simulated, using the micro simulator in conjunction with the CAV control algorithm, for each scenario to extract vehicle trajectory data, vehicle record file and network performance metrics. Trajectory files are processed using SSAM to extract surrogate safety metrics of potential collisions. It is worth noting that the potential collisions (traffic conflicts) are not an accurate indicator of crashes, since it depends on the threshold values, given by the analyst, to flag it as a potential collision. Threshold values for TTC, PET, rear-end angle and crossing angle is 1.5 seconds, 5 seconds, 30º and 80º respectively. The threshold values are recommended by the United States Federal Highway Administration and also used in previous studies [1, 11]. It is necessary to note that these threshold values are calibrated for manual vehicles only. Traffic conflicts can be declared as a collision if the PET value is equal to 0 [12]. We deployed DeltaS of the collision (PET = 0) for indicating collision severity, after examining the two interpretations of the term severity as discussed in section 2.

5. Results

In the following section, we present the results of the analysis, with the overarching theme of investigation the effect of CAVs on network safety. Network performance is presented in section 5.1, followed by crash rates and crash severity results and discussion.

5.1. Network Performance

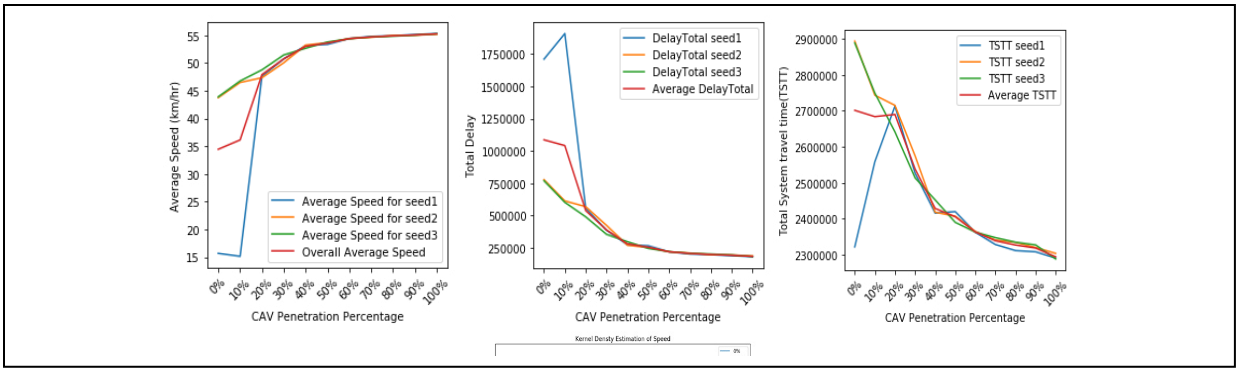


Fig. 2. Network Performance

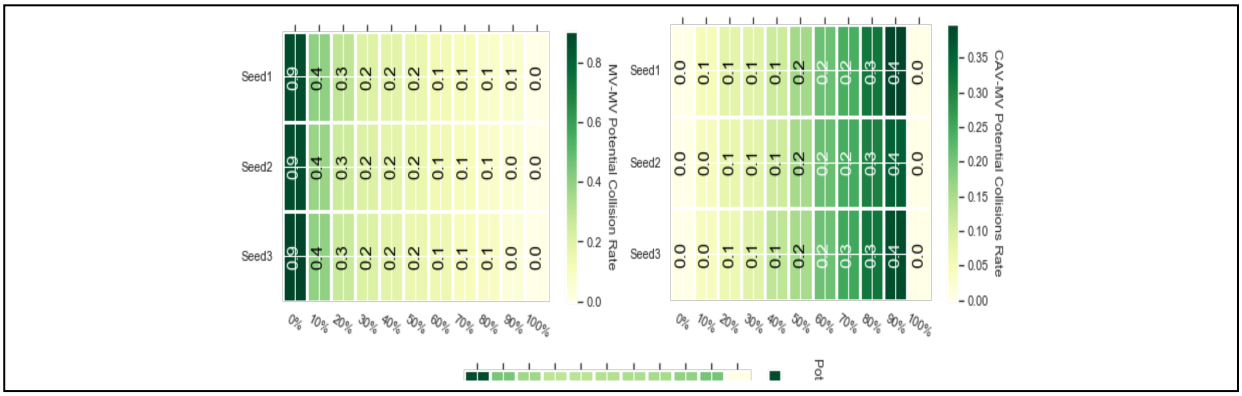


Fig. 3. (a) MV-MV crash rate; (b) CAV-MV crash rate; (c) Total (MV-MV + CAV-MV) crash rate

Figure 2 (a), (b), (c) exhibits the variation of average speed, total system travel time and total delay with different CAV penetration rates. It is evident from the figure that the network performance improves as the penetration increases. This result is similar to previous studies. Figure 2 (d) exhibit that with increasing penetration of CAVs, driving behaviour is becoming robust and synchronised and consequently resulting in efficient network performance.

Uniformity of the fleet is disrupted because of the variation of the fundamental behaviour of vehicle classes (CAV and MV). This results in high variability in the network performance metrics. This variation is diminished with higher CAV penetration due to the re-establishment of synchronised behaviour.

5.2. Crash Rates

Next step of this study is to investigate the network safety. Therefore, we extracted the surrogate safety measures from the simulation model and utilised these metrics to evaluate the safety of the network. A detailed discussion is presented in the following subsections.

There are four car-following (and crash) scenarios in a mixed fleet environment; manual vehicles followed by manual vehicles (MV-MV), manual vehicles followed by CAV (MV-CAV), CAV followed by manual vehicles (CAV-MV) and, CAV followed by CAV (CAV-CAV). Currently, there are no universally acceptable thresholds of surrogate safety measures for CAVs in the literature. However, the SSM for manual vehicles are validated and calibrated and have been used in several past studies. Therefore, in this study, we scrutinise only the MV-MV and CAV-MV potential collisions. The penetration of CAVs varies in each scenario, and hence the magnitude of the interaction of CAVs and manual vehicles also varies. Therefore, we use crash rates and not crash frequency, which is functional in fixed demands or throughputs. For our study, crash rates are defined as the number of potential collision/ collisions normalised by the throughput of manual vehicles corresponding to each scenario. Lastly, it is important to mention that the terminology used in this study. Potential collision is the sum of actual collisions (PET=0) and conflicts ($0<PET<1.5$).

Figure3(a) and figure3(b) shows the potential collision rate for MV-MV and CAV-MV scenario, respectively. The heatmap exhibits that the rate of MV-MV potential collisions is decreasing with increasing CAV penetration. Additionally, the rate of CAV-MV potential collisions is increasing with increasing CAV penetration. Figure 3(c) represents the combined crash rate of MV-MV and CAV-MV cases. The results depict that there is a decrement in the crash rate from 0% CAV to 60% CAV scenario and then started increasing from 60% CAV penetration scenario, given that the parameters used in the study are intact. Inevitably, the crash rate drops to zero at 100% CAV scenario since there are no more manual vehicles in the network. The extant of diverse human driving behaviour in a synchronised CAVs environment is resulting in the increment in crash rates. That is to say that human drivers may not be able to adapt to the robust and synchronised driving behaviour of CAVs.

5.3. The severity of a conflict

In this section, we discuss the repercussion of CAVs on conflict severity. As discussed in section 2, the magnitude of PET and TTC are ideal indicators of traffic conflict severity [8]. Lower TTC and lower PET values indicate a higher probability of a collision. We will be utilising this information to investigate the conflict severity.

Figure 4(a), (b), (c) and figure 5(a), (b), (c) presents the non-parametric distribution of PET values for the three seeds and 10 cases of MV-MV and CAV-MV conflicts respectively. Seed1 PET distribution of 0% and 90% CAV penetration for MV-MV and CAV-MV conflicts are presented separately in 4(d) and 5(d) respectively. Figure 4(e), (f), (g) and 5(e), (f), (g) shows the non-parametric distribution of TTC values for the three seeds and 10 cases of MV-MV and CAV-MV conflicts respectively. Seed1 TTC distribution of 0% and 90% CAV penetration for MV-MV and CAV-MV conflicts are presented separately in the same figure 4(h) and 5(h) respectively. The distributions of TTC and PET delineate that the probability of lower magnitude of PET and TTC is higher at 90% CAV penetration in comparison to 0% CAV penetration. Consequently, the probability of a collision as a sequel of conflict is higher in 90% CAV scenario due to the lower magnitude of PET and TTC values. Altogether, we can conclude that the TTC and PET depict that the increment in potential collision severity from 0% to 90% CAV penetration, even though the crash rate is decreasing in MV-MV scenarios. In case of CAV-MV interactions, the severity is increasing with higher

CAV penetration (10% to 90% penetration) along with minimum crash rate first decreasing and then increasing and finally diminishing to zero in 100% CAV scenario. In other words, we can infer that manual drivers will experience higher exposure to critical events in a CAV deployed mixed fleet. This does not imply that actual collisions will be more since they are merely potential collisions. This attenuates the proposition that the full-scale benefits of CAVs can only be achieved at 100% CAV penetration. It is worth noting that the most critical TTC and PET distribution is not occurring at 90% CAV penetration. For instance, the critical case in seed1 PET distribution of MV-MV instance

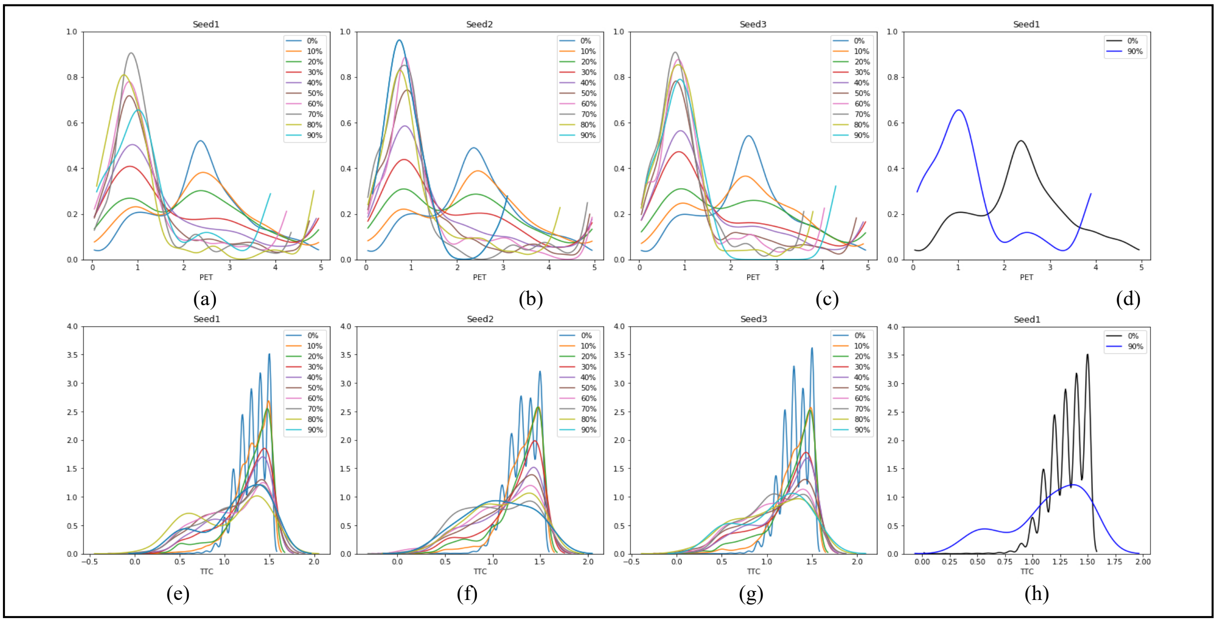


Fig. 4. (a) MV-MV conflict PET distribution seed1; (b) MV-MV conflict PET distribution seed2; (c) MV-MV conflict PET distribution seed3; (d) 0% and 90% penetration PET distribution seed1 for MV-MV conflict; (e) MV-MV collision TTC distribution seed1; (f) MV-MV crash TTC distribution seed2; (g) MV-MV conflict TTC distribution seed3; (h) 0% and 90% penetration TTC distribution seed1 for MV-MV conflicts

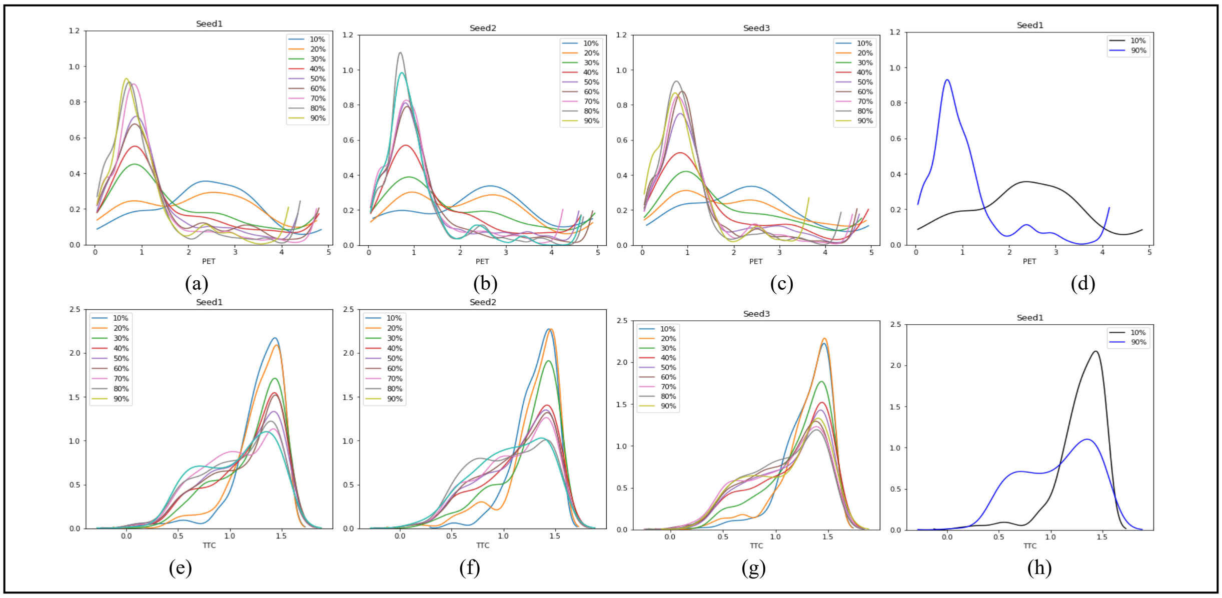


Fig. 5. (a) CAV-MV conflict PET distribution seed1; (b) CAV-MV conflict PET distribution seed2; (c) CAV-MV conflict PET distribution seed3; (d) 0% and 90% penetration PET distribution seed1 for CAV-MV conflict; (e) CAV-MV conflict TTC distribution seed1; (f) CAV-MV conflict TTC distribution seed2; (g) CAV-MV conflict TTC distribution seed3; (h) 0% and 90% penetration TTC distribution seed1 for CAV-MV crash

is occurring at 90% CAV penetration. This can be explained by inefficient adoption of human drivers in accordance with synchronised and efficient CAVs. This is congruous with the proposition in section 5, which provide a possible explanation of increment in crash rates in CAV-MV interaction.

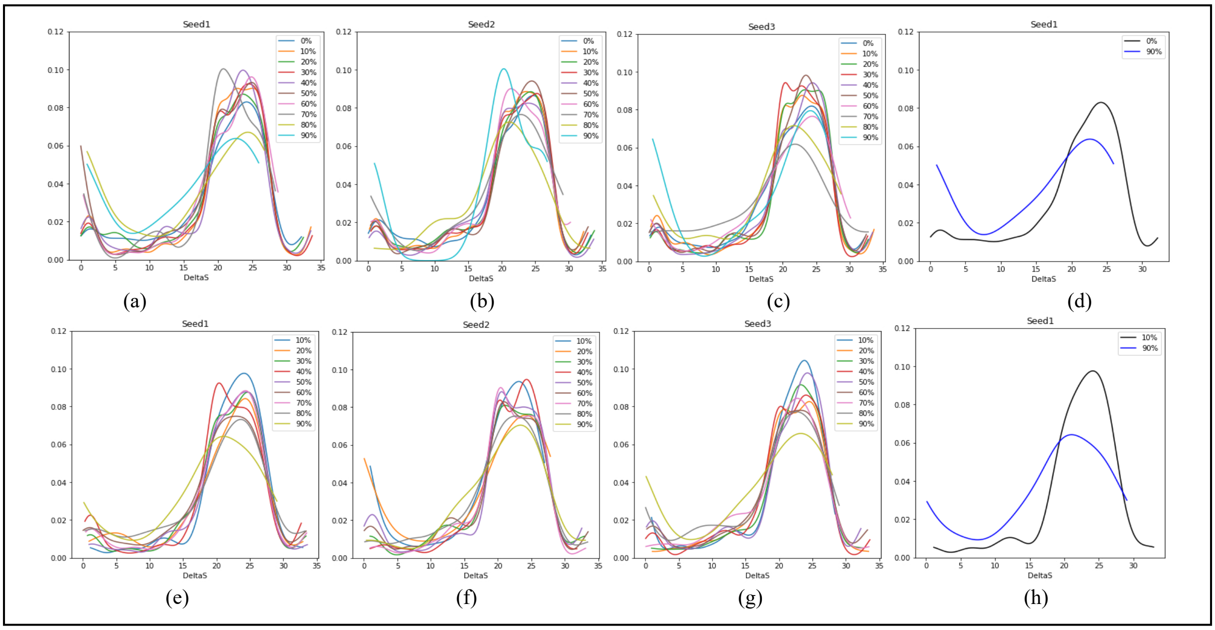


Fig. 6. (a) MV-MV collision DeltaS distribution seed1; (b) MV-MV collision DeltaS distribution seed2; (c) MV-MV collision DeltaS distribution seed3; (d) 0% and 90% penetration DeltaS distribution seed1 for MV-MV collision; (e) CAV-MV collision DeltaS distribution seed1; (f) CAV-MV collision DeltaS distribution seed2; (g) CAV-MV collision DeltaS distribution seed3; (h) 0% and 90% penetration DeltaS distribution seed1 for CAV-MV collision

5.4. The severity of a collision

As discussed in section 2, DeltaS is not coherent in anticipating crash severity of collisions. Instead, DeltaS should be used for severity analysis of collisions (conflicts with PET=0). The non-parametric distribution of DeltaS for collisions in MV-MV and CAV-MV scenarios for three seeds is presented in figure 6 (a), (b), (c) and figure 6 (e), (f), (g) respectively. The distributions in figure 6 (d) and 6 (h) delineate that it is likely to have a lower DeltaS value in 90% penetration in comparison to 0% in MV_MV and 10% penetration in CAV-MV scenario. Lower DeltaS indicates that the lower crash severity, given that the conflict has resulted in a collision. This translates that the introduction of CAVs will reduce the severity of MV-MV as well as CAV-MV collision.

6. Conclusion and Closing Remarks

This study presents predominantly four conclusions. First, network performance is invariably improving with CAV penetration for all the different CAV operational behaviour. The instantaneous kinematic variable distribution depicts that the CAVs are introducing synchronisation and robustness in the network, making it efficient and well-ordered. Secondly, the crash rates involving conventional vehicles (MV-MV and CAV-MV) will not invariably reduce with increment in CAV penetration. The possible explanation of the preceding statement is extant of diverse human driving behaviour in a synchronised CAV environment. Human drivers cannot adopt with the efficient, robust and synchronised operational behaviour of CAVs. Third, PET and TTC distribution depicts that the conventional vehicles will experience higher exposure to critical events in the CAV deployed environment. Fourth, the DeltaS distribution translates that there will be a reduction in the severity of both MV-MV and CAV-MV collision, given that the conflict resulted in an actual collision. Lastly, this study identifies that network safety will not invariably improve with increased CAV penetration and a full-scale benefit of CAVs can only be achieved at cent per cent CAV penetration.

For our study, we have only considered MV-MV and CAV-MV crashes due to unavailability of a suitable tool to flag the critical MV-CAV and CAV-CAV events which is a limitation of this study. Additionally, human visibility related crashes are significantly affected by average speed, and nearest downstream of crash location and the coefficient of variation in speed observed at nearest upstream. Since human visibility related crashes are irrelevant in CAVs, use of speed distribution in our study may underestimate the safety benefits. Nevertheless, if human visibility related crashes are absent in CAVs, new crash types like perception error collisions may arise. Lastly, the network-level analysis is efficacious, albeit there is the inconsistency of CAV's operational characteristics among various studies. Also, the operational characteristics of simulated CAVs are different from real CAVs, and as a result, these studies fail to comprehend unprecedented crash causes. Additionally, CAV penetration will amplify with time, and consequently improving CAV operational characteristics (more trained CAV 'brain'), but these studies, including this study, are incongruous with this postulation.

References

[1] N. Virdi, H. Grzybowska, S.T. Waller, V. Dixit,(2019) "A safety assessment of mixed fleets with Connected and Autonomous Vehicles using the Surrogate Safety Assessment Module", Accident Analysis & Prevention, 131 95-111.

[2] D. Stanek, R.T. Milam, E. Huang, Y.A. Wang, Measuring autonomous vehicle impacts on congested networks using simulation, in, 2018.

[3] A. Papadoulis, M. Quddus, M. Imprialou,(2019) "Evaluating the safety impact of connected and autonomous vehicles on motorways", Accident Analysis & Prevention, 124 12-22.

[4] M.S. Rahman, M. Abdel-Aty, J. Lee, M.H. Rahman,(2019) "Safety benefits of arterials' crash risk under-connected and automated vehicles", Transportation Research Part C: Emerging Technologies, 100 354-371.

[5] L. Ye, T. Yamamoto,(2019) "Evaluating the impact of connected and autonomous vehicles on traffic safety", Physica A: Statistical Mechanics and its Applications, 526 121009.

[6] S. Hallerbach, Y. Xia, U. Eberle, F. Koester,(2018) "Simulation-based identification of critical scenarios for cooperative and automated vehicles", SAE International Journal of Connected and Automated Vehicles, 1 93-106.

[7] H. Yang, Z. Wang, K. Xie,(2017) "Impact of connected vehicles on mitigating secondary crash risk", International journal of transportation science and technology, 6 196-207.

[8] D. Gettman, L. Head,(2003) "Surrogate safety measures from traffic simulation models", Transportation Research Record, 1840 104-115.

[9] VicRoads open data platform,2017 https://vicroadsopendata-vicroadsmaps.opendata.arcgis.com/

[10] Traffic Modelling Guidelines - Roads and Maritime Services, Transport, New South Wales, in, February 2013.

[11] F. Huang, P. Liu, H. Yu, W. Wang,(2013) "Identifying if VISSIM simulation model and SSAM provide reasonable estimates for field measured traffic conflicts at signalised intersections", Accident Analysis & Prevention, 50 1014-1024.

[12] PTV VISSIM 10 User Manual, 2018, http://vision-traffic.ptvgroup.com/

[13] Surrogate Safety Assessment Model (SSAM)–SOFTWARE USER MANUAL, 2008, https://www.fhwa.dot.gov/publications/research/safety/08050/