Safety Performance of Autonomous Vehicles on an Urban Arterial in Proximity of a Driveway

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ABSTRACT
Urban traffic network has been growing as an integral part of cities. Urban arterials, as the backbone of the urban traffic network, are characterized by closely spaces driveways and carry a high traffic volume per day. The literature consistently reported that there is a positive relationship between driveway density and crash rate. Therefore, managing driveways, which usually work as three-legged unsignalized intersections, located along urban arterials is crucial, especially under high traffic demand, to improve both safety and operation. However, due to the cost and space limitation, conventional methods are impractical and, therefore, new solutions should be implemented. Autonomous Vehicles (AVs), as a multidisciplinary technology, have been the focus as a replacement for human-driven vehicles to improve both traffic safety and operation. In this study, the effect of AVs on the safety of an urban arterial in the proximity of an unsignalized intersection was evaluated. A microsimulation model was used to develop an urban network with an unsignalized access point under various traffic congestion levels for both conventional vehicles and AVs. Afterward, the frequency and distribution of the conflicts for conventional vehicles and AVs were compared. The results indicated that AVs can enhance safety significantly compared to the conventional vehicles in proximity of an access point, especially under congested traffic situations. However, providing an exclusive lane on the arterial for the driveway vehicles to merge to the arterial promotes safety and operation of the network.

INTRODUCTION
Transportation systems, as an integral part of cities, have experienced several transformations and growths over time. The growth of urban areas leads to significant traffic congestion, more conflicts, delay, air pollution, and fuel consumption (*1*). The growth of cities and traffic congestion contributes to roadway crashes, injuries, and fatalities. Based on World Health Organization (WHO), nearly 1.25 million people died, and up to 50 million people were injured in roadway crashes in 2013 for the entire world, which makes the roadway safety a major concern (*2*). In general, traffic congestion resulted in $160 billion loss in the United States in 2014 (*3*). The number of fatalities for the U.S. roadways was 37,461 in 2016 (*4*).

While traditional countermeasures are not capable of reducing roadway crashes significantly, there is a need to acquire an innovative solution to decrease traffic congestion to improve safety, traffic delay, air pollution, fuel consumption, and noise level. As about 94% of the U.S. crashes involve human errors including fatigue, alcohol, or drug, eliminating or reducing the effect of the human factor can reduce the risk of roadway collisions ((*5*) (*1*) (*6*)).

During the past few decades, the integration of the sensing technology and wireless communication in the traffic systems promotes autonomous vehicle technology (*7*). Autonomous vehicles, also known as automated or self-driving cars, can navigate themselves through various types of roadways and environments without any interference of human control. Therefore, autonomous vehicles (AVs) can address important issues in transportation, including (*8*) (*5*):

- Improving roadway safety by eliminating the human element;
- Providing mobility for everyone, including disabled people and all age groups who are not capable of driving;
- Saving time by reallocating commute time to another task;
- Shortening travel time;
- Reducing parking cost;

- Increasing roadway capacity by reducing the headway/gap due to the improved safety features; and
- Saving fuel and decreasing emission.

Automated vehicles have the potential to improve roadway safety in addition to the traffic operation by gradually reducing and restraining the leading cause of roadway crashes that is human errors and human-driven vehicles (*9*).

Due to the lack of real-world data, the exact safety and operational impacts of AVs cannot be confirmed or quantified accurately (*10*). In addition, there are concerns associated with AVs such as overreliance on vehicle automation and loss of drivers' awareness that can cause critical issues in case of complex traffic situations (*11*). Therefore, it is crucial to evaluate the safety impacts of the AVs even though it is challenging due to the unavailability of the real-world data.

Urban arterials are a fundamental element of the transportation system as they connect urban activity centers and carry high traffic volumes daily. Urban arterials are characterized by high traffic demands and closely spaced signalized and unsignalized intersections, including driveways, to provide access to the adjacent land-uses. This operational scheme leads to more traffic congestion, conflicts, and operational and safety concerns (*12*). While vehicle to infrastructure (V2X) communications offers several benefits that may improve the operational characteristics of such arterial locations, they may suffer from compliance issues that may limit these benefits. AVs, on the other hand, have the potential to overcome the driver compliance issue and eliminate drivers' judgment from the equation. Thus, the focus of this study is to evaluate the operational benefits of AVs in urban arterials near unsignalized intersections. In doing so, a simulation model is developed to assess the performance of fully automated systems compared to conventional vehicle environments in different levels of service.

LITERATURE REVIEW

AVs have been developed to limit the human factor and behavior from driving in order to improve the operation and safety of roadways. AVs are assumed to benefit the operational and safety performance of the roadway network, but the true safety benefits that can be gained through implementing the AVs is unknown. Besides the advantages associated with AVs, they are also subject to uncertainties such as unaffordable initial cost and state-level licensing that lead to security concerns, inconsistencies, and undefined liability details. Moreover, the interaction between AVs and other transportation system components, especially in a mixed traffic environment, remains undefined (*8*). The following section focuses on the safety impacts of AVs.

Influence of Vehicle Automation on Traffic Safety

Drivers' distraction, misjudgment, and fatigue lead to 10-30% of the fatal crashes. By implementing AVs, the perception-reaction time (PRT), and as a result the fatal and severe crashes, will be minimized to improve safety (*13*). However, after implementing AVs, other types of crashes may be expected due to the software and hardware hacking and glitches of the AVs. During a course of testing autonomous vehicles, 2,700 disengagements were detected, which means that AVs could still be involved in motor vehicle crash (*13*). Bad weather, poor pavement marking, construction zones, and potholes were such situations in which the humans took over the control of the vehicles (*14*).

Implementing partially automated crash avoidance features, including lane departure warning, blind-spot monitoring, and forward-collision warning indicated a reduction in the crash frequency and severity due to the diminished impact of human errors. The results of the cost-benefit analysis of crash avoidance features within the U.S. light-duty vehicle fleet revealed that the frequency and severity of the crashes could be reduced or even prevented by 1.3 million events per year (*15*).

Studies have indicated that the evolution of technologies and implementation of AVs improve the operation of the roadways as well as reduce in the number and severity of crashes. However, the transition period to reach a fully autonomous vehicle fleet is expected to take a lot of time and remains a challenge (*14*) (*15*).

Analyzing the real-world data from testing AVs in California indicated that the AVs were not at fault in any of the AV involved crashes. The rear-end crashes were the most common collision type with AVs being rear-ended 1.5 times more than regular vehicles. Besides, the overall severity of the AV crashes was lower than the conventional vehicle crashes (*16*). Notably, even AVs reduce the total number of crashes, they also may cause new types of crashes.

The semi and fully autonomous vehicles are growing by implementing the Advanced Driver Assistance System (ADAS). This advancement develops a mixed traffic condition in which equipped and unequipped vehicles use the same infrastructure (*17*). California PATH (*18*) evaluated and indicated that by implementing platoons using Cooperative Adaptive Cruise Control (CACC), the time gap could be reduced to 0.6-1.5 sec. This reduction in the gap can improve roadway capacity; however, it may endanger the safety of the regular vehicles at the same time. Gouy et al. (*17*) evaluated the effect of autonomous vehicles Time Headway (THW) on the THW of human-driven vehicles and indicated that in the mixed traffic environment, conventional vehicles spent most of the time to adjust their THW to the AVs THW, which is below the safety threshold. Therefore, the mixed traffic environment may threat regular vehicles safety.

A few studies implemented micro-simulation models to analyze the safety and operational impacts of AVs on traffic (*19*) (*11*). Morando et al. (*5*) evaluated the safety impacts of a signalized intersection and a roundabout under various AV penetration rates using a micro-simulation software. The results indicated that AVs improve traffic safety significantly under higher Market Penetration Rates (MPRs). Papadoulis et al. (*10*) proved the safety benefits of implementing Connected and Automated Vehicles (CAVs) on motorways, even at a low MPR. Another study by Saunier (*20*) considered two different approaches, including vehicle safety-based maneuvering (VSM) and traffic safety-based maneuvering (TSM) to evaluate the effect of an optimization process using a micro-simulation model. The optimization minimizes the overall crash risk by focusing on vehicle maneuvering control parameters on a freeway traffic stream under different MPRs of Automated Driving Systems (ADS). The results suggested significant reductions in the rear-end crash risk for both VSM and TSM (*20*). Fagnant and Kockelman (*8*) estimated that at 90% AV MPR, a saving of 4.2 million dollars due to the crash reductions and 21,700 dollars due to the fatality reductions could be obtained per year.

The purpose of this study is to evaluate the safety impacts of autonomous vehicles in proximity of an unsignlized intersection under various MPRs.

Surrogate Safety Measures and Surrogate Safety Assessment Model

The traditional way of analyzing roadways safety is through tracking the historical crash data. However, due to the infrequency and random nature of the crashes, it needs more time to observe enough number of crashes to be able to perform safety analysis (*21*). Surrogate safety measures can be used as a substitute for crashes to detect the potential crash-prone locations before encountering any fatalities and injuries (*22*) (*23*) (*24*). Time-to-collision (TTC), gap time (GT), deceleration rate (DR), jerk, the proportion of stopping distance (PSD), and post-encroachment time (PET) are such surrogate safety measures that have been used in previous research (*5*) (*25*) (*22*) (*26*) (*27*).

TTC is an indicator of the crash risk and is defined as the required time to collide if two vehicles continue moving on the same path with the same speed (*28*). **Equation 1** mathematically defines TTC.

$$\text{TTC} = \begin{cases} \dfrac{d_2}{v_2} & \text{if } \dfrac{d_1}{v_1} < \dfrac{d_2}{v_2} < \dfrac{d_1 + l_1 + w_2}{v_1} \text{ (side)} \\ \dfrac{d_1}{v_1} & \text{if } \dfrac{d_2}{v_2} < \dfrac{d_1}{v_1} < \dfrac{d_2 + l_2 + w_1}{v_2} \text{ (side)} \\ \dfrac{X_1 - X_2 - l_1}{v_2 - v_1} & \text{if } v_2 > v_1 \text{ (read-end)} \\ \dfrac{X_1 - X_2}{v_2 + v_1} & \text{(head-on)} \end{cases} \quad (1)$$

Where:
v_1 and v_2: vehicle speeds;
l_1 and l_2: vehicle lengths;
w_1 and w_2: vehicles widths;
X_1 and X_2: vehicle positions; and
d_1 and d_2: distance to conflict areas.

In general, lower TTC associated with a higher crash risk (*29*). Several studies evaluated the value of TTC at which any value smaller than the defined TTC represents a critical and unsafe situation (*29*). Archer (*30*) determined 1.5 seconds as the critical TTC value for urban areas (*31*); however, Horst introduced a higher value, 2.5 seconds. TTC threshold for the AVs is known to be 1.5 seconds due to the ability of the AVs to react to different situations more quickly (*5*).

METHODOLOGY

The purpose of this research is to evaluate the safety impact of AVs on urban arterials in the proximity of a driveway under various traffic levels of service (LOS). In fact, a driveway is assumed to work as a three-legged semi-controlled unsignalized intersection in which the driveway vehicles should give the right of way to the arterial traffic. Also, the LOS was considered as a boundary for various levels of traffic congestion to assess how AVs affect traffic safety under different congestion levels compared to conventional vehicles.

VISSIM (*32*) was used, as a micro-simulation software, to develop a three-lane urban arterial with an access point perpendicular to it that has two lanes for entering and exiting traffics, as shown in FIGURE 1.

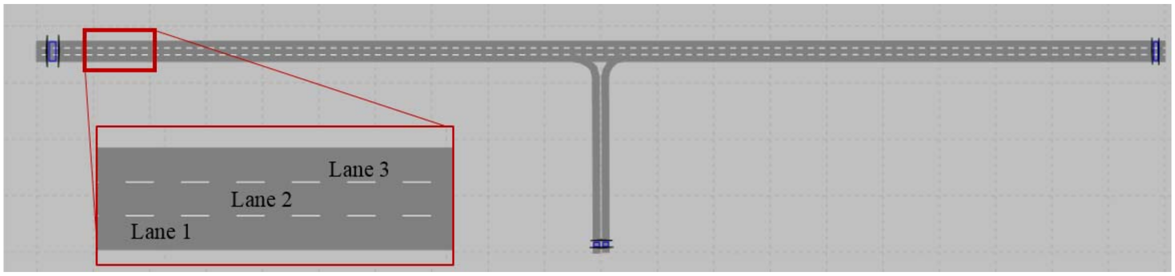

FIGURE 1 Simulated Roadway Network

The impact of AVs on the safety was investigated and compared to the conventional vehicles under four levels of traffic congestion including LOS A, LOS B, LOS C, and LOS D. **TABLE 1** represents traffic volumes associated with each LOS. The traffic volume of the arterial was changed according to **TABLE 1** for each scenario, however, the volume of the driveway remained constant at 240 pc/hr/ln across all the scenarios to represent the maximum number of vehicles that could merge to the arterial from the most congested scenario, which was the conventional vehicle environment under LOS D.

Two different AV MPR of 0%, representing a fully conventional vehicle environment, and 100%, representing a fully AV environment, were evaluated. Each scenario was run for ten times, and each time for 60 minutes to capture the stochastic nature of the simulation models. Also, the first five minutes were considered as a warm-up period and excluded from further analysis.

Eventually, the evaluation results for the simulation runs were stored for every 50 ft. segment length and 0.1 seconds time interval. This short time interval was selected to be capable of capturing vehicles movements with adequate details.

TABLE 1 Traffic Volume for Multilane Highways for Different LOS

LOS	Maximum Service Flow Rate (pcphpl)	Input Volume for Driveway (pcphpl)
A	600	240
B	1,000	240
C	1,400	240
D	1,670	240

RESULTS AND DISCUSSION

SSAM was used to determine the number of conflicts, as a surrogate safety measure, for each scenario using the associated critical TTC for each vehicle type, 1.5 seconds for conventional vehicles and 1.0 sec for AVs. The following sections describe the results of each LOS, separately.

FIGURE 2 depicts the aggregated distribution of the conflicts across all the 10 runs of each vehicle type for LOS A. Based on the figure, no conflict was observed for the AV environment under LOS A; however, in the conventional vehicle environment there is a risk of getting involved in a conflict especially when the driveway vehicles approach the merging points to the arterial.

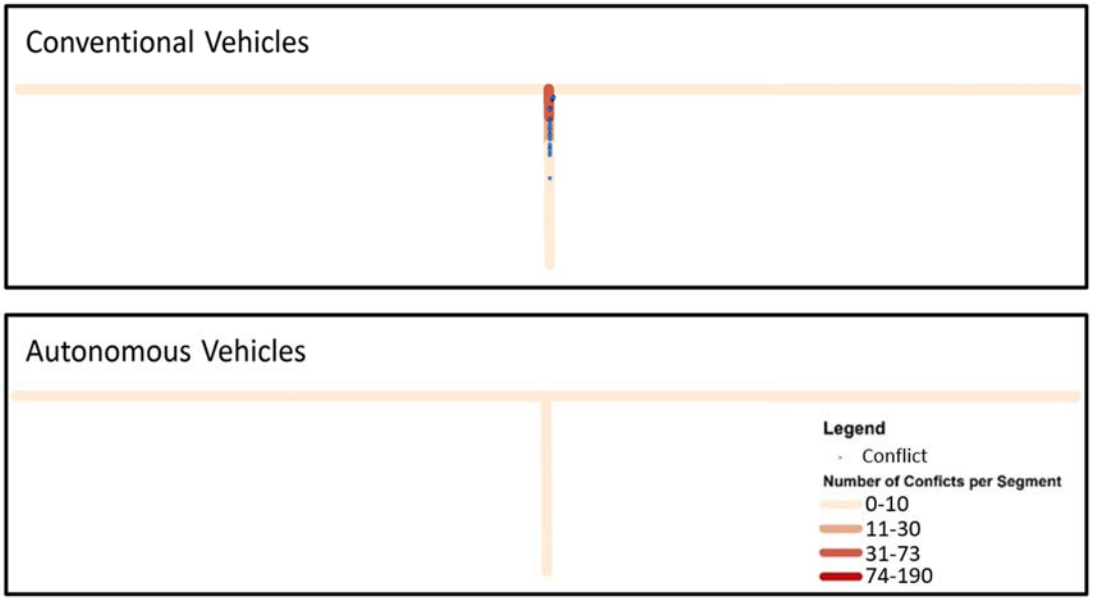

FIGURE 2 Distribution of the Conflicts for Conventional Vehicle vs. AV Environments for LOS A.

To evaluate the per lane distribution of the conflicts, the roadway network was split into arterial lane 1, arterial lane 2, arterial lane 3, entering driveway lane (for vehicles to enter to the arterial), and exiting driveway lane (for vehicles to exit from the arterial). **TABLE 2** represents the per lane distribution of the conflicts for the conventional vehicle vs. AV environments.

TABLE 2 Distribution of Conflicts per Lane for LOS A

Lane	Percent Conflict per Lane-Conventional Vehicle	Percent Conflict per Lane-AV
Arterial 1	0%	0%
Arterial 2	0%	0%
Arterial 3	0%	0%
Entering Driveway Lane	100%	0%
Exiting Driveway Lane	0%	0%

As depicted in **FIGURE 2**, **TABLE 2** also indicates that 100% of the conflicts for the conventional vehicle environment occurred on the entering driveway lane.

A paired t-test was also conducted to statistically compare the overall performance of the conventional vehicle and AV environments. **TABLE 3** represents the results of the paired t-test and indicates that there is no statistically significant difference between the mean value of the conflicts in the conventional vehicle and AV environments at a 5% confidence level under LOS A.

TABLE 3 Statistical Comparison of Conventional Vehicle and AV Environments for LOS A

Variable	Value
df	46
t Stat	-1.40
P(T<=t) one-tail	0.084
t Critical one-tail	1.678
P(T<=t) two-tail	0.168
t Critical two-tail	2.013

Increasing the traffic demand for the network to represent LOS B resulted in **FIGURE 3**. The figure depicts that the conflicts are more concentrated on the driveway segments for both vehicle types, however, comparing the heat-maps illustrate that AVs are associated with a fewer number of conflicts and can provide a safer environment than the conventional vehicles.

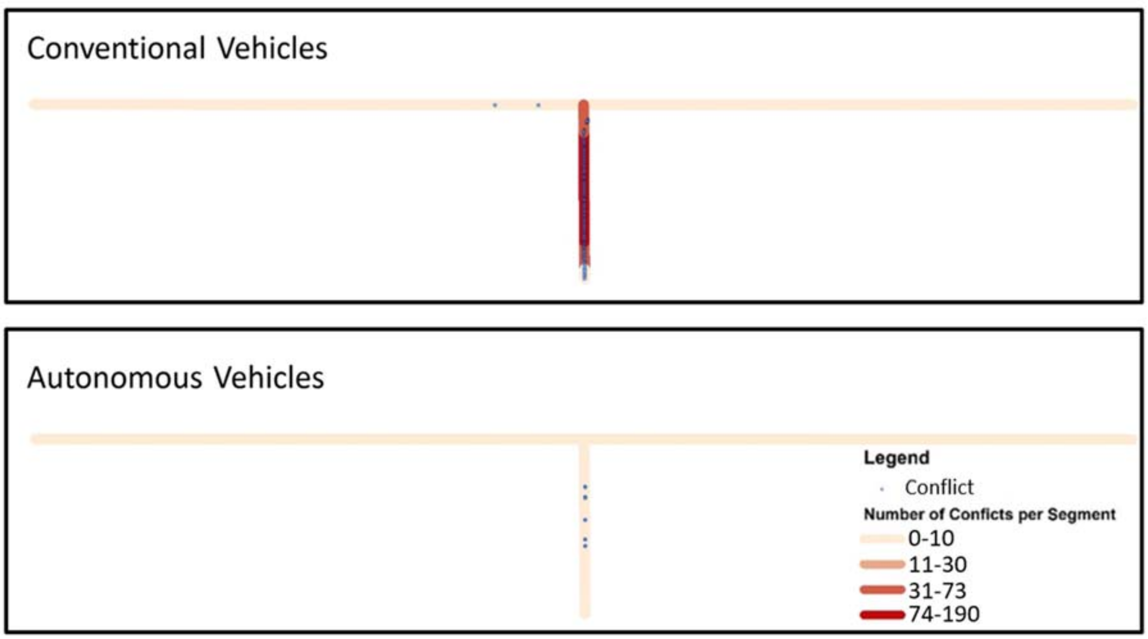

FIGURE 3 Distribution of the Conflicts for Conventional Vehicle vs. AV Environments for LOS B.

TABLE 4 summarized the distribution of the conflicts per lane for LOS B. The results indicate that the conflicts started to propagate to the arterial lane 2 for the conventional vehicle environment. However, in the AV environment, all the conflicts occurred on the entering driveway lane.

TABLE 4 Distribution of Conflicts per Lane for LOS B

Lane	Percent Conflict per Lane-Conventional Vehicle	Percent Conflict per Lane-AV
Arterial 1	0%	0%
Arterial 2	0.36%	0%
Arterial 3	0%	0%
Entering Driveway Lane	99.6%	100%
Exiting Driveway Lane	0%	0%

TABLE 5 shows the results of a paired t-test to compare the overall performance of conventional vehicles and AVs for LOS B. The results confirm that there is a statistically significant difference between the mean number of conflicts in the conventional vehicle and AV scenarios at a 5% confidence level. In other words, AVs result in a statistically fewer number of conflicts.

TABLE 5 Statistical Comparison of Conventional Vehicle and AV Environments for LOS B

Variable	Value
df	46
t Stat	-2.45
P(T<=t) one-tail	0.009
t Critical one-tail	1.68
P(T<=t) two-tail	0.02
t Critical two-tail	2.01

Inserting more vehicles to the urban arterial to replicate LOS C resulted in a higher number of conflicts for both conventional vehicle and AV environments, as indicated in **FIGURE 4**. The conflicts not only increased for the driveway for both vehicle types but also propagated to the arterial upstream of the driveway.

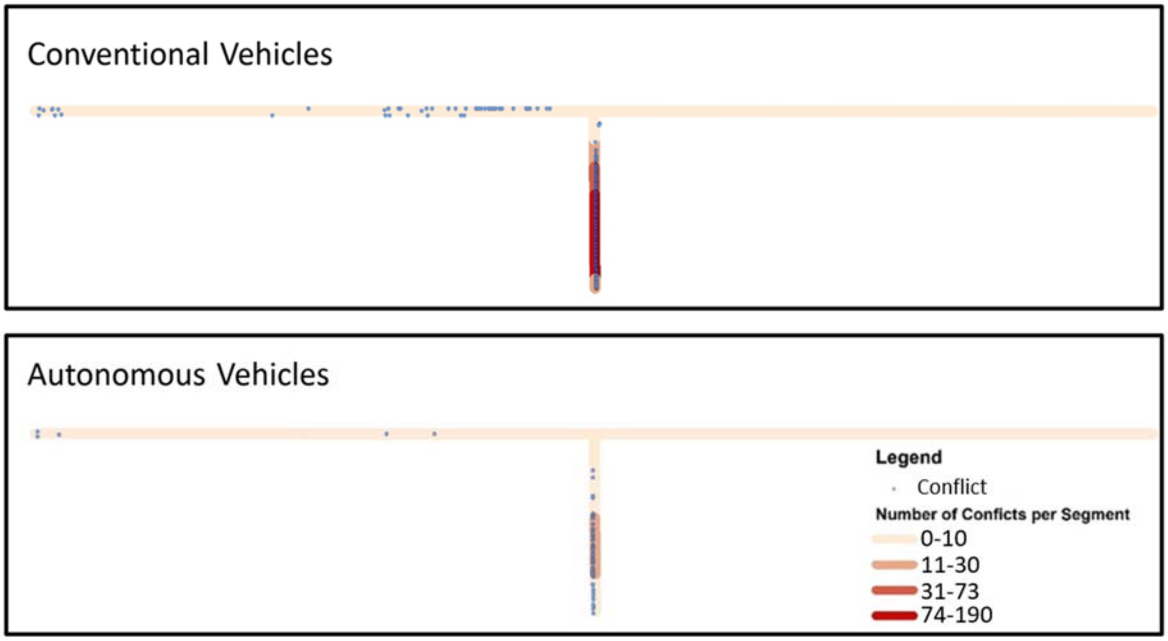

FIGURE 4 Distribution of the Conflicts for Conventional Vehicle vs. AV Environments for LOS C.

TABLE 6 summarizes the distribution of the conflicts on the roadway network lanes. As indicated, the conflicts for the conventional vehicles, as well as AVs, are extended to the lane one and lane 2 of the arterial, in addition to the entering lane of the driveway.

TABLE 6 Distribution of Conflicts per Lane for LOS C

Lane	**Percent Conflict per Lane- Conventional Vehicle**	**Percent Conflict per Lane- AV**
Arterial 1	1.47%	3.51%
Arterial 2	5.31%	5.26%
Arterial 3	0%	0%
Entering Driveway Lane	93.22%	91.23%
Exiting Driveway Lane	0%	0%

Additionally, the results of the statistical analysis demonstrate the difference in the mean number of conflicts for the conventional vehicle and AV environment (See **Table 7**). The value of the t-Stat verifies that in the AV environment, there is a lower chance of getting involved in a conflict/crash.

TABLE 7 Statistical Comparison of Conventional Vehicle and AV Environments for LOS C

Variable	**Value**
df	46
t Stat	-2.35
P(T<=t) one-tail	0.01
t Critical one-tail	1.68
P(T<=t) two-tail	0.02
t Critical two-tail	2.01

Lastly, **FIGURE 5** demonstrates the performance of conventional vehicles and AVs for LOS D. Based on the figure, there is a chance of getting involved in a conflict for both conventional vehicle and AV environments at LOS D, compared to LOS A, B, and C. In addition, at LOS D, the distribution of the conflict points and heat map show that the conventional vehicle environment is less safe compared to the AVs.

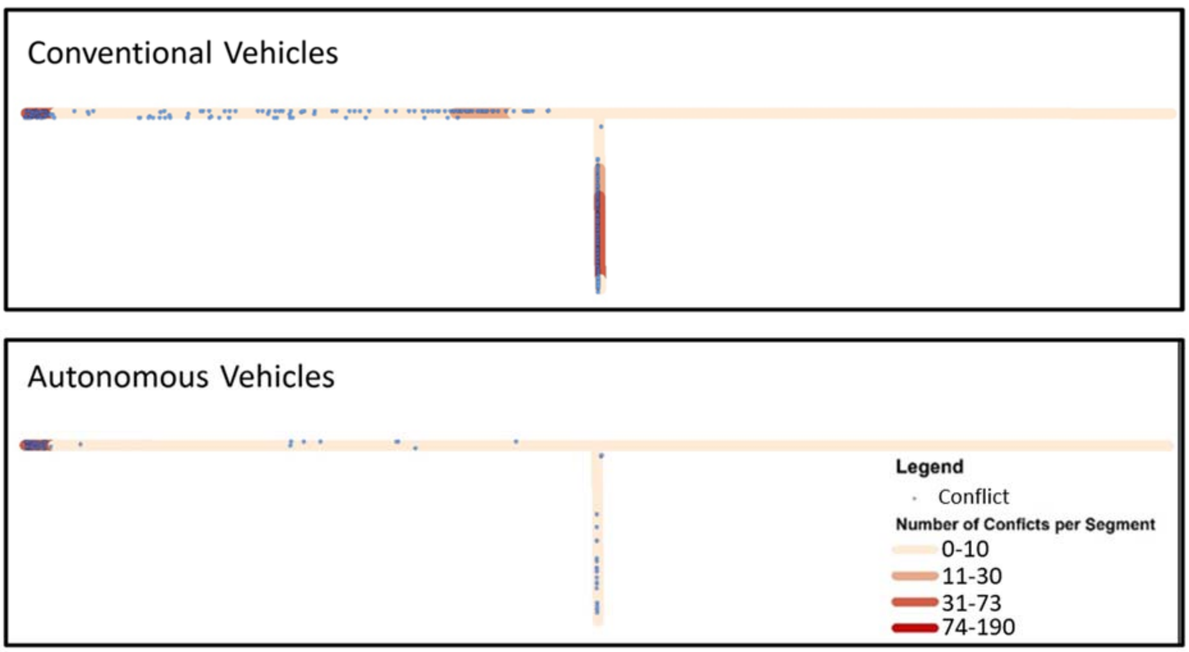

FIGURE 5 Distribution of the Conflicts for Conventional Vehicle vs. AV Environments for LOS D.

TABLE 8 represents the conflict distribution based on the lane for LOS D. As indicated, the percentage of conflicts on lane one and two of the arterial is increased for LOS D, compared to the less congested traffic situations. The high percentages of the conflicts for the arterial in the AV environment, compared to the conventional vehicle environment might arise from not having any connectivity between the vehicles. In other words, as the vehicles are not connected, the arterial vehicles cannot receive a call for a gap from the driveway vehicles that intend to merge to the arterial, and therefore, a near-crash event may occur when a driveway vehicle merges to the arterial. However, under the low traffic volume condition, the driveway vehicles can more often find a gap to merge to the arterial. Also, in the conventional vehicle environment, as the human-driven vehicles can detect the driveway vehicles, they can provide an acceptable gap for the driveway vehicles to merge without interfering the operation of the arterial.

TABLE 8 Distribution of Conflicts per Lane for LOS D

Lane	Percent Conflict per Lane-Conventional Vehicle	Percent Conflict per Lane-AV
Arterial 1	16.17%	30.26%
Arterial 2	32.08%	42.11%
Arterial 3	0%	0%
Entering Driveway Lane	51.75%	27.63%
Exiting Driveway Lane	0%	0%

The results of the statistical analysis, shown in **TABLE 9**, also show that the mean number of conflicts in the conventional vehicle environment is statistically significant and higher than the mean number of conflicts in the AV environment at a 95% confidence interval.

TABLE 9 Statistical Comparison of Conventional Vehicle and AV Environments for LOS D

Variable	Value
df	46
t Stat	-3.61
P(T<=t) one-tail	0.0003
t Critical one-tail	1.68
P(T<=t) two-tail	0.0008
t Critical two-tail	2.01

As the last step, to be able to determine an overall safety performance of the conventional vehicles and AVs in the proximity of an unsignalized intersection, a negative binomial (NB) regression model was developed. The number of conflicts at each 50 ft segment was considered as the dependent variable, and vehicle type and traffic volume as the predictors. **TABLE 10** presents the results of the NB regression model.

TABLE 10 Negative Binomial Regression Model

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-22.06	3.81	-5.79	<.0001*
Log (Traffic Flow)	3.01	0.54	5.62	<.0001*
Vehicle [CV]	3.16	0.40	7.89	<.0001*
Dispersion Parameter= 0.0784 AIC= 957.19				

Equation 2 can be implemented to estimate the total number of conflicts for an urban arterial in the proximity of a driveway.

(2)

$$Total\ number\ of\ conflicts = 2.63 \times 10^{-10} \times TF^{3.01} \times e^{3.16(\mathrm{CV})}$$

Where:
TF = Traffic flow (pcphpl).
CV= Assign a value of 1.0 if it is a conventional vehicle environment.

Based on the NB regression results, given in **TABLE 10**, both vehicle type and traffic volume significantly affect the safety of a network at a 95% confidence interval. The results show that autonomous vehicles are capable of decreasing the total number of conflicts significantly. Also, by increasing the traffic volume, the number of conflicts will increase significantly, as expected.

CONCLUSIONS

Urban areas and, subsequently, the transportation system have experienced growth over time. The growth leads to more traffic congestion, and, therefore, more traffic conflicts and crashes, which escalates the overall traffic operation and safety concerns. Urban arterials, as a fundamental element in the urban roadway network, connect major urban activity centers, carry high traffic volumes each day, and are characterized by closely spaced signalized and unsignalized intersections. These are all together, undermine the operation and safety performance of urban arterials, especially in the proximity of an intersection at which multiple roads intersect.

To address the safety and operational concerns of the roadway networks, the traditional solutions are not beneficial anymore due to the cost and space restrictions. Therefore, innovative technologies should be assessed for their operational and safety impacts of implementation. AVs, as a trending technology, have been evaluated for their safety and operational advantages and limitations. Various studies showed the operational benefits associated with AVs; however, very few studies have focused on the safety aspect of AVs. Therefore, this study evaluated the safety impact of AVs on an urban arterial near an unsignalized intersection.

For this purpose, a micro-simulation software was used to determine if AVs can enhance the safety of an urban arterial in the proximity of a driveway, compared to the current human-driven vehicles, under various levels of traffic congestion.

The number of conflicts was used, as a surrogate safety measure, to evaluate the safety performance of conventional vehicles and AVs. The results indicated that AVs have the potential to decrease the overall number of conflicts in the proximity of an unsignalized intersection for both the urban arterial and driveway segment, especially under congested traffic conditions. However, by increasing the traffic congestion in the AV network, the higher percentage of the conflicts occur on the arterial. The reason might be due to the fact that vehicles are only automated and not connected; therefore, the arterial vehicles are not capable of providing an adequate gap for the driveway vehicles to merge as they do not receive a call from the driveway vehicles that intend to merge to the arterial. But, in the conventional vehicle environment, even though there is a significantly higher number of conflicts, the lower percentage of the conflicts occur on the arterial as the human-driven vehicles detect the driveway vehicles and provide a reasonable gap for them to perform their merging maneuver.

In conclusion, even though AVs promote the safety of roadways in the proximity of an intersection, providing an exclusive lane on the arterial for the driveway vehicles to merge improves both traffic safety and operation. The exclusive lane allows driveway vehicles to merge to the arterial smoother without abruptly joining the arterial and causing a conflict. Moreover, the exclusive lane prevents the driveway vehicles from spilling back.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm the contribution to the paper as follows: study conception and design: Seyedeh Maryam Mousavi; simulation modeling: Seyedeh Maryam Mousavi; analysis and interpretation of results: Seyedeh Maryam Mousavi and Domonique Lord; draft manuscript preparation: Seyedeh Maryam Mousavi, Domonique Lord, Seyed Reza Mousavi, Maryam Shirinzad. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Gora, P., and I. Rub. Traffic Models for Self-Driving Connected Cars. Transportation Research Procedia, 2016, pp. 2207- 2216.
2. World Health Statistics. 2017.
3. ASCE. 2017 Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure. 2017.
4. NHTSA. Traffic Safety Facts 2015. 2015.
5. Morando, M.M., Tian, L. T. Truong, and H. L. Vu. Studying the Safety Impact of Autonomous Vehicles Using Simulation-Based Surrogate Safety Measures. Journal of Advanced Transportation, 2018.
6. Ahangari, S., Z. Rashidi Moghaddam, M. Jeihani, C. Chavis, H. Chen, H. Rakha, and K. Kang. Investigating the Effectiveness of an Eco-Speed Control System in the Vicinity of Signalized Intersections Using a Driving Simulator. in Transportation Research Board 98th Annual Meeting Transportation Research Board, Washington D.C., 2019.
7. Gouy, M. Behavioral Adaptation of Drivers of Unequipped Vehicles to Short Time Headways Observed in a Vehicle Platoon. Affiliated Research Centre of the Open University, 2013.
8. Fagnant, D. J., and K. Kockelman. Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. Transportation Research Part A, 2015, pp. 167-181.
9. Milakis, D., B.v. Arem, and B.v. Wee. Policy and Society Related Implications of Automated Driving: A Review of Literature and Directions for Future Research. Journal of Intelligent Transportation Systems, 2017, pp. 324-348.
10. Papadoulis, A., M. Quddus, and M. Imprialou. Evaluating the Safety Impact of Connected and Autonomous Vehicles on Motorways. Accident Analysis & Prevention, Vol. 124, March 2019, pp. 12-22.
11. Aria, E., J. Olstam, and C. Schwietering. Investigation of Automated Vehicle Effects on Driver's Behavior and Traffic Performance. Transportation Research Procedia, 2016, pp. 761-770.
12. FHWA (Federal Highway Administration). FHWA-SA-10-002: Access Management in the Vicinity of Intersections. Department of Transportation, 2010.
13. Malek, F.A. Autonomous Vehicles: Safety, Sustainability, and Fuel Efficiency. i-manager's Journal on Future Engineering & Technology, 2017.
14. Bhavsar, P., P. Das, M. Paugh, K. Dey, and M. Chowdhury. Risk Analysis of Autonomous Vehicles in Mixed Traffc Streams. Transportation Research Record: Journal of the Transportation Research Board, 2017, pp. 51-61.

15. McMurry, T. L., G. S. Poplin, G. Shaw, and M. B. Panzer. Crash Safety Concerns for Out-Of-Position Occupant Postures: A Look toward Safety in Highly Automated Vehicles. Traffic Injury Prevention, 2018.
16. Schoettle, B., and M. Sivak. A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles. The University of Michigan Transportation Research Institute, Michigan, UMTRI-2015-34, 2015.
17. Gouy, M., K. Wiedemann, A. Stevens, G. Brunett, and N. Reed. Driving Next to Automated Vehicle Platoons: How Do Short Time Headways Influence Non-Platoon Drivers' Longitudinal Control? Transportation Research Part F, 2014, pp. 264-273.
18. Bu, F., H.-S. Tan, and J. Huang. Design and Field Testing of a Cooperative Adaptive Cruise Control System. in American Control Conference, Baltimore, MD, 2010, pp. 4616-4621.
19. Mousavi, S. M., O. A. Osman, and D. Lord. Impact of Urban Arterial Traffic LOS on the Vehicle Density of Different Lanes of the Arterial in Proximity of an Unsignalized Intersection for Autonomous Vehicle vs. Conventional Vehicle Environments. in International Conference on Transportation and Development, Alexandria, VA, 2019.
20. Jeong, E., C. Oh, and S. Lee. Is Vehicle Automation Enough to Prevent Crashes? Role of Traffic Operations in Automated Driving Environments for Traffic Safety. Accident Analysis and Prevention, 2017, pp. 115-124.
21. U.S. Department of Transportation. FHWA-HRT-08-049: Surrogate Safety Assessment Model (SSAM). McLean.
22. Wolshon, B., S. A. Parr, and S. M. Mousavi. Identifying High-Risk Roadways for Infrastructure Investment Using Naturalistic Driving Data. Maritime Transportation Research and Education Center (MarTREC), Fayetteville, 2015.
23. Grzebieta, R. Australia's Naturalistic Driving Study. Journal of the Australian College of Road Safety, Vol. 26, 2015.
24. U.S. Department of Transportation. DOT HS 811 382: Evaluating the Relationship between Near-Crashes and Crashes: Can Near-Crashes Serve as a Surrogate Safety Metric for Crashes. 2010.
25. Mousavi, S. M. Identifying High Crash Risk Roadways through Jerk-Cluster Analysis. Louisiana State University, Baton Rouge, 2015.
26. Xiao, L. D.W.G.T.C.A.M. Enhancing Driving Safety: Discovering Individualized Hazardous Driving Scenes using GIS and Mobile Sensing. Transactions in GIS, 2019.
27. Mousavi, S. M., H. Marzoughi, S. A. Parr, B. Wolshon, and A. Pande. A Mixed Crash Frequency Estimation Model for Interrupted Flow Segments. in International Conference on Transportation and Development, ASCE, Alexandria, VA, 2019.
28. Hayward, J. C. Near-Miss Determination through Use of a Scale of Danger. The Pennsylvania State University, 1972.
29. Dijkstra, A., P. Marchesini, F. Bijleveld, V. Kars, H. Drolenga, and M. v. Maarseveen. Do Calculated Conflicts in Microsimulation Model Predict Number of Crashes? Transportation Research Record, 2010, pp. 105-112.
30. Horest, A.R.A. v.d. A Time-based Analysis of Road User Behavior in Normal and Critical Encounters. 1990.
31. Archer, J. Indicators for Traffic Safety Assessment and Prediction and Their Application in Micro-Simulation Modelling: A Study of Urban and Suburban Intersections. 2005.
32. PTV VISSIM. PTV VISSIM 10 User Manual. Karlsruhe, Germany, 2017.