Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Examining Drivers' Behaviors to Connected and Automated Vehicles

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Final Report

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16. Abstract

It is envisioned that Connected and Automated Vehicles (CAVs) are the future of transportation as they can assist in minimizing some inefficiencies with the current transport systems. However, it is not clear how drivers of conventional vehicles would interact with CAVs in a mixed traffic environment containing both CAVs and human driven vehicles (HDVs). Thus, this study aims to investigate drivers' behaviors towards CAVs through driving simulation experiment and national survey study. Two on-ramp and two off-ramp driving simulation scenarios were designed where drivers were asked to merge with two-lane highway in presence of HDVs and CAVs truck platoon in the on-ramp scenarios. In the two off-ramp scenarios, they were asked to take exit in presence of HDVs and CAVs truck platoon in the lane to their right. A before-after survey was conducted among the participant of the driving simulation experiment and an online survey was conducted to investigate their opinion in different traffic, road and environmental condition in presence of CAVs. Furthermore, two driving simulation scenarios were designed to test drivers' behaviors during automated driving mode and their reaction when the control was shifted to the manual driving mode. Results from the on-ramp scenarios and off-ramp scenarios indicate that more than half of the drivers preferred to merge in front of CAV truck platoon and around two-third of the drivers chose to diverge behind the platoon. The online survey revealed that around two-third of the respondents would not overtake CAV platoon in two-lane two-way road, whereas around 60% would do so in case of three lane highway. During automation failure, drivers demonstrated lower take-over reaction time (TORt), lower deceleration and higher TTC in scenarios with non-driving related tasks (NDRT) compared to the scenarios with no NDRT (manual mode). The before-after survey results suggest that most of the drivers found the navigation with CAV easier after participating in the experiment.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

CAVs	Connected and Automated Vehicles
AVs	Automated Vehicles
TTC	Time-To-Collision
TORt	Takeover Reaction Time
HDVs	Human Driven Vehicles
THW	Time Headway
CACC	Cooperative Adaptive Cruise Control
ACC	Adaptive Cruise Control
NDRT	Non-Driving Related Tasks
TOR	Takeover Request
ANOVA	Analysis of Variance
MLC	Mandatory Lane-Changing
GLM	Generalized Linear Model

EXECUTIVE SUMMARY

Connected and Autonomous Vehicles (CAVs) are expected to minimize some of the inefficiencies of current transport systems by improving traffic operation, reducing likelihood of traffic collisions (through eliminating drivers' errors) and by reducing fuel consumption and emissions. Autonomous vehicles (AVs) and CAVs are currently being developed in both commercial and research projects across the world and are expected to be publicly available soon. During the early phase of CAVs, drivers might face additional challenges in a mixed traffic environment containing both CAVs and other human driven vehicles (HDVs). Therefore, it is crucial to understand the drivers' behaviors and challenges in a mixed traffic environment especially at complex traffic areas (e.g., merging, and diverging areas).

Not only does studying the actual drivers' behaviors to other CAVs affect the safety of all road users, but also plays a significant role in acceptance and propagation of CAVs. In this regard, little is known about the acceptance of CAVs among different sociodemographic groups of drivers. Therefore, this study aimed to achieve the following three main objectives to address the abovementioned issues.

1. Examine how drivers will interact with other human-driven vehicles and CAVs under different traffic/road/environmental conditions. To achieve this goal, different driving simulator scenarios were designed and developed using LSU driving simulator.
2. Investigate drivers' behaviors to possible cases of automation failure of CAVs.
3. Explore the changes in the willingness and preferences of drivers toward CAVs before and after participating in the driving simulator experiments. A before and after questionnaire study was designed to identify the extent to which familiarizing the population with CAVs would affect their acceptance and willingness toward using CAVs.

To achieve the first objective, different driving simulator scenarios were designed including examining the most challenging driving maneuvers and conditions (e.g., on-ramp and off-ramp merging/diverging in the presence of CAVs). Results from on-ramp scenarios showed that more than half of the drivers who participated in this study merged in front of CAV platoon and only 2 cut-ins happened between the vehicle of the CAV platoon., On the other hand, during off-ramp scenarios, more than 60% of the drivers chose to take exit behind the CAV platoon and two cut-ins happened in presence of CAV platoon. In terms of difference in participants' behavior to HDVs and CAVs, 27% lower maximum deceleration was observed for off-ramp scenarios with CAVs than the scenarios with HDVs. This means that drivers were less aggressive while taking exit in presence of CAVs compared to when they took exit in presence of HDVs. Also, drivers with previous involvement in accident had 10% higher average diverge speed in presence of HDVs compared to their counterparts. With respect to demographic characteristics, it was found that female drivers had larger TTC than male drivers during merging. This result means that female drivers are more careful during merging at on-ramp compared to male drivers. An interaction effect between gender and vehicle type (HDVs and CAVs) showed that merging with CAVs had higher TTC for female participants than the male participants compared to merging with HDVs while the opposite happened during taking exit. This result means that though female drivers behaved more safely during on-ramp scenarios, male drivers' behavior was safer during off-ramp scenarios.

In addition, an online national survey was designed to examine drivers' interaction in presence of CAV platoon on straight section of the highways which included interaction in two-lane two-way road, in 3-lane highway and during adverse weather conditions. To collect a nationally representative sample for this study, the online survey was administered by the Qualtrics organization, which manages online panels of the general public and offers a range of services to facilitate data collection through surveys. A total of 1565 samples were collected to investigate drivers' preferred interaction with CAV platoon in the aforementioned scenarios. Two-third of respondents reported that they would not overtake a CAV car platoon in a 2-lane 2-way road as they did not consider it safe. However, over 50% of participants claimed that they would do so if CAVs yield to them by increasing gap. In case of multilane divided highway, around 60% of the respondents reported that they would overtake the platoon.

To achieve the second objective, driving simulation experiments were conducted including two automated driving scenarios with automated driving mode (called non-driving related tasks (NDRT)) and no non-driving related tasks (NDRT). The simulator was in automation mode in both scenarios. However, participants were allowed to use their phone, browse internet etc. during NDRT scenario and they were only allowed to relax in the no NDRT scenario. Results showed that 50% of the drivers used their phone while they were allowed to do NDRT and the simulator was on the full autonomous mode. Around 60% of the drivers solely paid attention to monitoring driving during no NDRT scenarios while a little over 20% did so in the scenario with allowance of NDRTs. With respect to the difference in the reaction to take-over requests (TOR) when the simulator was shifted back to the human driven mode and participants received an audio message to take control of the car, lower deceleration, lower take-over reaction time (TORt), and higher time-to-collision (TTC) were observed in the scenario with NDRT (using phone or browsing internet) compared to the scenario without NDRT (no phone use, only relaxing was allowed).

A before-after survey was developed and distributed among participants in the driving simulation experiment to achieve the third objective. Participants were asked about the difficulties in navigation with CAVs. Over 50% of the drivers thought it would be difficult before participating in the experiment, but only around 25% drivers found it difficult after the experiment. Around two-third of the participants reported that CAVs should be on a dedicated lane before the experiment which increased slightly to about 70% after participation in the experiment. Only around 25% of the drivers felt stressed during driving in the presence of CAVs.

Results from this study provide valuable insights about the actual driving behaviors and challenges of drivers in the most critical driving conditions (merging and diverging) in a mixed traffic environment containing both CAVs and other human driven vehicles. The results of this study also shed light on whether public acceptance of CAVs would be affected by training, publicizing, and educational programs. Overall, the findings might provide transportation authorities and traffic safety authorities in the United States and elsewhere with actionable measures/countermeasures that can help in improving the safety of all road users.

1. INTRODUCTION

Connected and Automated Vehicles (CAVs) technology enables a vehicle to communicate with other vehicles (V2V), roadway infrastructure (V2I), network (V2N) and pedestrians (V2P) which can be collectively called vehicle-to-everything (V2X). CAVs are a new and transformative technology, and they are rapidly evolving and developing its capabilities. The CAV technology has significant potential to lower traffic accidents, improve quality of life, and increase the effectiveness of transportation systems [1]. For example, it can reduce the crash severity as well as frequency by minimizing drivers' error due to less human input [2]. It can also improve mobility by reducing congestion [3]. By exchanging information about traffic, roads and weather conditions (e.g., road incidents, speed etc.) CAVs can maintain short headway distance between each other and form platoon together which can also increase traffic efficiency and improve traffic operation [4].

Prior studies indicated that the maximum benefits from CAVs can be achieved at higher market penetration percentages. However, before reaching higher percentages of market penetration, there will be coexistence of CAVs and conventional vehicle in the transportation roadway network. During the early stage of CAVs, it is not clear how drivers of conventional vehicles would interact with other CAVs in such a mix traffic environment especially at complex traffic areas (e.g., merging and diverging areas). Thus, it is necessary to thoroughly understand whether drivers would face additional challenges in a network of mixed traffic that includes both CAVs and human-driven vehicles.

Previous studies which focused on drivers' behavior in mixed traffic environments mostly focused on headway and gap acceptance. For example, Wang et al. [5] studied three headway gaps (0.3 s, 0.5 s and 0.7 s) for merging scenarios in microscopic simulator and found out that the number of vehicles unable to merge in time is decreased by smaller time gaps between the vehicles of a platoon. Authors attributed this result to the longer barrier created by a platoon with a bigger time gap which blocks the merging area. A driving simulation study by Chityala et al. [6] with different CAV penetration rate during merge scenario showed that drivers accepted shorter gaps to merge in case of increased CAV penetration. Another driving simulation study by Guo et al. [7] indicated that participants preferred 1.1 s gap over 0.8 s gap to change lane.

Preference of larger gaps were also reported in a study by Aramrattana et al. [8] where four time headways (0.5 s, 0.7 s, 0.9 s and 1.3 s) were tested in a driving simulation experiment using car platoon. Authors concluded that larger gaps contributed to more cut-ins as well as less crashes. Using fixed time headway of 0.5 s, Spasovic et al. [9] also examined drivers merging behavior in a driving simulation experiment with truck platoon. Around 60% of the drivers recruited for the experiment preferred to merge behind the truck platoon and 50% of them preferred to stay behind the platoon during taking exit.

In terms of following behavior in the presence of CAVs, drivers were found to maintain shorter time headway when they drive beside a dedicated lane of CAVs compared to while having CAVs on any lane and no CAVs at all [4]. Even difference exists between two types of dedicated lane. Smaller headway was observed when driving nearby a dedicated lane of CAVs with continuous access compared to the dedicated lane with limited access [10].

Though drivers' merging and diverging scenario in the presence of CAV platoon of car and truck platoon were already investigated in the previous studies, behavior difference in case of closely spaced human driven vehicles (HDVs) and CAV platoon near on ramp and off ramp has not been explicitly studied yet. Therefore, to understand behavioral adaptation and safety performance of drivers in presence of CAVs, it is necessary to investigate drivers' behavior towards CAVs as well as HDVs. Moreover, very little is known about the acceptance of CAVs among different sociodemographic groups of drivers. Therefore, it is also imperative to examine their attitude and preference towards CAVs.

Considering the aforementioned gaps, this study aims to investigate drivers' behavior towards CAVs using three methods: driving simulation experiment, online survey and before-after survey. Driving simulation experiment focused on examining driver's interaction and behavior towards CAVs near highway exits and entrances. Online survey examined driver's preference and opinion towards CAVs on straight section of 2-lane and multi-lane highways. Finally, driver's attitude, opinion and preference changes were explored based on the before-after survey.

2. OBJECTIVES

The primary objectives of this study were to:

1. Examine the interaction of drivers with other CAVs under different traffic and environmental conditions. In this regard, several on-ramp and off-ramp driving simulator scenarios were designed and developed using the LSU driving simulator and through online survey.
2. Investigate drivers' behaviors to different levels of vehicular automation. Using several cameras inside the driving simulator, drivers' activity during the automation mode of subject vehicle as well as their reaction after automation failure were examined.
3. Explore changes in the willingness and preferences of drivers toward CAVs before and after participating in the driving simulator experiments. A before and after questionnaire study was designed to identify the extent to which familiarizing the population with CAVs affected their acceptance and preferences toward CAVs.

Figure 1 shows the overall research methodology and tasks to achieve the aforementioned objectives.

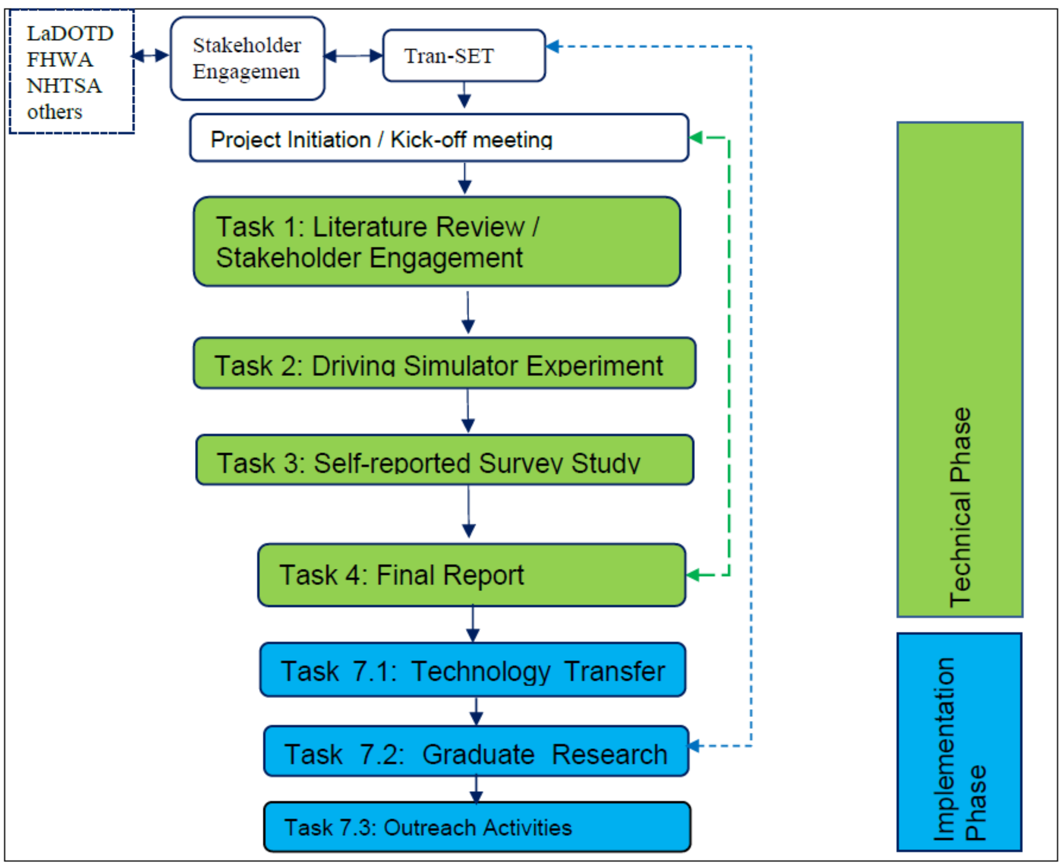


Figure 1. Research methodology and tasks.

3. LITERATURE REVIEW

In this section, a comprehensive literature review is presented to identify the most relevant recent studies to the scope of the proposed research that includes the following topics.

- Drivers' behaviors towards CAVs under different traffic/road/environmental conditions.
- Drivers' preferences, challenges and needs while driving on roads including CAVs.
- Drivers' behaviors towards different levels of CAVs automation (full automation mode vs. manual mode).
- Willingness and preferences of road users toward CAVs.

3.1. Behavior and Interaction with CAVs

Ali et al. [11] used CARRS-Q Advanced Driving Simulator to investigate the effect of connected environment on mandatory lane-changing (MLC) behavior of the drivers. The authors examined the manner in which drivers decided to change lanes when receiving information related to driving tasks. Their experiment had three scenarios – 1) driving without any aids; 2) driving in perfectly connected environment with necessary aids such as available gaps in the target lane, speeds of the nearby vehicles etc., and 3) driving in a connected environment with delay of 1.5 s in providing the aid. Driving aids were provided via audio and display messages in the forms of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Total of 78 people with valid driver license and between 18 and 65 years old participated in the experiment. To analyze the gap acceptance behavior of the drivers, initial speed, wait time, acceleration or deceleration, spacing, time to complete lane change were selected as the performance indicators. Repeated measures ANOVA technique showed that there were statistically significant differences in the performance indicators across the three driving scenarios. For example, the time taken to execute the MLC decision was 1.53 s for scenario 2 (aid without delay) and 1.77 s for scenario 3 (delayed aid). The chi-square test of the accepted gaps in the scenarios showed that selection of risky gap was reduced by 50% while perfect communication was provided.

To investigate the impact of connected environment on drivers' behavior and safety, Ali et al. [12] used driving simulator with 78 participants. They investigated the car following behavior and lane changing behavior for this purpose. Their scenarios were without driving aid (suggestion or information to assist in driving), with continuous aid, with delayed aids and temporary loss of communication. By using linear mixed models, t-test and Fisher's exact test, the results showed that drivers maintained larger TTC towards pedestrians as well as during car following. Less yellow light running was observed as they received advisory information during interaction with traffic lights. Also, in the case of delayed assistance and lost communication, safety margins were deteriorated.

As part of CAV applications, red-light violation warning, forward collision warning, curve speed warning and pedestrian collision warning were provided to 93 participants in a driving simulation experiment. Braking behavior, speed change, steering control of the participants were measured to examine the effect of CAV applications on drivers' behavior. Results indicated that red-light violation warning, and pedestrian collision warning affected the braking behavior significantly. For example, time for reducing the speed was longer at the presence of these warnings. This study also found drivers' demographics (age, miles driven etc.) associated with takeover reaction time (TORt) [13].

However, drivers in the above studies had the advantage of using assistance through connected environment in some of the scenarios. The scope of this study is related to the behavior of HDVs which do not have access to connectivity and driving with CAVs. Therefore, following studies are focused on behaviors of HDVs in the presence of CAVs as well as interaction of HDVs with CAVs.

Rahmati et al. [14] studied the difference between the interaction of HDV to other HDV, and HDV to automated vehicles (AV). They examined the car following behavior of the drivers using Texas A&M University's automated Chevy Bolt in a field test track with 9 drivers. In one of the scenarios, subject vehicle followed a HDV and an AV in the second scenario. Data collected as driver's behavior were gap with the lead vehicle, acceleration, and speed profile. According to a comparison of their car-following behavior for the two scenarios indicated that the spacing or gap between the subject driver and the lead vehicle was smaller when following an AV as opposed to following an HDV. Also, it was found that human drivers drive more smoothly and with fewer sudden accelerations/decelerations and they are more comfortable following the AVs.

For safety analysis of the performance measures of the above field test, Mahdinia et al. [15] used driving volatility (for speed and acceleration) and TTC as surrogate safety measures. In addition, they measured fuel consumption and emission for determining the environmental impact. Results showed around 18% speed volatility reduction and around 23% acceleration volatility reduction. Also, the TTC result revealed that drivers have larger TTC (i.e., following an AV involves safer following behavior compared to following an HDV). Regarding the fuel consumption, around 10% lower consumption was found in case of following an AV than following an HDV. Limitation of this study are the small number of drivers (9), scenarios, platoon size and speed profiles.

Soni et al. [16] conducted a field test to investigate adaptation of drivers' behavior in mixed driving situations where the number of automated vehicles are expected to be low during the early stage of implementing automated vehicles in the transportation network. They aimed for one-on-one interaction of human driver and automated vehicles and recruited 18 participants. Two scenarios were examined – the test vehicle which was followed by the participants was an 1) HDV; and 2) AV. Car following behavior, overtaking behavior and gap acceptance at intersection were investigated. The results indicated that drivers of the conventional vehicle maintained shorter headway after they overtook the AV compared to overtaking other conventional vehicles. Time headway was not significantly different in the two scenarios.

Using microscopic simulator, Wang et al. [5] focused on platoons of two or three trucks in the on-ramp area with fixed distance between the vehicles of platoon. This study simulated a 2-lane freeway section. Varying penetration rates of 0%, 25%, 50%, 75% and 100% were considered. Other factors used in this study were three types of traffic intensity – low, medium, high, and congested, and three types of gaps - 0.3 s, 0.5 s and 0.7 s. However, the platoon of this study was designed to yield others and give space for merging. To assess the performance, indicators such as merge location distribution, total time spent in the network, merging speed distribution and maximum outflow were measured. It was found that merging became difficult in presence of truck platooning. Thus, some participants managed to merge at the very end of the acceleration lane and some were not able to merge at all. Findings also showed that when there were truck platoons, the capacity of the roadway increased from 2% to 19% during congested traffic scenario.

To investigate the effect of time headway during changing lane in presence of platoon, Rad et al. [4] investigated the behavior of HDV in a mixed traffic environment (i.e., containing both HDV and CAVs) where CAVs were placed in a dedicated lane. A driving simulator experiment with 30 participants was conducted where time headway and accepted merging gaps were considered as performance measures. Scenarios considered were HDV scenario, platoons of 2-3 CAVs on any lane and platoons of 2-3 CAVs on a dedicated lane. Vehicle trajectory data was recorded from the driving simulator experiment and behavior characteristics calculated from the trajectory data were time headway (THW) in car following, time gap in lane changing, time of accepting gap to enter a slow lane from acceleration lane, time of accepting gap to enter a slow deceleration lane from middle lane etc. Box plot analysis of THW showed that it was smaller in the dedicated lane scenario in comparison with the other two scenarios. Also, drivers accepted smaller merging gaps when driving closed to the dedicated lane. A future research direction mentioned by this study was investigating the imitation behavior of drivers after they are educated about CAVs in detail.

Schoenmakers et al. [10] tested the dedicated lane impacts using two scenarios. In the first scenario, participants had continuous access to the dedicated lane, while in the second scenario, they had limited access. Drivers' behavior while they were exposed to dedicated road configurations for AVs were studied using driving simulator experiment. Number of participants in this experiment was 34 and their age ranged from 20 to 30. This study observed the time headway of participants and used ANOVA to analyze the results. It was found that drivers were following too closely (lower headway) when they were driving closed to a dedicated lane with continuous access. On the other hand, the headway was higher when they were driving closed to a dedicated lane with limited access. An important future direction of research mentioned in this study was to consider exposure to platoons for longer duration and then testing its effects on drivers' behavior.

Another study had similar results of maintaining shorter THW by studying the effect of THW of CAV platoons. This study used a driving simulator study with 30 participants. The three scenarios considered were platoons with short following distance, platoons with long following distance and no platoons. Time headway analysis using ANOVA showed that drivers maintain short THW while driving in closed proximity of the platoons with short THW which increases collision risk. Exploring the contributor factors behind this behavioral adaption was mentioned as a possible research direction in this study [17].

Guo et al. [7] also tested headways using different headway gaps in a 2-lane simulated freeway for exit ramp with platoon of 8 Cooperative Adaptive Cruise Control (CACC) vehicles. A total of 11 participants were recruited and three headways (0.8 s, 1.1 s and 1.4 s) were designed. Each participant repeated each headway three times taking 1.5 hours for the entire experiment. The participants were told that they could change lanes into the platoon whenever they wanted. Standard deviation of position, speed, and acceleration as well as lane change duration were measured to evaluate the performance. It was concluded that participants were reluctant to switch lanes with headway of 0.8 seconds and this resistance was reduced when headway of larger than 1 second was provided.

To investigate drivers' behavior in a mixed traffic environment while merging on freeway ramp, Chityala et al. [6] recruited 42 participants for a driving simulator experiment. This study considered both freeway vehicle and ramp merging vehicles. Also, different CAV penetration rates (0, 50 and 75%) were used to simulate three scenarios. Gap acceptance, vehicles' speed and acceleration rate were considered to measure the performance. Analysis of these parameters showed that accepted gaps decreased with increased percentage of CAVs. Also, while there were more CAVs, drivers accelerated to merge. Studying more penetration variation and incorporating ramp metering were recommended as a future direction of research.

Aramrattana et al. [8] also investigated drivers' behavior during merge with CAVs but they designed the platoon of CAVs in a driving simulation experiment. They simulated two-lane highway platoon of vehicles on the on-ramp and used variable spacing between the vehicles of the platoon. Four spacing times (0.5 s, 0.7s, 0.9 s and 1.3 s) were simulated, and 16 participants were recruited to conduct the study. Participants encountered four spacings two times with a total of 8 runs for every participant. The number of entries into the platoon and crashes with the vehicles in the platoon were collected. Analysis of the drivers' merging behavior showed that the longer gaps (0.9 s and 1.3 s) experienced more cut-ins and fewer crashes than the shorter gaps (0.5 s and 0.7 s). Also, around one third of entries into the platoon with 0.7 s gap resulted in a crash. On the other hand, 1.3 s gap resulted in more entries and less crashes compared to a 0.9 s gap.

Spasovic et al. [9] used truck platooning in both entry and exit of the highway to see the effect of platooning on behavior of the surrounding drivers. Four scenarios were developed in a driving simulation experiment for this study. In the first two scenarios, truck platoons existed in the right most lane of the entry and exit where the subject driver was trying to enter or exit the highway. In the second two scenarios, truck platoons itself took the exit and entry of the highway. The spacing was 0.5 s in all the scenarios. Twelve drivers participated in the study and number of vehicles in the platoon were 5, 7 and 10. Results showed that subject drivers tended to pass the platoon when a platoon was approaching their way. On the other hand, when they saw the platoon on the right lane and they wanted to take the exit, they would wait till the platoon was gone. Also, more than 60% of drivers were observed to merge behind the platoon and 50% of drivers were observed to take exits behind the platoon.

Lane changing behavior of HDVs in presence of AV platooning was investigated by Lee et al. [18] using a driving simulator study with 30 participants. Seven vehicles were used to form platoons with varying penetration rates of AV in mixed traffic environment. ANOVA and binomial regression model were used to analyze the lane change behavior. Results showed that platooning affected the behavior of the drivers of HDVs which was demonstrated by long preparation time to change lane, greater steering velocity, and steering magnitude during the lane change.

3.2. Reaction to Vehicular Automation and Automation Failure

In case of automation failure, Borowsky & Oron-Gilad [19] examined drivers' action towards road hazards using a fixed based simulator. Eighteen participants drove through four scenarios – automated driving, manual driving, automated driving with secondary task, and manual with secondary task. One of the secondary tasks given to drivers was in-vehicle task where they had to identify the lighted square from nine squares in the touchscreen with feedback after every identification. Another secondary task was outside the vehicle where participants had to touch a flag button if the centerline became a double line. Visual and audio alerts on the automation failure were provided. The events when automation failure occurred were 9 seconds prior to a car merging in the main road as lead vehicle and slowed down suddenly and 9 seconds prior to a car overtaking a truck in the opposite direction requiring the subject vehicle to stop in the right shoulder. Using two-tailed Fisher exact test to compare between the scenarios, it was revealed that drivers faced difficulty in handling hazardous conditions when they were involved in the in-vehicle secondary tasks. Authors mentioned that there was no significant impact on crashes due to the automation failure.

Using driving simulation experiment with 36 participants, Strand et al. [20] used deceleration failure as the indication of automation failure to investigate the performance of drivers in case of automation failure. The factorial design was 2×3 where semi-automation and high-automation were independent variables for the between-groups, and moderate, severe, and complete deceleration failures were independent variables for the within-groups. However, this deceleration failure did not affect the manual braking system. The performance measures considered were minimum TTC (MTTC), minimum time headway (MTHW), point-of-no-return (PoNR) and response time. Analysis was done by SPSS using 0.05 as the level of significance. PoNR which is defined as the point where a collision cannot be avoided by taking any measures were lower for the semi-automated driving than the highly automated driving. With the increase of deceleration failure, MTTC and MTHW increased whereas response time decreased remarkably.

Shen & Neyens [21] conducted driving simulator study to examine drivers' behavior in case of automation failure for different level of automation. The two levels of automation differed by the presence of Lane Keeping (LK) systems – one had both adaptive cruise control (ACC) and LK systems, another one had only ACC. They also considered three types of road conditions which were straight lane condition, curve lane condition, and in-traffic condition. To measure the characteristics of the 48 participants of the driving simulator, score from complacency potential rating scale (CPRS), interpersonal trust scale (ITS), acceptance scale (AS) and trust scale (TS) were gathered through survey questionnaire. Bonferroni multiple comparisons and Bonferroni pairwise t-test were used for analysis. Results of this study showed that drivers' response time to the automation failure was longer with higher level of automation. It also mentioned that lane deviation was higher with the failure of higher automation. Regarding the trust on the system, drivers with high level of trust encountered larger maximum lane deviation than the drivers with lower trust in the system.

Shen & Neyens [22] conducted another study of automation failure where drivers were engaged with non-driving related tasks (NDRT). Number of participants were 48 including equal number of males and females. Scenarios considered were no automation and level 2 automation in rural interstate. Also, level of NDRTs were no NDRT and watching a movie. Participants were given to answer multiple choice questions after each video clip which were analyzed by binomial logistic regression model. Performance measures selected were lane departure duration, reaction time, and maximum steering wheel angle. The reaction time was longer for both automation and for the scenario with watching movies. Similarly, lane departure duration was longer and steering wheel angle was larger for the level 2 automation compared to no automation. Authors concluded that participants had higher engagement in the NDRT in L2 automation than in the no automation driving. Thus, the automation system considered in this study distracted the drivers with NDRT and their reaction time to the lane departure event was slower. Dogan et al. [23] also found similar results of slower reaction time to TOR. They implemented two groups (No NDRT and NDRT) in a driving simulation experiment with 28 participants where 50% of the drivers performed NDRT and took longer time to regain control from automation to manual while engaged in NDRT.

Dogan et al. [24] also explored the impact of NDRT and type of takeover situations on the performance of driver using level 3 automation which frees drivers from controlling and supervising the vehicle and they can do non-driving related tasks. The NDRTs were watching videos and writing emails whereas scenarios considered for takeover were avoidance of obstacle on the lane and missing markings. A dynamic driving simulator with 44 participants was considered in this study. Dependent variables considered for analysis were takeover time, lane change time, lane change speed, maximum deceleration, minimum TTC, minimum time headway etc. Results showed that takeover time was shorter for the avoidance of obstacle and type of NDRT had no effect on it. Also, lane change happened earlier in the manual driving compared to the automated driving. Both minimum TTC and minimum THW was shorter after the automated driving. Authors concluded that type of NDRT does not influence the performance of drivers, rather automation itself does.

An automaton failure was tested in the approaching curve situation by Mok et al. [25] through a driving simulator study with 30 participants. Transition time from automation to manual was 8 s, 5 s and 2 s before the entry to the curve. Both visual and audio alerts were provided on the turning off automation system to take control in the given time period. Performance measures were lane position deviation, standard deviation of the position of steering wheel, and analysis techniques used were ANOVA, and post-hoc analysis using Wilcoxon rank sum test. Results suggested that the minimum amount of time needed for the transition was between 5 and 8 seconds. Also, most drivers were able to mitigate the hazard situation in the 8 s and 5 s scenario whereas only few drivers were able to do so in the case of 2 s transition time.

Failure of lateral vehicle control in work zone while drivers are engaged in NDRTs was investigated by Naujoks et al. [26] using partially automated control in a driving simulator experiment with 34 participants. Drivers were instructed that they were fully responsible for safety in the presence and absence of automation. They also had the option to override the automation system by braking, pushing button, by steering wheel and by gas pedal. Scenarios considered were missing lane markings, work zones, high curvature. Dependent measures considered were deactivation methods used, time to deactivate, velocity, standard deviation of lateral position, maximum lateral deviation, understanding the reason of take over requests, etc. Though the drivers of this study were able to complete the transition safely instead of the availability of NDRTs, most of them were not able to understand the reason for requesting the transition.

In addition to the work zone situation, Vogelpohl et al. [27] tested four other scenarios to explore drivers' reaction to take over requests while drivers are engaged in NDRTs. A total of 60 participants took part in the driving simulator study. Four experimental scenarios considered were manual driving, automated driving-no NDRT, automated driving-reading, and automated driving-gaming. Five take over request scenarios were necessity of navigation decision, missing lane markings, sensor or software failure, roadwork zone, and heavy rainfall. Performance measures calculated were brake reaction time, first glance after TOR, time to deactivate the automation etc. Analysis method used was ANOVAs (split-plot) and SPSS was used for all the statistical tests with a significance level of less than 0.05. Results showed that the deactivation time was 7-8 s for 90% of the drivers when they were distracted. First gazes after the TOR were delayed by 5 s for the distracted drivers in case of automation compared to the drivers in manual driving.

It is believed that drivers in automation mode may feel fatigued faster than that in the manual mode. Thus, TOR in the condition of fatigue may pose lack of safety. To analyze the performance of drivers towards TOR in such situation of fatigue, Vogelpohl et al. [28] considered mixed factorial design for a driving simulation study with 60 drivers. Fatigue sources considered were lack of sleep and monotonous driving, and driving modes were automation and manual. The TORs were provided via auditory signal and symbol for heavy degradation of sensor due to heavy rainfall and inability to identify pavement marking and other objects. To analyze the reaction, ANOVA (two-way) and t-test was used to compare brake reaction times, and no significant difference was found between two fatigue groups. Results indicated drivers in the automated driving faced fatigue earlier than the manual driving condition due to loss of engagement in driving tasks, and the deactivation time was longer for some of the drivers from the group with lack of sleep. Also, despite having enough sleep, automation made the drivers fatigued and they were slow to react to TOR [28].

To compare the lane changes in automated driving with semi-automated or manual lane change, Dillmann et al. [29] conducted a driving simulator experiment with 85 drivers considering three scenarios of lane changes. The scenarios were automated, semi-automated and manual. There was a critical take-over situation at the end of every scenario. Drivers' engagement in the NDRT were evaluated by the number of multiple-choice questions answered. Time duration between take-over control and brake pedal release as well as time duration between take-over signal and maximum deceleration were measured for analyzing braking behavior. Using linear mixed modeling, results showed that manual and semi-automated lane change resulted in 17% and 13.5% faster deceleration time, respectively compared to the automated lane change. Also, percentage of the gaze off-the-road was significantly lower for manual and semi-automated lane changes. Overall this study suggests that manual and semi-automated lane change will help drivers to maintain the perception-action loop and improve the safety of automated driving.

To observe the intention of drivers in accepting the NDRT (texting task) offered before the TOR, a driving simulation experiment was conducted by Wandtner et al. [30] using level 3 automation. Number of participants in this study was 20 who drove in the automated and manual mode. One group was aware of the upcoming track with highly automated driving condition, but the control group was not aware of this situation. TOR requests were given in auditory and icon form. Between the subject factor of the mixed design was group who knew about upcoming track and the one who didn't. Within subject factors were driving mode (automation and manual) and NDRTs (texting, no texting). As a form of performance, number of tasks accepted during the driving task were calculated. Engagement in task was higher in the manual mode. However, drivers who knew about the availability rejected the NDRT more often than their counterparts and their take over performance was safer.

Drivers' engagement with NDRTs have relation with the driving experience. This fact was shown in a driving simulator study by He & Donmez [31] with 16 novice drivers and 16 experienced drivers. Participants were tested by giving NDRTs on the in-vehicle display. Performance measures considered were average glance duration (ms), manual interaction rate (taps/minute), glance rate (glances/minute), long glance rate (glances longer than 2s/minute), and percent time looking at the secondary-task display. Using measures like heart rate, GSR and NASA-TLX, workload was also assessed. Models used for the analysis were negative binomial models and mixed-effects models. The results demonstrated that novice drivers' interaction rate with the task display was higher than the experienced drivers in case of automated driving.

Chen et al. [32] assigned both novice (24) and experienced (24) drivers in a driving simulator experiment to examine the effect of experience in the performance of takeover. Two-time budgets for the takeover – 7 s and 5 s and visual NDRT were examined. The results suggested that novice drivers, who had worse maneuvers and takeover stability in longitudinal control, were affected mostly than lateral control. On the other hand, there was no significant differences in these two driver groups in terms of takeover time, automation disengagement time, and minimum time to collision.

Large et al. [33] used a medium fidelity driving simulator with 6 participants to explore the effect of automation in driving performance. To simulate regular driving such as commuting to work, participants drove 30 minutes in the simulator for five days consecutively. The drive started with manual driving and participants could start the automated driving with a voice command at 70 mph with a transition period of 5 s. There was a beep and voice message when the automation got functional after the 5 s transition period. Every day, the drives ended with a take-over to manual control. This take-over happened with a warning ("approaching take-over") and an alert (resume manual control") with a 5 s transition period. Authors summarized different activities performed by the participants during automated driving such as reading paper copy, accessing websites, reading articles on iPad, social networking activities etc. Regarding the posture, participants used the time of automated control to relax and had a strict posture immediately after resuming the manual control from automated driving.

Considering the traffic density as factors in addition to manual and automated control, Jamson et al. [34] conducted a driving simulator study by using two factor design. The objective was to explore the drivers' behavior due to the impact of automation and 49 drivers were recruited. Highly automated driving was available on request for longitudinal and lateral control together. Participants were allowed to choose different forms of entertainment in the vehicle such as magazines, games, films, TV programs etc. Dependent variables chosen for behavior assessment were drivers' lane choice to overtake slower traffic and TTC for safety measurement. Eye tracking for assessing distraction and percentage of eyes closed were also observed to assess the drowsiness of participants. The results indicated that automation did not increase the chance of rear end accidents even in the presence of heavy traffic. This study also observed higher interaction with the NDRTs in case of highly automated driving.

Tang et al. [35] used peppermint odor to increase the alertness among the participants when taking over control from a conditionally automated driving mode. 60 participants in the driving simulation experiment had to avoid a stopped car after they woke up from a light sleep (NDRTS) state and received a TOR. Participants were required to have at most 6 hours of sleep during the night before the experiment so that they could enter into a state of light sleep during the experiment. The subject factors included three modes of TOR which were tactile, auditory, and combined. Receiving peppermint odor and just air as placebo were between subject factors. Results suggested that the peppermint odor did not influence the reaction time but the drivers became more careful after receiving the odor thus improving the takeover quality.

Using level 2 automation mode, a driving simulator study with 60 participants was conducted by Yang et al. [36] to investigate the effect of foot and hand placement on reaction time towards a TOR. Authors of this study used a real-life scenario and the TOR was given at the boundary of the automation mode. They found that during the event, more than 64% of the participants' foot was close to the pedals whereas only 12% kept their hand on the steering wheel. Results indicated risky situations during takeover in case of older drivers. Also, reaction time that contributed to crashes was greater than 0.9 seconds.

To determine the effect of supervised automation system on drivers' performance, Pipkorn et al. [37] performed a test track experiment with 76 participants. Among them, 30 drivers needed to place their hands on the steering wheel under the supervised automation or driver assistance system. Other factors considered were avoiding a stopped vehicle and a garbage bag to prevent crash. To assess the drivers' performance, surprise reaction timepoint, hands on wheel timepoint, steering timepoint, brake timepoint, on-path glance etc. were considered. Results showed low-trust drivers were faster in response and hands on wheel did not change the drivers' response during conflict, rather the response during conflict changed due to level of trust and type of conflict object. It was also concluded that low trust was accompanied by appropriate response whereas high trust was connected to crash and late responses.

Sahaï et al. [38] examined the effect of training programs on drivers' performance of taking over control. 52 participants were trained via paper, video, and practice. The trained participants drove an automated vehicle on public roads where they were assigned both urgent and non-urgent TOR. To assess the performance, take over time, mental workload, visual behavior, and flow levels were measured. It was found that practice trained participants responded faster than others.

Some other studies which also focused on the performance of drivers when they are given TOR are Radlmayr et al. [39], Mok et al. [40], Gold et al. [41], Eriksson & Stanton [42], Roche et al. [43], Roche et al. [44], Roche [45], Gold et al. [46], Linehan et al. [47], Varotto et al. [48], Sanghavi et al. [49], and S. Yang et al. [50].

3.3. Preferences and Willingness towards CAVs

A web-based survey for Chicago metropolitan area was conducted by Shabanpour et al. [51] to investigate the preferences of consumers for electric and automated vehicles. Number of respondents to this survey was 1253. Respondents were given four types of vehicle options and select the one most favorable to them. The alternatives include gasoline vehicle with automation and no automation, and electric vehicle with automation and no automation. To analyze the responses, random parameter logit model was applied. Results indicated that demographic characteristics, driving patterns of the respondents, anticipating benefits of AV and electric vehicles, and experience about the technology are the contributing factors behind the participants' adoption behavior.

Rahimi et al. [52] also investigated the user adoption of AV technology by a survey. According to the distinct set of attitudes from the survey results, three user groups were recognized: users who are auto-dependent, users of all-modes, and non-drivers. To identify the user groups, latent class clustering was used whereas structural equation modeling (SEM) was used to differentiate their attitude as well as to determine their affinity to AV. The findings demonstrated that attitudes are crucial in determining how people embrace AV. Even when self-driving capabilities might encourage auto dependent users to adopt AV technology, driving assistance capabilities appeared to be more crucial for all-mode users in AV adoption. Authors recommended finding the validity of this result by surveying a nationally representative sample.

Wali et al. [53]focused on consumer affinity towards CAVs using data of 3500 households from the California Vehicle Survey (CVS). This study focused on both partial CAVs and full AVs. The findings indicated that 64% of the families surveyed were in favor of partial AV and that 35% would consider purchasing full AV in the future. Number of households that had lower affinity towards full AVs was higher than the number of households with lower affinity towards partial CAV. Households that have safety concerns about full AVs have lower probability of buying them. Also, current owners of electric vehicles have positive correlation with affinity towards both partial

CAVs and full AVs. Authors suggested integrating the findings into travel forecast model to predict future use and ownership patterns of partial and full AVs.

To compare the attitudes, perception and experience of people who used CAVs and who did not, Dennis et al. [54] designed two types of survey questionnaires. One survey was for general public (236 responses) while the second survey was conducted among those who experienced CAVs (153 responses). Analysis method adopted for the responses was discrete choice models penalized logistic regression. Analysis revealed that male respondents were less resistant to CAVs than females, people with higher levels of education were more receptive to CAVs, and younger individuals tended to be more accepting than older individuals. Additionally, those who used work vehicles and ride-hail anticipated receiving lower benefits from CAVs.

Bansal & Kockelman [55] surveyed 1088 people from Texas to understand the opinion about CAVs and other relevant decisions regarding CAVs. Using ordered probit (OP) and interval regression (IR) models, relation between response variables (willingness to pay (WTP), adoption rate etc.) and independent variables (demographics, travel patterns, crash histories etc.) was estimated. The WTP for connectivity and all degrees of automation was lower among older and more experienced drivers, but people with higher incomes and greater safety concerns showed higher WTP by the addition of these technologies. People of Texas expressed their opinion to pay on average, $2,910 for Level 2, $4,607 for Level 3, $7,589 for Level 4 automation, and $127 for connectivity to get the advantage of automation and connectivity. While cost and failure of equipment are the two major concerns, the most expected benefits are fuel efficiency and crash reduction.

Besides attitudes, preference, and willingness to pay, acceptance of the automated technology is another important aspect. Castritius et al. [56] surveyed 536 participants in Germany and California to understand the acceptance level of truck platoons among the road users after they received information on truck platoon driving. They also investigated the influencing factors behind the acceptance. Respondents were questioned regarding both their behavioral intentions to cooperate with the platoons of truck and their attitudes toward the platooning technology. With acceptance rates much higher in California than in Germany, the aggregate results showed that 70% of respondents stated their acceptance toward the technology.

Hartwich et al. [57] investigated the acceptance, enjoyment, and comfort towards automated driving between younger and older age groups. Effects of automation and style of automated driving were considered in this study. A total of 20 older and 20 younger drivers were recruited for conducting a driving simulation study. A negative impact of automation on the enjoyment of automated driving for younger people was found. However, increased comfortability was observed for both age groups. In terms of acceptance, younger drivers accepted the system in case of familiar driving style in automation, whereas older people did so in case of unfamiliar driving style. In another study, Hartwich et al. [58] examined the trust and acceptance after initial experience of the system and conducted two automated driving sessions in a driving simulation experiment among 40 participants. Results showed that trust and acceptance increased significantly after the initial system experience and remained constant. However, older drivers showed more positive attitude towards highly automated driving.

Frison et al. [59]used different scenario types in a driving simulation experiment to evaluate their impact on perceiving the automation. The tested scenarios included light, moderate and heavy traffic as well as rural, highway and urban road. Total of 30 participants completed three trips each in fully automated car of a driving simulator. It was concluded that perception on automation varies with respect to the type of use and trust issue occurs in case of complex scenario with other road users (e.g., pedestrians, other vehicles).

In Czech Republic, a survey was conducted among 1065 participants to investigate their attitude and perception regarding CAV policy makings [60]. The participants were older than 15 years of age and were personally interviewed. Only 65% of the survey respondents heard about CAVs before participating in the survey study. However, there was a connection between the negative attitude towards CAVs and lower household income, low education level and older age. Another survey among the general public of the Czech Republic was conducted after providing some information on CAVs to the focus groups [61]. As part of this survey, 1116 individuals were interviewed personally by 59 professionals. Results revealed that women were mostly neutral and negative about CAVs whereas men showed more awareness about CAVs. While older people did not prefer any new information on CAVs, younger people preferred internet as a source of receiving new information related to CAVs.

While connectivity and convenience are important, some people also have concerns on the security threat via connected and automated vehicle technology. To explore this fact, 602 people were assigned for a pilot survey in South Korea and 1000 people between the ages of 20 to 70 were surveyed [62]. The objective was to examine the information security risks consumers believe to be the most threatening as well as customer preference for information security solutions that secure their CAVs from these attacks. To analyze the responses, Mixed logit model and mixed probit model were developed. According to the results, consumer perception of information security risks includes miscommunication and unauthorized acquisition of personal information which suggests that confidentiality and availability are more crucial to CAV security than other elements. When selecting a CAV information security solution, ease of use is also crucial. Examples include automatic upgrades and a security dashboard.

3.4. Gaps in Previous Studies

Based on the reviewed literature on drivers' behavior and interaction in section 3.1, it is clear that many prior studies focused on examining drivers' gap acceptance and following headways. Other driving behaviors such as speed, acceleration, deceleration and TTC are not comprehensively studied yet. Also, to compare between different scenarios of merging and diverging in a simulation experiment, different CAV penetration rate, different platoon size etc. were considered. Though HDVs were considered as base scenario in most of these studies, closely spaced HDVs which can also create some challenges for drivers near on-ramp and off-ramp was not considered to compare their interaction in the presence of CAV platoon near on-ramp and off-ramp.

Though many prior studies investigated drivers' reaction in case of automation failure or transition from automation to manual mode, most of these studies focused on highway driving. The reaction of drivers to automation failure in local road with low traffic intensity, especially their reaction during the automation mode in local road is not yet clear. Also, very little is known about the acceptance, preference, need and challenges of drivers towards CAVs.

4. METHODOLOGY

To achieve the objectives of this study, three different methodologies were followed. Figure 2 illustrates the project's objectives and the followed methodologies.

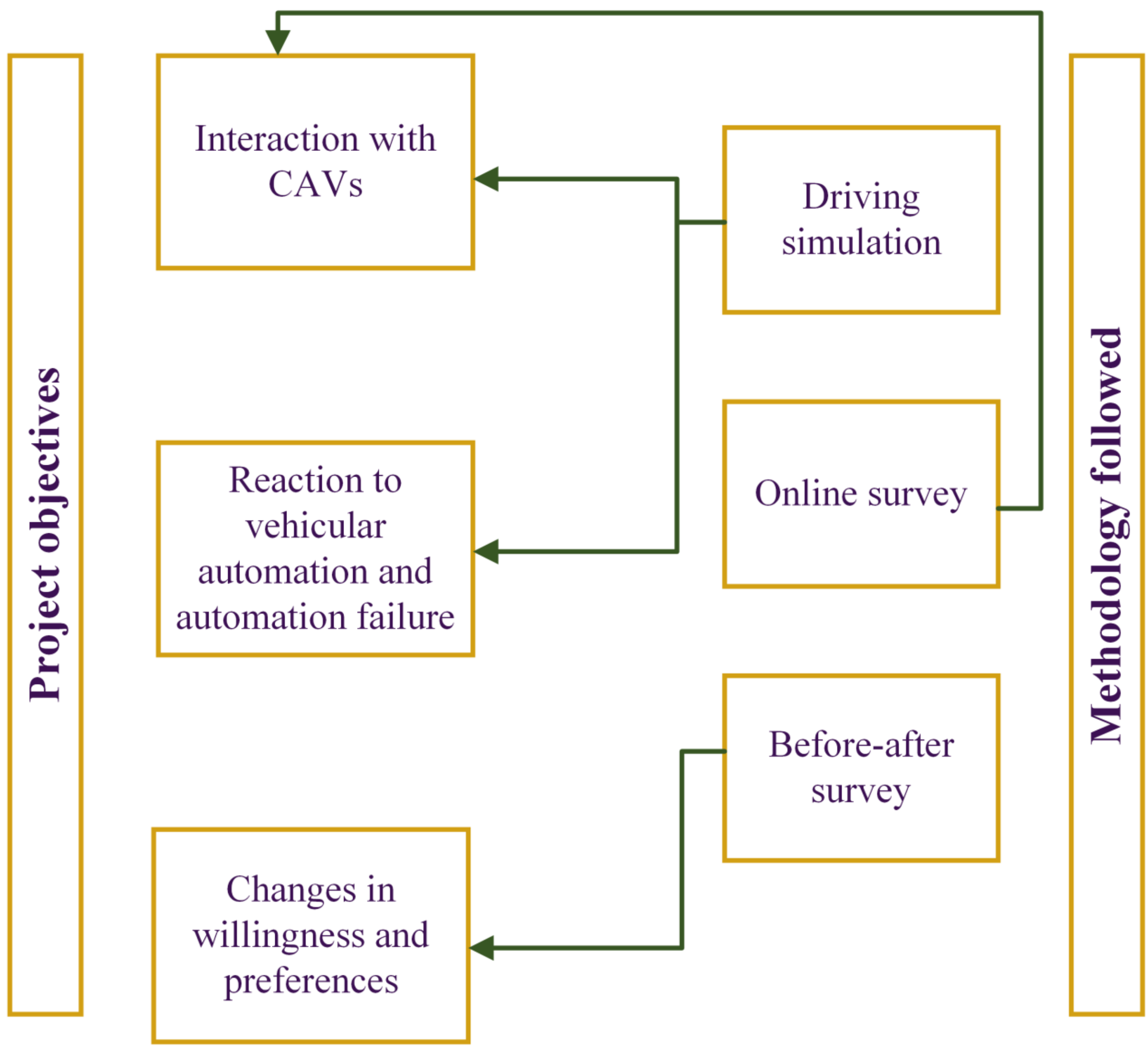


Figure 2. Project objectives with followed methodology.

4.1 Driving Simulation Experiment

To investigate drivers' interaction with HDVs and CAVs platoon of trucks near on-ramp and off-ramp, a driving simulation experiment was designed and conducted among a sample of drivers. The LSU driving simulator was used to design the experiment for the driving simulation. The current LSU Driving Simulator is a full-sized passenger automobile (Ford Fusion) coupled with a number of cameras, projectors, and screens to generate a high-fidelity virtual environment that gives a high degree of driving realism. It offers a motion simulation with one degree of freedom so that a driver can experience similar driving efforts to those in an instrumented vehicle. Its open architectural software tools enable the building of new networks, an infinite number of simulation scenarios (virtually), and data collection during simulation experiments. Figure 3 shows the LSU driving simulator with a part of the scenarios designed for this study.

Figure 3. LSU driving simulator.

4.1.1. Merge and Diverge Scenarios Design

A 4.5-mile section of 2-lane highway was designed which consisted of on-ramp and off-ramp sections. The speed limit near on-ramp and off-ramp was set at 50 mph. Each participant in the ramp scenarios interacted with two different types of vehicle platoon types - HDVs and CAVs trucks (as shown in Figure 4). Scenarios with HDVs include truck and passenger cars to represent regular traffic situations and scenarios with CAV platoon included four CAV trucks.

Since the simulation design software (SimCreator DX) does not have a built-in feature to create platoons of vehicles, the CAV platoons and HDVs were designed using the software's path editing capabilities. This function enables a particular vehicle to start once the subject vehicle has reached a predetermined position on the roadway network. Four trucks with similar colors (blue as shown in Figure 4) and similar headways were manually placed in the network to create the platoon. Similarly, HDVs were manually inserted in a predetermined spot. To ensure that all participants interact with the platoon and the HDVs near the entrance and exit, the ideal trigger point for these vehicles to be started was determined through multiple iterations of trial and error.

Headway gaps from 0.3 s to 1.4 s were used in previous studies. A headway of 0.5 seconds was selected since this study considers closely spaced HDVs near on-ramp and off-ramp of two-lane busy highways. Though identical spacing between HDVs is unfeasible, the headways for CAV platoon and HDV were set with similar headway in order to simplify comparisons. Following are the four scenarios tested for this part.

- On-ramp scenario with HDVs shown in Figure 4 (a)
- On-ramp scenario with CAV (truck) platoon shown in Figure 4 (b)
- Off-ramp scenario with HDVs shown in Figure 4 (c)
- Off-ramp scenario with CAV (truck) platoon shown in Figure 4 (d)

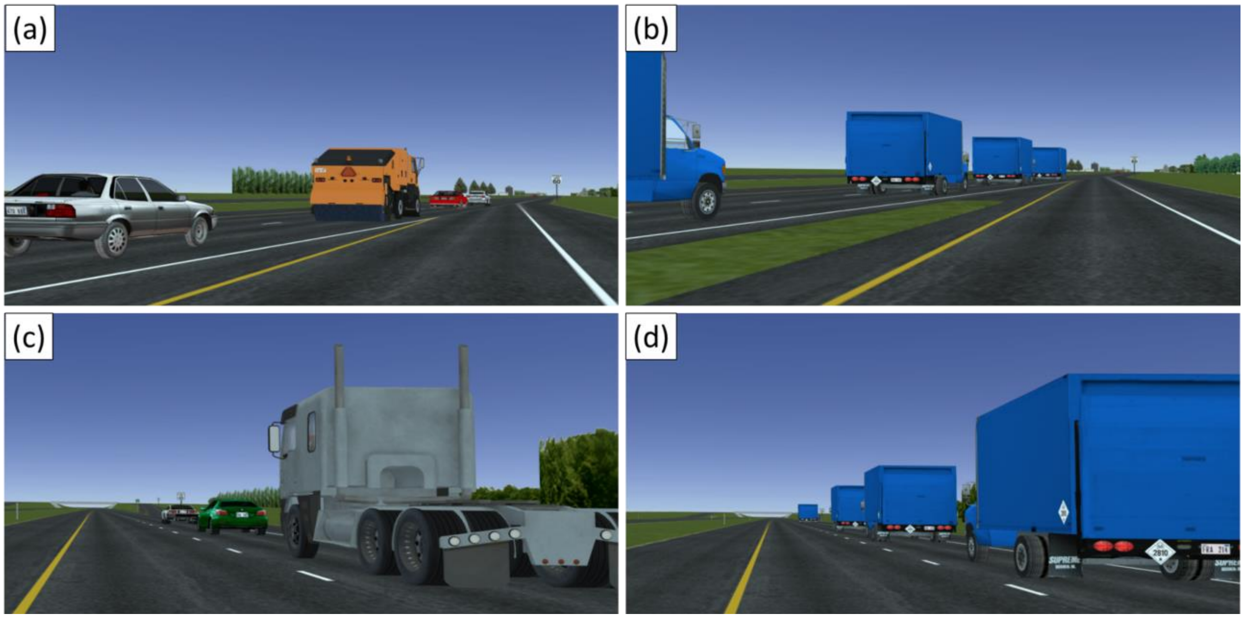


Figure 4. On-ramp and off-ramp scenarios.

4.1.2. Vehicular Automation Scenario Design

A 6000 meters (around 3.75 mile) non-highway road network consisting of three signalized intersections was designed for testing drivers' reaction to automation failure. After driving around 0.5 mile on the local road, an audio message was relayed to let the participants know that the vehicle will be switched to an automation mode, so driver's control is not needed. According to the Society of Automotive Engineers (SAE) Levels of Automation, there are six levels of automation from SAE level 0 (no automation) to SAE level 5 (full automation). Level 0, 1, 2, 3, 4 and 5 represent no driving automation, driver assistance, partial driving automation, conditional driving automation, high driving automation and full driving automation, respectively [63] . From level 3 to level 5, drivers though might be seated, they do not have to drive when automation is engaged. However, in case of level 3, they have to drive if requested by the feature [64].

This study simulates level 3 automation, in which drivers are not responsible for steering, accelerating, braking etc. until the need for transition arrived due to automation failure. In case of automated vehicle, necessity of taking over comes to accommodate the transition from automation mode to human driver mode which includes resuming control of the vehicle, monitoring the environment, monitoring other road users etc. [65]. In this study, the subject vehicle was in automation mode for 2.2 miles where changing lanes, accelerating, braking at intersection, steering etc. was performed by the car itself. After 2.2 miles, when the vehicle was 110 m away from an intersection, automation got disabled and participants were asked to take control at that time through an audio message – "*please take over control*".

Speed limit on the local roads was set at 45 mph, thus the automation mode was also set to drive at 45 mph. According to AASTHO guidelines, stopping sight distance for 45 mph speed is 360 ft (109.73 m) [66]. Thus, to provide sufficient time to resume the manual control of the vehicle, takeover request (TOR) was issued before 110 m from the intersection. If participants take control appropriately and drive at 45 mph, once the automation gets disengaged, they can safely stop before the intersection where the light turned to red, and two pedestrians were crossing the road (Figure 5). All the participants drove 2 scenarios with automation mode. In the first scenario, they were not allowed to do any non-driving related task, but they could relax. In the second scenario, they were allowed to use their phone as well as relax if they wanted to.

Figure 5. Automation failure scenario.

4.1.3. Procedures

To take part in the driving simulator experiment, a sample of Louisianan drivers from various age groups were recruited. Participants were scheduled for an assigned time to participate in the simulation experiment. The research assistant/experimenter of this project briefed participants on the experiment upon arrival to satisfy the requirements of the Institutional Review Board (IRB) and get their approval to conduct experiments on human subjects. After knowing the study's goals, their involvement in the experiment, how to take part, how the information on driving behaviors would be kept anonymous, participants were then asked to sign a consent form. This was followed by answering a few questions about their backgrounds (age, gender, education etc.)

The participants were then directed to the simulation car, where the experimenter explained the steps to begin driving after adjusting the seat, mirrors, etc. If the volunteers felt uncomfortable or queasy due to motion sickness while driving in the experiment, the experimenter instructed them to press a red button close to the gear shift. Participants had then about a minute to check if the air conditioning and seat adjustments were comfortable for them. Then, each participant drove a warm-up scenario for 4 minutes to become accustomed to using the driving simulator, including making right and left turns, braking, changing lanes, merging, taking exits, etc. Finally, each participant drove through the four scenarios of merging and diverging scenarios and two scenarios of automation failure test which took approximately 20 minutes.

4.1.4. Participants

The experiment involved 42 participants, including 22 males and 20 women. Among them, 34 drivers (20 male and 14 females) completed the experiment successfully, while 8 drivers had to stop after a short period of time due to motion sickness. Regarding participants' age, 60% were between 18 and 24 years old while the remaining 40% being made up of drivers between the ages of 25 and 39, 40 to 54, and 55 to 64. Fewer than 6% of these drivers had less than 5 years of driving experience, whereas more than 60% had more than 5 years, around 30% had between 2 and 5 years of experience. About 70% of the participants had a bachelor's degree or higher, while the remaining 30% had a high school diploma or a college degree or lower. About 70% of the participants reported that they had not been involved in any accidents in the previous three years. Table 1 summarizes demographic characteristics for the 34 participants.

Table 1. Participants' demographic characteristics.

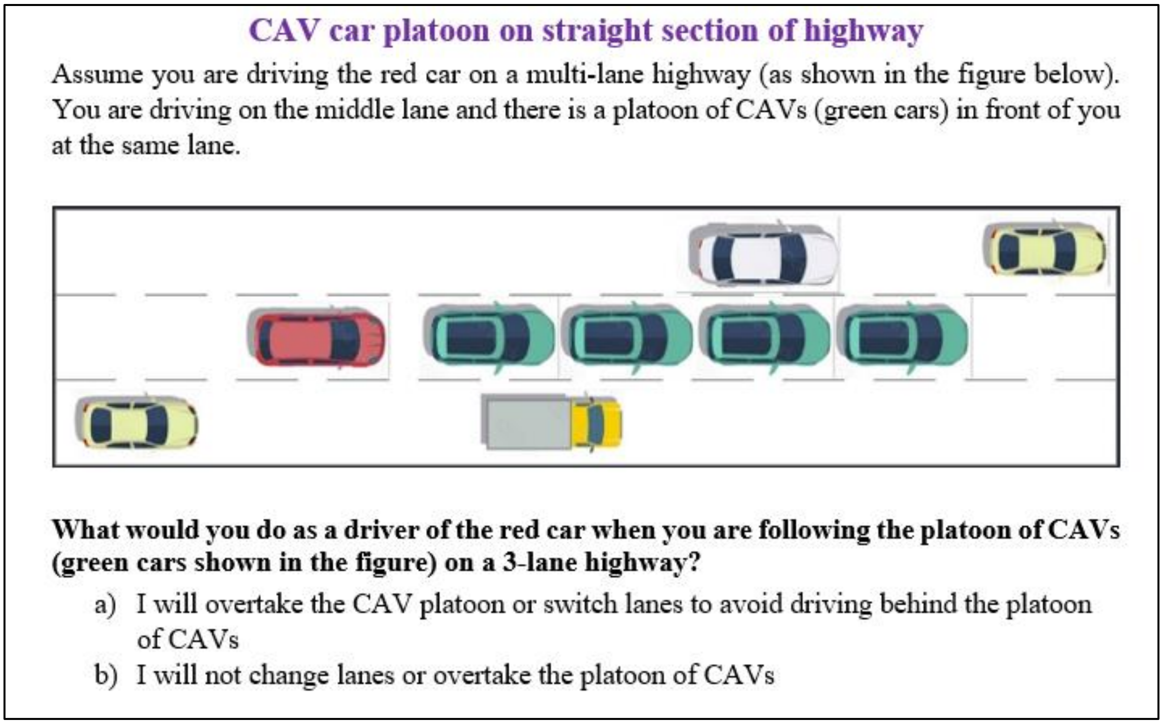
Factors	**Categories**	**Gender**		**Age**				Total
		Female	**Male**	**18-24**	**25-39**	**40-54**	**55-64**	
Driving experience	Less than 2 years	1	1	2	0	0	0	2
	2-5 years	2	9	11	0	0	0	11
	More than 5 years	11	10	8	7	5	1	21
Total		14	20	21	7	5	1	34
Education	High School Diploma	2	5	6	0	0	1	7
	College Diploma	1	3	3	1	0	0	4
	Bachelor's degree	9	10	12	5	2	0	19
	Master's degree	2	1	0	0	3	0	3
	Doctorate degree	0	1	0	1	0	0	1
Total		14	20	21	7	5	1	34
Accident Involvement	Yes	5	6	8	3	0	0	11
	No	9	14	13	4	5	1	23
Total		14	20	21	7	5	1	34

4.2. Survey Design

4.2.1. Online Survey

In addition to the driving simulation design to test driver's reaction during merge and diverge, an online survey was developed. The objective of this survey was to investigate driver's preference and interaction towards platoon of CAV cars and trucks on straight section of a highway and during adverse weather condition. Following aspects were covered in the survey questions.

- Demographic characteristics (e.g., age, gender, driving experience, employment status, education level etc.)
- Drivers' preference and challenge toward CAV car and truck platoon in different road and environmental conditions. Questions in the survey included driver's preference in interacting with CAV platoon on 2-lane 2-way highway, 3-lane highway, during adverse weather conditions etc. Figure 6 shows one of the survey questions along with the picture used to make the question clearer to the respondents.


CAV car platoon on straight section of highway

Assume you are driving the red car on a multi-lane highway (as shown in the figure below). You are driving on the middle lane and there is a platoon of CAVs (green cars) in front of you at the same lane.

What would you do as a driver of the red car when you are following the platoon of CAVs (green cars shown in the figure) on a 3-lane highway?

a) I will overtake the CAV platoon or switch lanes to avoid driving behind the platoon of CAVs
b) I will not change lanes or overtake the platoon of CAVs

Figure 6. One of the survey questions asked in the online survey.

The design and execution of the survey used an iterative, collaborative, human-centered, and design thinking methodology and the survey was administered by Qualtrics, which manages online panels of the general public and offers a range of services to facilitate data collection through surveys. Qualtrics constantly work to maintain a database of survey panelists who are representative of the target population. In our case, the target demographic was American people who were at least 18 years old and in possession of a valid driver's license. A soft launch was used to begin the data collection process and check for any inconsistencies in the responses. Final data collection was subsequently initiated based on the evaluation of the soft launch and a total of 1565 responses were gathered and used in the analysis.

4.2.2. Before and After Survey

A before and after survey study was designed and conducted among the participants in the driving simulator experiment. The main goal was to explore the changes in the opinion, attitude, and preferences of drivers toward CAVs after participating in the driving simulator experiments. The survey design, development, test, and implementation of the survey followed a design-thinking and user-centered approach. Key themes covered by this survey includes the following.

- Demographic characteristics of participants
- Self-reported preferences and challenges on a mixed road environment that has both CAVs and HDVs.
- Drivers’ behaviors and interactions with CAVs.

4.3. Analyzing method

Descriptive statistics were used for analyzing questionnaire survey data, before-after survey data and initial analysis of driving simulation data. Several driving simulator variables were collected to investigate drivers' interaction with CAVs and their reaction to automation failure.

All individual participants drove the two scenarios for on-ramp (with HDVs and CAVs), two scenarios for off-ramp (with HDVs and CAVs) and two scenarios for automation failure (no NDRT and with NDRT). Therefore, the measurements of the dependent variables (speed, maximum acceleration, maximum deceleration, TORt, TTC) were repeated and General Linear Model (GLM) repeated measures was used to analyze the results in IBM SPSS. An important requirement that must be fulfilled before performing repeated-measures ANOVA is the sphericity assumption. This assumption measures whether variance of differences between the measures are homogeneous. All these dependent variables of this study have only two measures such as interaction with HDVs and interaction with CAV truck platoon for ramp scenarios, no NDRT and NDRT for automation failure scenario. Thus, sphericity assumption needed for conducting the analysis was met for all. Therefore, this assumption will not be checked during the analysis.

Within subject factors that vary within the subjects/participants are vehicle type (HDV and CAV) for ramp scenarios and NDRT (no NDRT and NDRT) for automation failure scenarios. On the other hand, drivers' demographic characteristics (age, gender, education, driving experience and involvement in accident) were considered as between subject factors that vary between independent groups.

5. ANALYSIS AND FINDINGS

To achieve the three objectives of this study, this section of the report categorizes the analysis in the following five subsections.

- Drivers' interaction with other CAVs in mixed environment under different traffic, road, and environmental conditions.
  - 5.1. Interaction with CAVs near entry and exit
  - 5.2. Interaction with CAVs on straight section
    1. 5.2.1. Interaction with CAV Platoon on 2-Lane 2-Way Roads
    2. 5.2.2. Interaction with CAV Platoon on Multilane Highways
  - 5.3. Interaction with CAVs during adverse weather
- Drivers' reaction to possible cases of vehicular automation failure
  - 5.4. Reaction to automation failure
- Drivers' willingness and preference change before and after participating in the driving simulator experiments
  - 5.5. Willingness and preference change

5.1. Interaction with CAVs near Highway Entry and Exit

This section analyzes results from driving simulation experiment where participants interacted with HDVs and CAV platoon of truck near entry and exit of a 2-lane highway. First, participants' merging and diverging pattern in presence of HDVs and CAVs in both on-ramp and off-ramp are discussed. After that their speed, acceleration, deceleration and TTC are analyzed to evaluate their behavior and interaction in these scenarios.

5.1.1. Merge Pattern

Figure 7 represents drivers' merging maneuvers where orange-colored bars represent behaviors with HDV scenarios and blue-colored bars represent behaviors with CAV scenarios. According to Figure 7, more than 50% of participants merged with the highway from the on-ramp in the front of the CAV platoon of trucks (57.1%) and HDVs (54.3%) that were in the right-most lane of the highway. This finding is in line with the study by Aramrattana et al. [8] who reported that the majority of drivers merged in front of the CAV car platoon with 0.5 s headway. However, the study by Spasovic et al. [9] found an opposite trend; 60% of the drivers in their study chose to merge with the highway from behind the truck platoon of 0.5 s headway. These findings indicate the necessity of a comprehensive study with both car and truck platoons.

In terms of difference in interacting with HDVs and CAV platoon, the findings indicated that more drivers merged onto the highway in front of the platoon of CAVs compared to those who merged in front of HDVs. When it comes to merging behind the platoon or HDVs, around 40% drivers merged behind the platoon and fewer than 30% of the drivers did so in presence of HDVs near on-ramp. During the merge, 8 cut-ins happened, among them only 2 of them were in presence of CAVs near the entry. These statistics demonstrate that though drivers were not resistant towards merging in front of the CAV platoon, they were not comfortable in merging between the vehicles of CAV platoon.

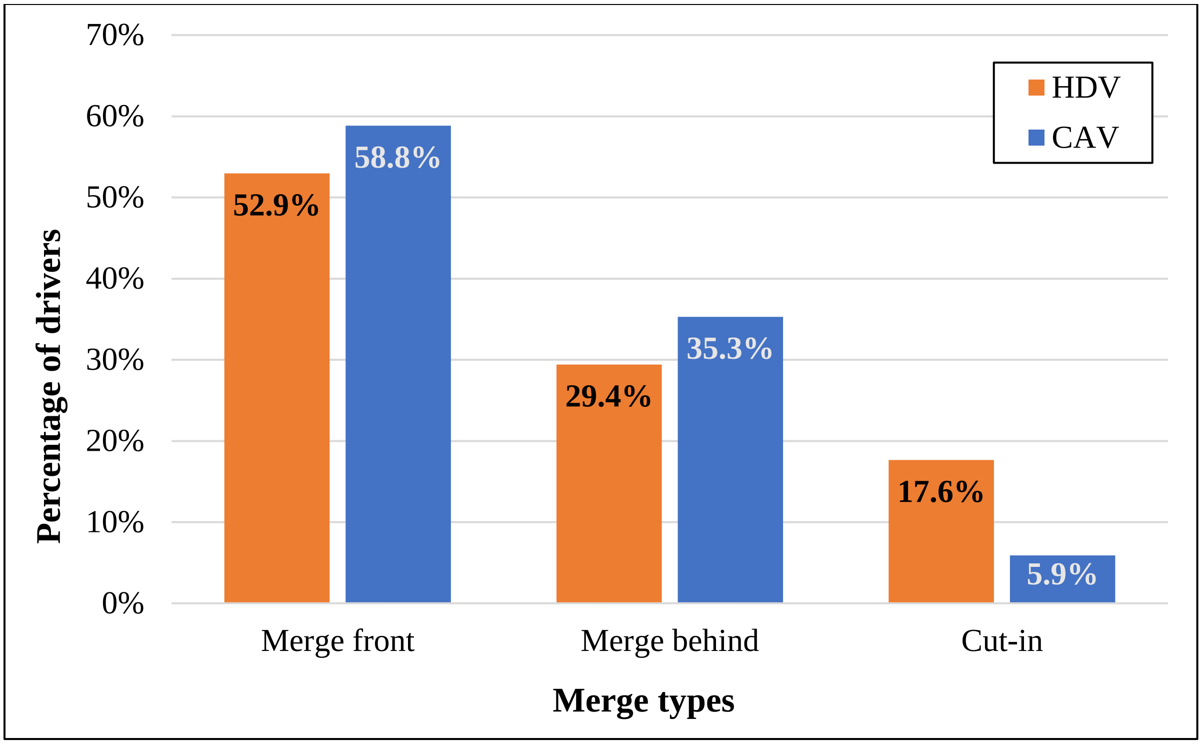


Figure 7. Drivers' merging paterns with HDVs and CAVs.

5.1.2. Diverge Pattern

Orange color bars in Figure 8 represents diverge pattern in presence of HDVs and blue-colored bars represent diverge pattern of the drivers in presence of CAV truck platoon. According to Figure 8, 60% of the drivers chose to diverge behind the HDVs and around two-third of the drivers behind the CAV truck platoon near the exit of the highway. One participant was confused whether to stay behind the CAV platoon or accelerate to pass them quickly, and thus missed the exit. However, 40% of the drivers accelerated to pass the HDVs and took the exit, whereas around one-quarter of them accelerated to pass the platoons near off-ramp. Only two cut-ins happened between the trucks of CAV platoon and no cut-ins were observed in presence of HDVs. While majority of the drivers in our study took exit behind the truck platoon, a previous study by Spasovic et al. [9] showed that only about 50% of the drivers took exit behind the truck platoon..

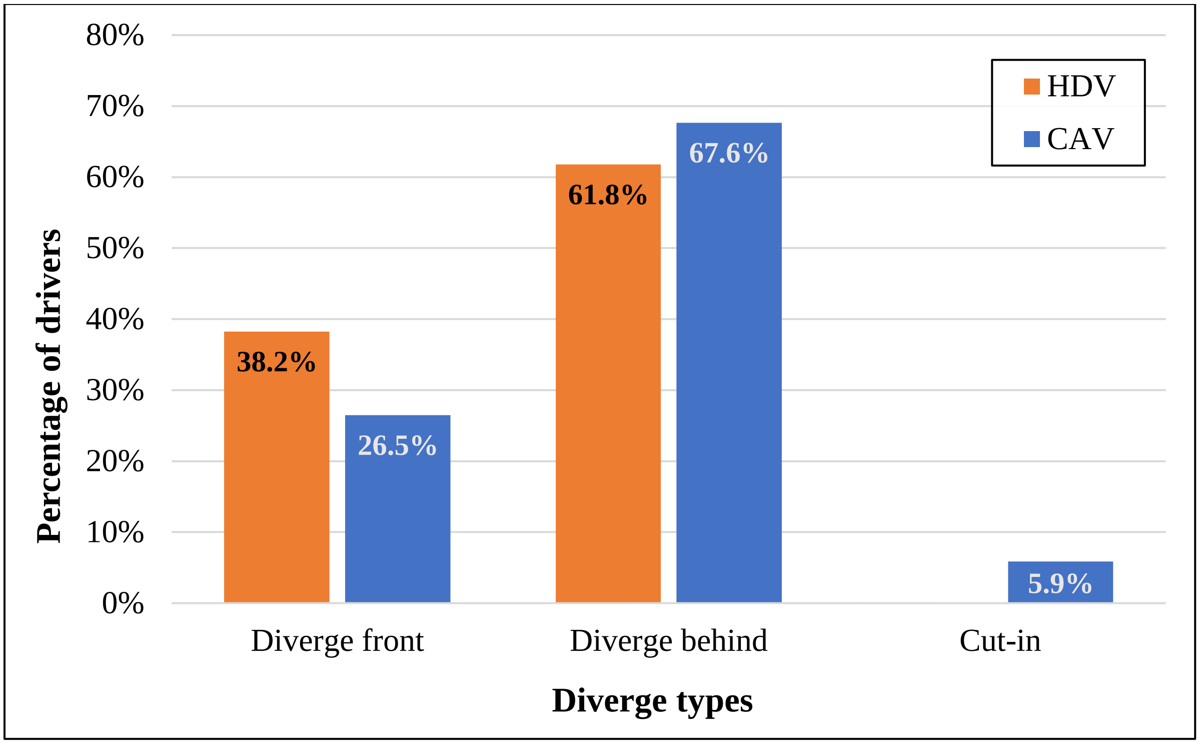


Figure 8. Drivers' diverging paterns with HDVs and CAVs.

5.1.3. Performance Measures

To investigate drivers' behavior during merge and diverge, four performance measures were selected. They are speed, acceleration, deceleration and minimum TTC. As indicated earlier, 34 observations were considered for analyzing drivers' behavior. However, two observations were disregarded as they were found to be extreme outliers. Thus, 32 samples were used for the following performance measures.

Average Speed: Drivers' average speed during merge or diverge near on-ramp and off-ramp in presence of HDVs and platoon of CAV trucks.

Maximum Acceleration: The maximum acceleration value during merge and diverge in presence of HDVs and CAVs.

Maximum Deceleration: The maximum deceleration value during merge and diverge in presence of HDVs and CAVs.

Minimum TTC: The minimum TTC value during merge and diverge in presence of HDVs and CAVs. Minimum TTC was used in this study as a surrogate measure for traffic safety.

5.1.4. Average Speed Analysis

Descriptive Statistics: Figure 9 represents boxplots for the average speed during merge and diverge in presence of HDVs and CAV truck platoon where blue color represents scenarios with CAV platoon and orange color stands for scenarios with HDVs. According to Figure 9, for both merge and diverge scenarios, average speed has higher variation in case of HDVs than CAV platoon. The range of average speed is almost similar for both HDVs and CAVs during exit. When it comes to merge, merge in presence of HDVs has way higher range of average speed than CAV scenario. Median average speed values are higher for merge scenarios (over 55 mph) than diverge scenarios (around 50 mph). Table 2 shows mean, SD, maximum and minimum values for average merge and diverge speed for HDV scenarios and CAV scenarios. In every situation examined in this experiment, average speed values were from 52 to 59 mph, exceeding the 50 mph speed limit. Standard deviation was higher for on-ramp scenarios in presence of HDVs, which is also supported by higher spread of the boxplot for merge HDV. To investigate whether average speed differs between the scenarios with HDVs an CAVs, repeated measure procedures were applied.

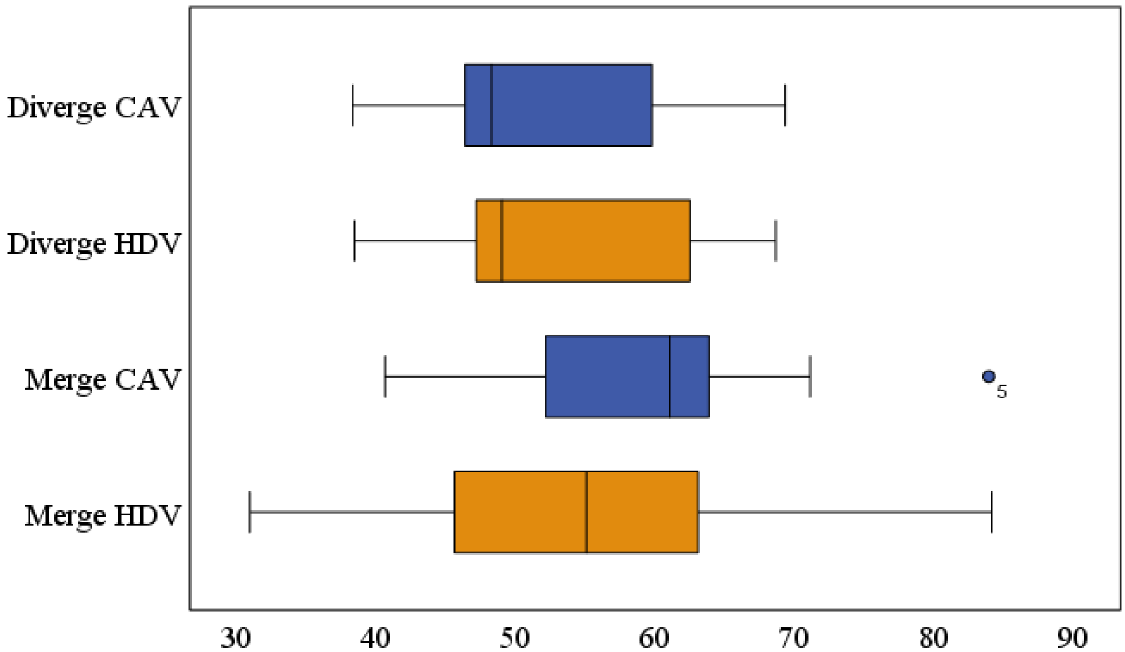


Figure 9. Average speed during merge and diverge.

Table 2. Summary of average speed statistics for merge and diverge scenarios.

Ramp	Vehicle type	Min	Max	Mean	SD
On-ramp	HDV	30.97	84.11	55.36	12.98
	CAV	40.66	83.95	59.64	9.86
Off-ramp	HDV	38.47	68.62	53.38	8.74
	CAV	38.33	71.35	52.65	9.47

Repeated Measure Analysis: Figure 9 shows only one mild outlier for merge scenario in presence of CAVs, therefore no significant outliers are present for average speed. Q-Q plots shown in Figure 10 denotes that average speed for all the scenarios are approximately normally distributed.

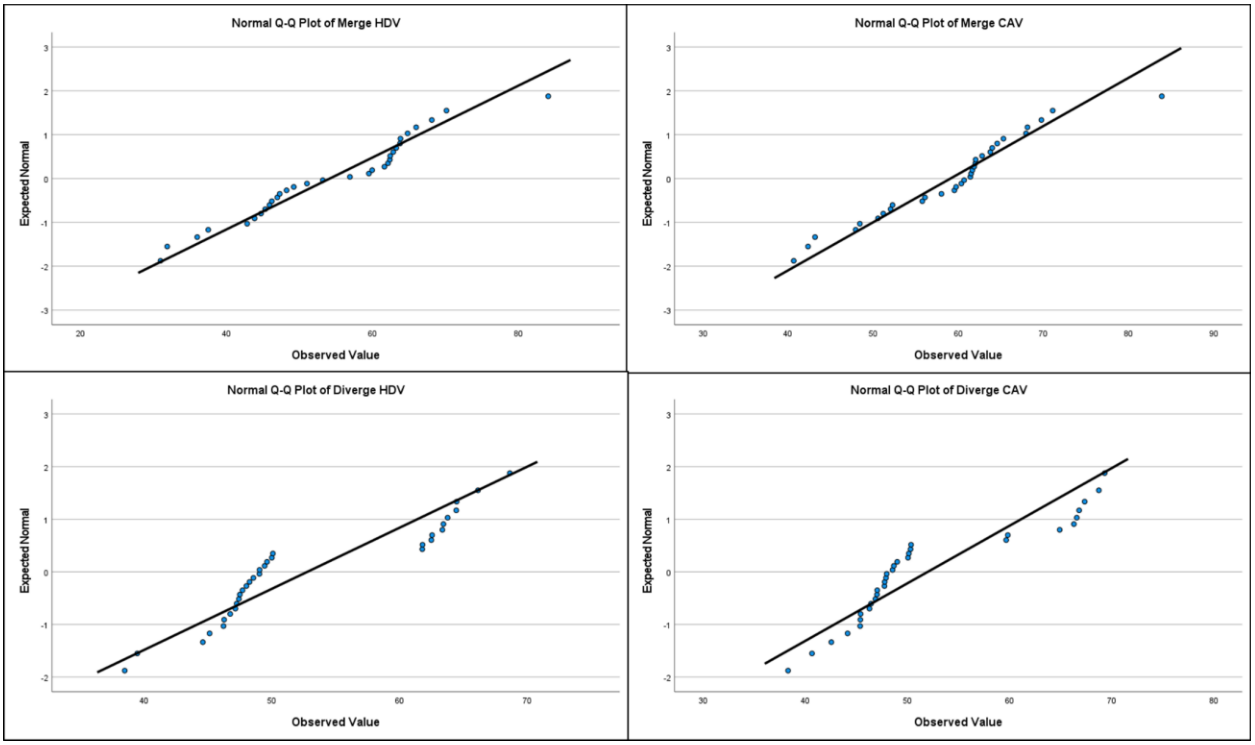


Figure 10. Q-Q plots for average speed in the ramp scenarios.

Results presented in Table 3 show no significant result at 95% confidence level. However, there is one significant main effect ($p = 0.06$) at 90% confidence level for vehicle type in case of merge scenarios. This means that there is statically significant difference between average speed during merging with HDVs and CAV platoon of trucks. The average speed was higher in case of merging in the presence of CAV platoon (59.64 mph) than when merging in the presence of HDVs (55.36 mph). No significant main effect was found for drivers' demographic characteristics such as gender, age, experience etc. However, a significant interaction effect ($p = 0.08$) was found between vehicle type and prior involvement in traffic accidents. The profile plot in Figure 11 shows the interaction effect between vehicle type (HDVs and CAVs) and participants' involvement in accident. According to the Figure 11, individuals who were not engaged in prior traffic accidents had lower average speeds while interacting with HDVs (51.1 mph) than those who were involved in accidents in the previous three years (56.5 mph). In case of CAVs, this trend was opposite. This indicates that in presence of CAV truck platoon near off-ramp, participants with no involvement in prior traffic accident had higher average speed than their counterparts.

Table 3. Analysis of variance results for average speed.

Ramp	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
On-ramp	**Vehicle**	**198.31**	**1**	**198.31**	**3.88**	**0.06**
	Gender	52.40	1	52.40	0.17	0.68
	Age	34.55	1	34.55	0.11	0.74
	Experience	290.83	1	290.83	0.96	0.34
	Education	50.47	1	50.47	0.17	0.69
	Accident	372.89	1	372.89	1.23	0.28
Off-ramp	Vehicle	51.83	1	51.83	1.45	0.24
	Gender	52.47	1	52.47	0.33	0.57
	Age	10.85	1	10.85	0.07	0.80
	Experience	66.10	1	66.10	0.42	0.52
	Education	27.95	1	27.95	0.18	0.68
	Accident	19.50	1	19.50	0.12	0.73
	Vehicle * Accident	**122.09**	**1**	**122.09**	**3.42**	**0.08**

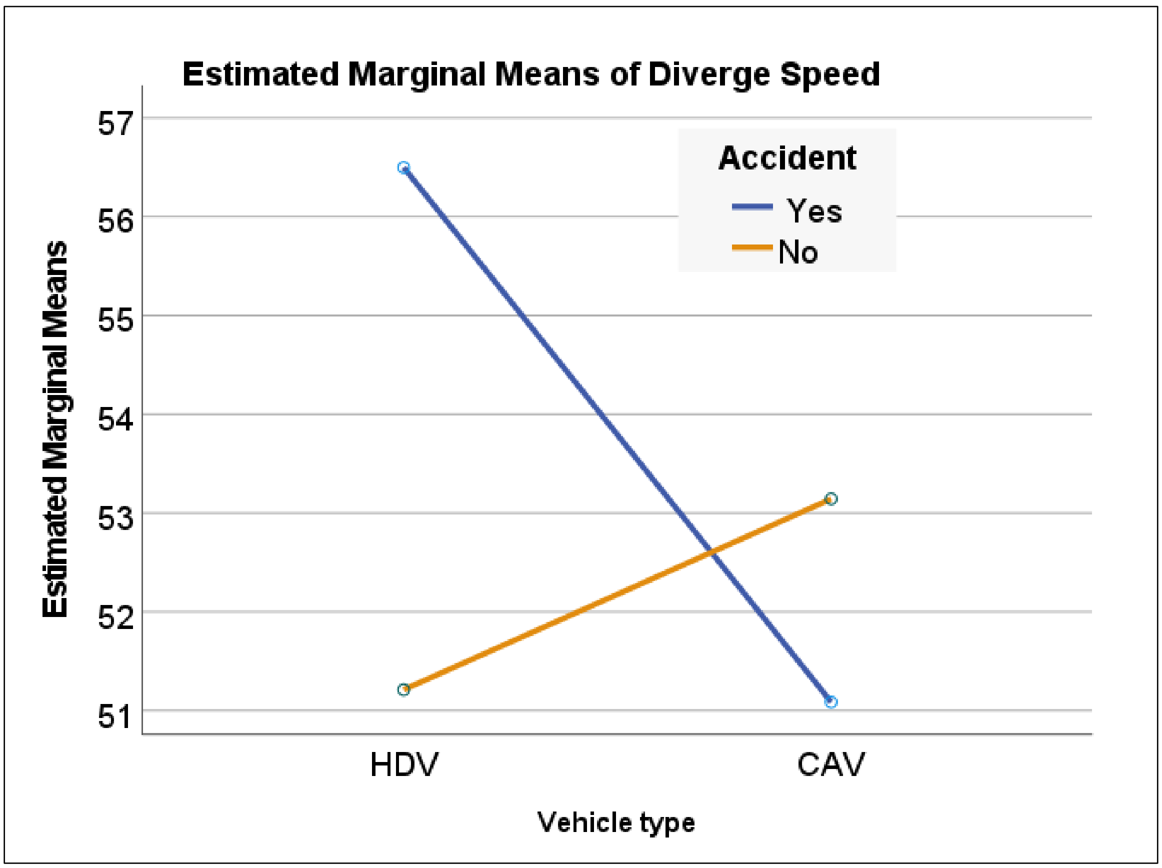


Figure 11. Interaction effect between vehicle type and accident involvement for average diverge speed.

5.1.5. Maximum Acceleration Analysis

Descriptive Statistics: Boxplots for maximum acceleration values in Figure 12 indicate that participants' maximum acceleration was higher in merge scenarios than in diverge scenarios. Also, median value and range of the maximum acceleration are similar in both on-ramp scenarios. On the other hand, median maximum acceleration was lower for HDVs than CAVs when diverging. Acceleration variability was higher during diverging in the presence of CAVs. Given that most participants merged in front of HDVs and CAV platoon and deviated from highway behind the platoon, it makes sense that maximum acceleration is higher at the on-ramp scenarios than the off-ramp scenarios. According to Table 4, the mean maximum acceleration values are around 0.16 fts^{-2} and 0.03 fts^{-2} for on-ramp and off-ramp scenarios, respectively. Minimum value, maximum value and standard deviation of acceleration values are given in Table 4. In both on-ramp and off-rap scenarios, standard deviation was higher for HDVs than CAVs.

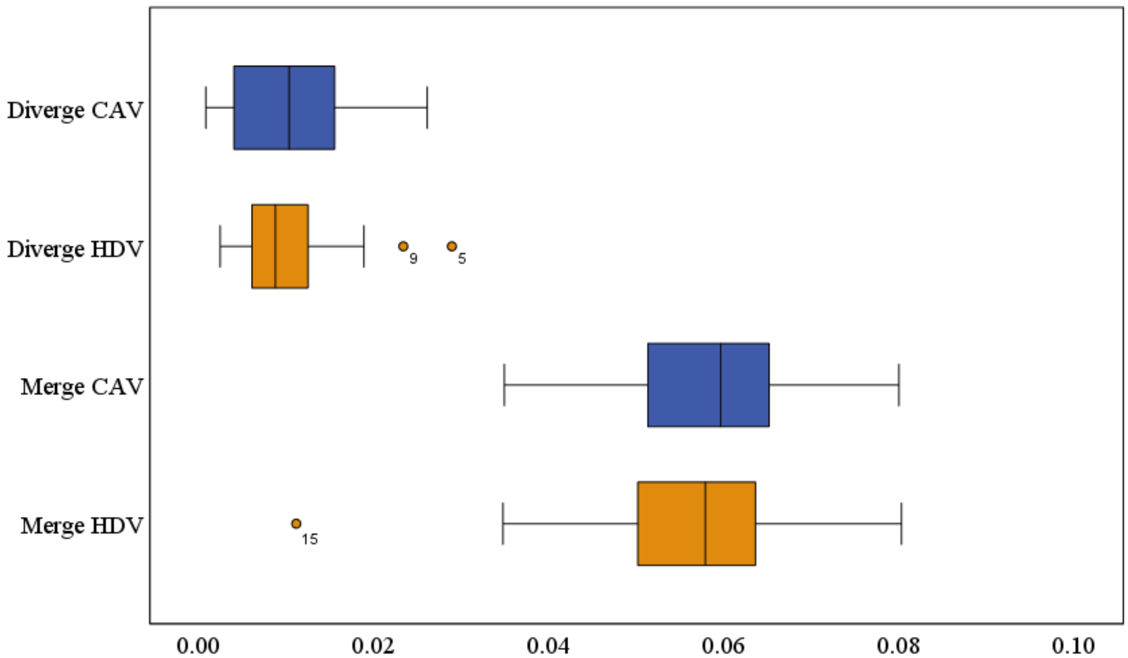


Figure 12. Maximum acceleration during merge and diverge.

Table 4. Summary of maximum acceleration statistics for merge and diverge scenarios.

Ramp	Vehicle type	Min	Max	Mean	SD
On-ramp	HDV	0.0112	0.0802	0.0567	0.0131
	CAV	0.0349	0.0799	0.0590	0.0102
Off-ramp	HDV	0.0025	0.0872	0.0132	0.0152
	CAV	0.0008	0.0315	0.0110	0.0073

Repeated Measure Analysis: Figure 12 shows few mild outliers for merge scenario and Q-Q plots in Figure 13 denotes that maximum acceleration for all the scenarios are approximately normally distributed.

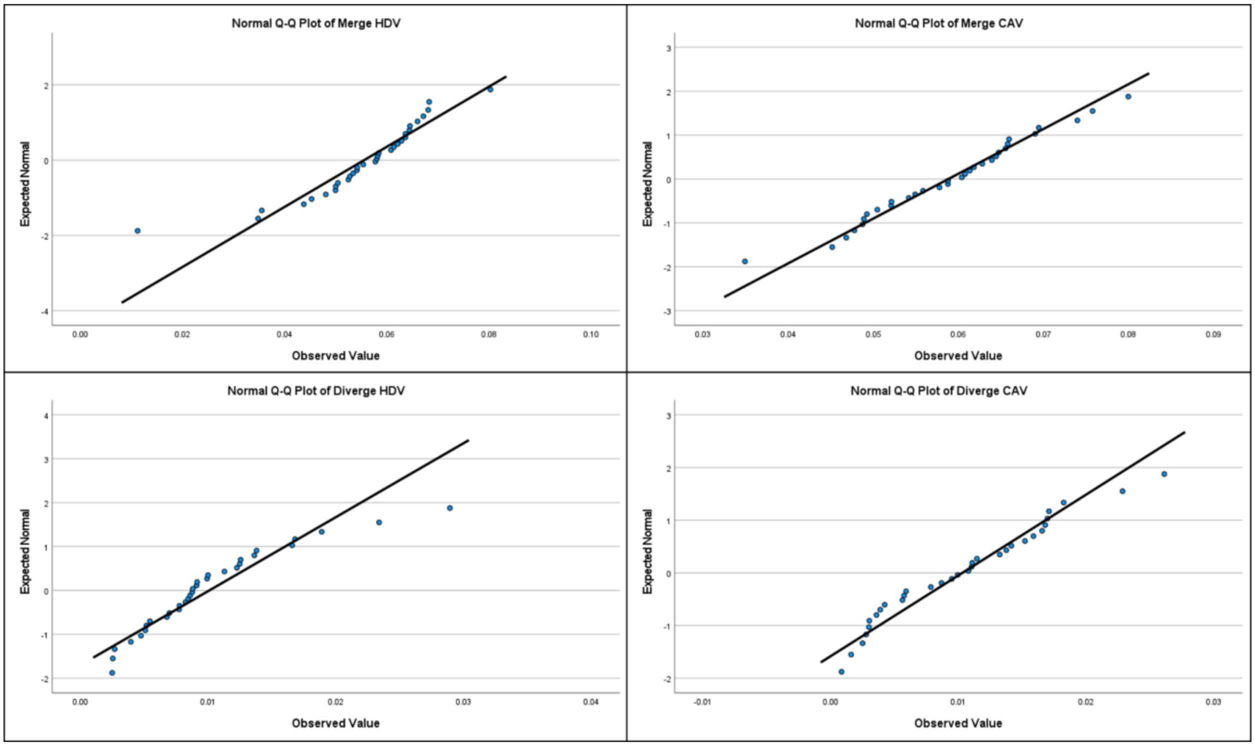


Figure 13. Q-Q plots for maximum acceleration in the ramp scenarios.

Results in Table 5 indicates that maximum acceleration does not differ significantly due to vehicle type (HDVs and CAVs) in merge and diverge scenarios. Also, maximum acceleration did not differ significantly across the drivers' demographics.

Table 5. Analysis of variance results for maximum acceleration.

Ramp	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
On-ramp	Vehicle	9.3E-06	1	9.3E-06	0.14	0.71
	Gender	3.2E-05	1	3.2E-05	0.26	0.61
	Age	3.4E-05	1	3.4E-05	0.28	0.60
	Experience	1.7E-04	1	1.7E-04	1.44	0.25
	Education	3.1E-05	1	3.1E-05	0.26	0.62
	Accident	1.6E-05	1	1.6E-05	0.13	0.72
Off-ramp	Vehicle	2.8E-05	1	2.8E-05	0.84	0.37
	Gender	3.7E-05	1	3.7E-05	1.23	0.28
	Age	6.0E-07	1	6.0E-07	0.02	0.89
	Experience	7.3E-09	1	7.3E-09	0.00	0.99
	Education	9.2E-07	1	9.2E-07	0.03	0.86
	Accident	5.2E-05	1	5.2E-05	1.73	0.21

5.1.6. Maximum Deceleration Analysis

Descriptive Statistics: Figure 14 shows the boxplot diagrams for maximum deceleration in both merge and diverge scenarios. Median deceleration was higher during merging in the presence of CAV platoon which was opposite during diverging scenario. This means that though participants decelerate more in the presence of CAV platoon during merging with the highway, they did not follow the same pattern during diverging in the presence of CAV platoon. Maximum decelerations were higher for both HDVs and CAV platoons during merging than the deceleration during diverging scenario. According to the simple statistics in Table 6, mean maximum deceleration was around -0.07 ft/s^2 in on-ramp scenario and around -0.03 ft/s^2 in off-ramp scenario. Standard deviation along with other statistics are enlisted in Table 6. As shown in the Figure 14, boxplots of HDVs and CAVs are overlapped with each other in both on-ramp and off-ramp scenario, so there might be no difference apparently. However, to further investigate the difference, repeated measure analysis was conducted.

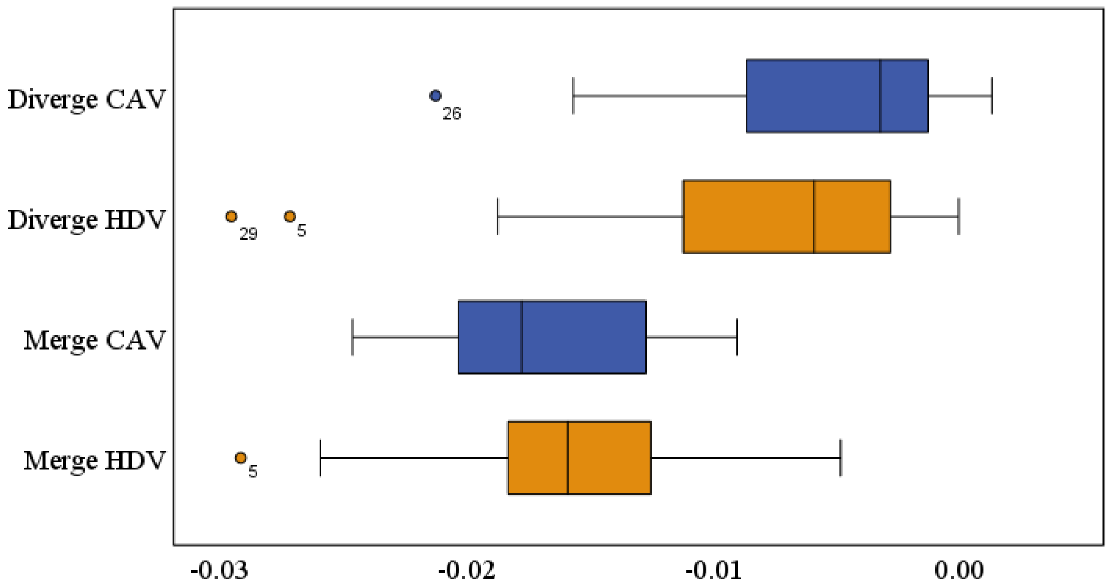


Figure 14. Maximum deceleration during merge and diverge.

Table 6. Summary of maximum deceleration statistics for merge and diverge scenarios.

Ramp	Vehicle type	Min	Max	Mean	SD
On-ramp	HDV	-0.0089	-0.0332	-0.0203	0.0055
	CAV	-0.0131	-0.0292	-0.0210	0.0048
Off-ramp	HDV	-0.0041	-0.0668	-0.0141	0.0118
	CAV	-0.0027	-0.0253	-0.0102	0.0059

Repeated Measure Analysis: Figure 14 shows few mild outliers for merge scenario and Q-Q plots in Figure 15 denotes that maximum deceleration for all the scenarios are approximately normally distributed.

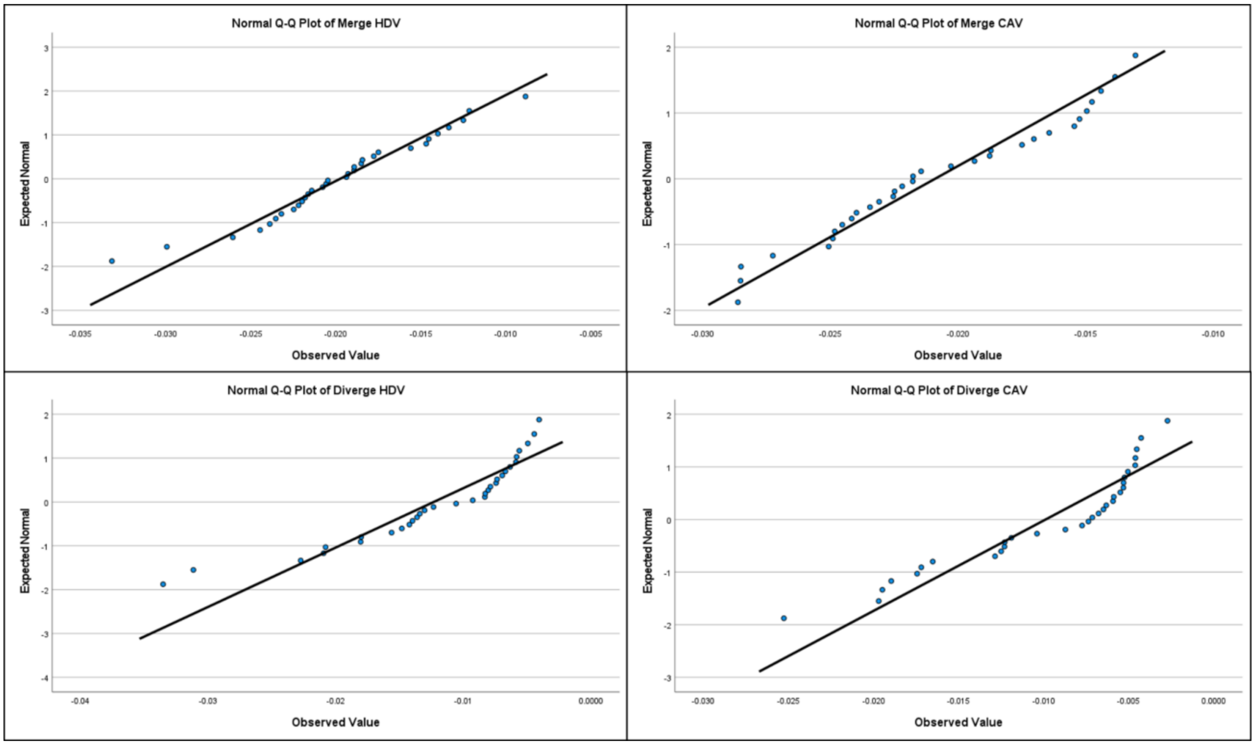


Figure 15. Q-Q plots for maximum deceleration in the ramp scenarios.

Table 7 shows the analysis of variance results for maximum deceleration where the purple highlighted rows represent statistically significant result. Unlike maximum acceleration, maximum deceleration is different for interaction with HDVs and with CAV platoon while taking exit. Results from repeated measure analysis revealed that maximum deceleration is significantly ($p = 0.05$) different at 90% confidence level while interacting with HDVs vs while interacting with CAV truck platoon near off-ramp. Maximum deceleration in presence of CAVs was approximately 27% lower than in presence of HDVs. No significant main effect of the demographics or interaction effect between vehicle type and the demographics was observed for maximum deceleration.

Table 7. Analysis of variance results for maximum deceleration.

Ramp	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
On-ramp	Vehicle	7.8E-07	1	7.8E-07	0.03	0.87
	Gender	1.5E-05	1	1.5E-05	0.61	0.45
	Age	8.0E-06	1	8.0E-06	0.33	0.57
	Experience	6.8E-05	1	6.8E-05	2.81	0.11
	Education	3.0E-06	1	3.0E-06	0.13	0.73
	Accident	2.8E-05	1	2.8E-05	1.16	0.30
Off-ramp	**Vehicle**	**1.2E-04**	**1**	**1.2E-04**	**4.44**	**0.05**
	Gender	3.9E-05	1	3.9E-05	0.57	0.46
	Age	3.8E-05	1	3.8E-05	0.55	0.47

	Experience	5.3E-07	1	5.3E-07	0.01	0.93
	Education	6.4E-05	1	6.4E-05	0.93	0.35
	Accident	2.0E-04	1	2.0E-04	2.93	0.10

5.1.7. TTC Analysis

Descriptive Statistics: According to the boxplots shown in Figure 16, median of the minimum TTC values are almost similar for HDVs and CAVs in both merge and diverge scenarios. However, diverge scenarios have higher TTC values. Table 8 shows that the mean minimum TTC values for off-ramp scenarios are 10.7 s and 9.7 s for HDVs and CAVs, respectively. On the other hand, these values are 5.1 s and 7.6 s for on-ramp scenario. Outliers during merging with CAV platoon indicates that these participants left larger spacing in case of merge with CAV platoon. Therefore, though most of the TTC values are below 10 seconds for this scenario, six of them had TTC value from 20 to 40 seconds. The very small TTC value (0.001 s) happened when one participant took exit very closed to CAV platoon. Review of the video for this participant revealed that no crash happened due to this maneuver.

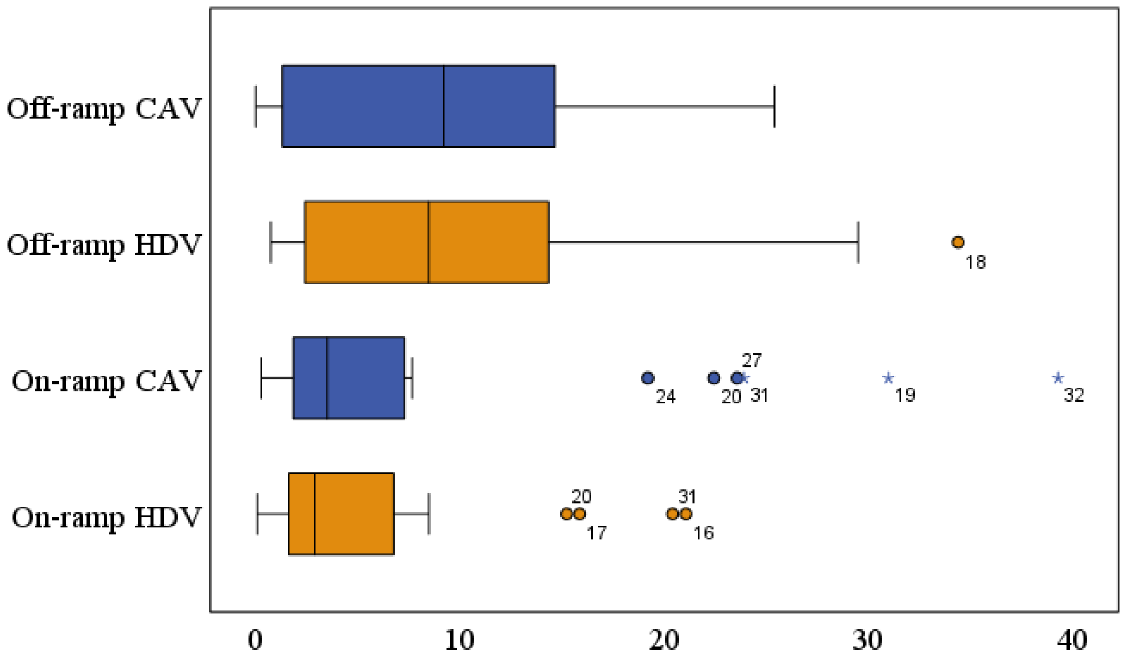


Figure 16. Minimum TTC during merge and diverge.

Table 8. Summary of minimum TTC statistics for merge and diverge scenarios.

Ramp	Vehicle type	Min	Max	Mean	SD
On-ramp	HDV	0.085	21.1	5.1	5.6
	CAV	0.274	39.3	7.6	10.1
Off-ramp	HDV	0.740	34.4	10.7	9.8
	CAV	0.001	25.4	9.7	8.2

Repeated Measure Analysis: Figure 16 shows outliers for merge scenario in case of merging with CAV platoon. However, as the TTC values can be larger when participants leave larger space in front of them, these outliers were kept in the analysis as they are part of true TTC values for this study. Q-Q plots in Figure 17 denotes that TTC for all the scenarios are approximately normally distributed.

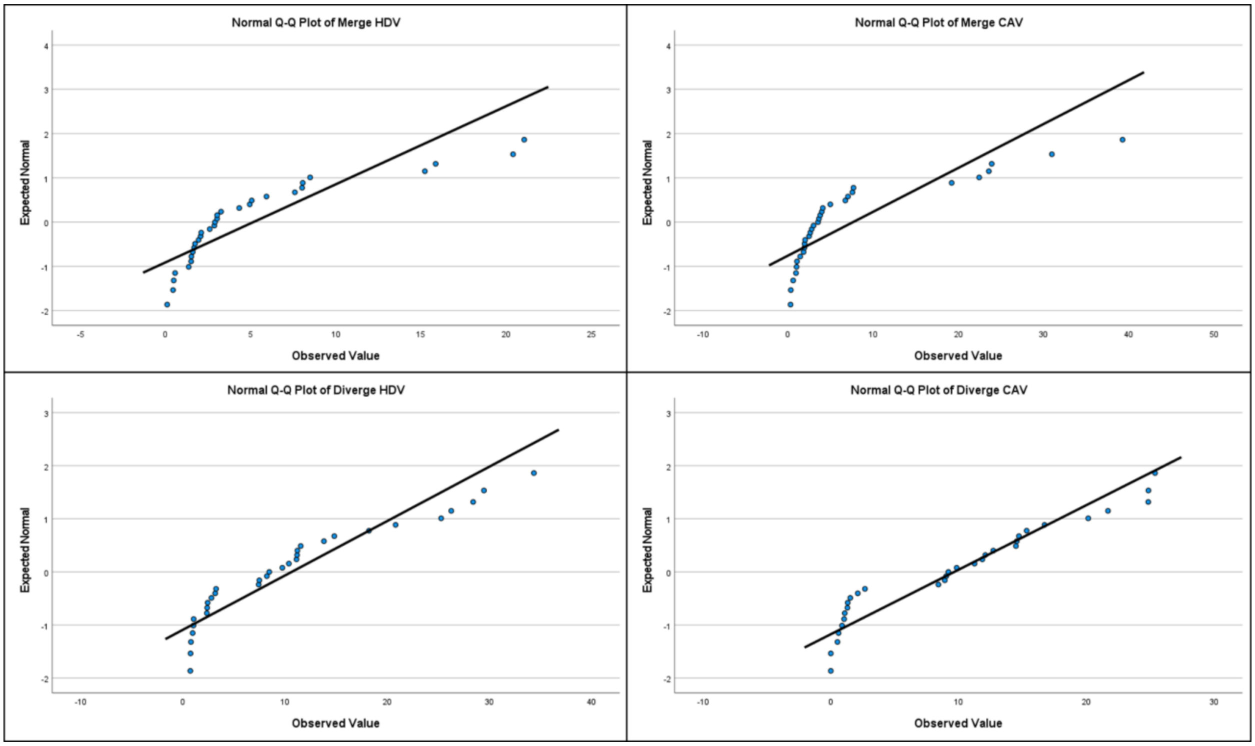


Figure 17. Q-Q plots for minimum TTC in the ramp scenarios.

Table 9 shows the analysis of variance results for minimum TTC where the purple highlighted rows represent statistically significant results. According to Table 9, minimum TTC values were significantly different (p = 0.004) in HDV and CAV scenarios near on-ramp at 95% confidence level. Minimum TTC is around 49% higher in case of CAV compared to HDVs. This denotes that drivers choose larger and safe distance ahead of them when they are merging with CAV compared to the situation where they are merging with HDVs. In terms of difference across the demographic groups, male and female have significantly different TTC (p = 0.04) during merging scenarios. The estimated marginal mean is 85% higher for female drivers than male drivers.

In both on-ramp and off-ramp scenarios, significant interaction effect was found between gender and vehicle. According to Figure 18, male and female have almost similar TTC (around 4.56 s) for HDV scenarios which were quite different in CAV scenarios. The estimated marginal mean of TTC was bigger by 0.723 s for male participant when they are merging with CAV compared to merging with HDVs, whereas TTC increased by 9.2 seconds in case of female participants. Previous studies also found higher TTC for women participants than male participants. For example, Ali et al. [12] reported higher TTC for women in case of car following, Montgomery et al. [67] mentioned the similar during braking.

Regarding the interaction effect of vehicle and gender in off-ramp scenarios, male participants' TTC value increased by around 40% in case of CAVs compared to HDVs whereas the TTC decreased by around 47% for female participants (Figure 19). This result indicates that though female drivers' TTC was higher in presence of CAV truck platoon near on-ramp, TTC was higher for male participants in presence of CAV truck platoon near off-ramp.

Table 9. Analysis of variance results for minimum TTC.

Ramp	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
On-ramp	**Vehicle**	**372.47**	**1**	**372.47**	**11.37**	**0.004**
	Gender	**390.90**	**1**	**390.90**	**4.79**	**0.04**
	Age	0.08	1	0.08	0.001	0.98
	Experience	119.53	1	119.53	1.47	0.24
	Education	6.60	1	6.60	0.08	0.78
	Accident	7.67	1	7.67	0.09	0.76
	Vehicle*Gender	**285.62**	**1**	**285.62**	**8.72**	**0.009**
Off-ramp	Vehicle	17.11	1	17.11	0.28	0.60
	Gender	1.78	1	1.78	0.01	0.91
	Age	58.8	1	58.8	0.41	0.53
	Experience	1.22	1	1.22	0.01	0.93
	Education	130.84	1	130.84	0.92	0.35
	Accident	158.82	1	158.82	1.12	0.31
	Vehicle*Gender	**274.04**	**1**	**274.04**	**4.48**	**0.05**

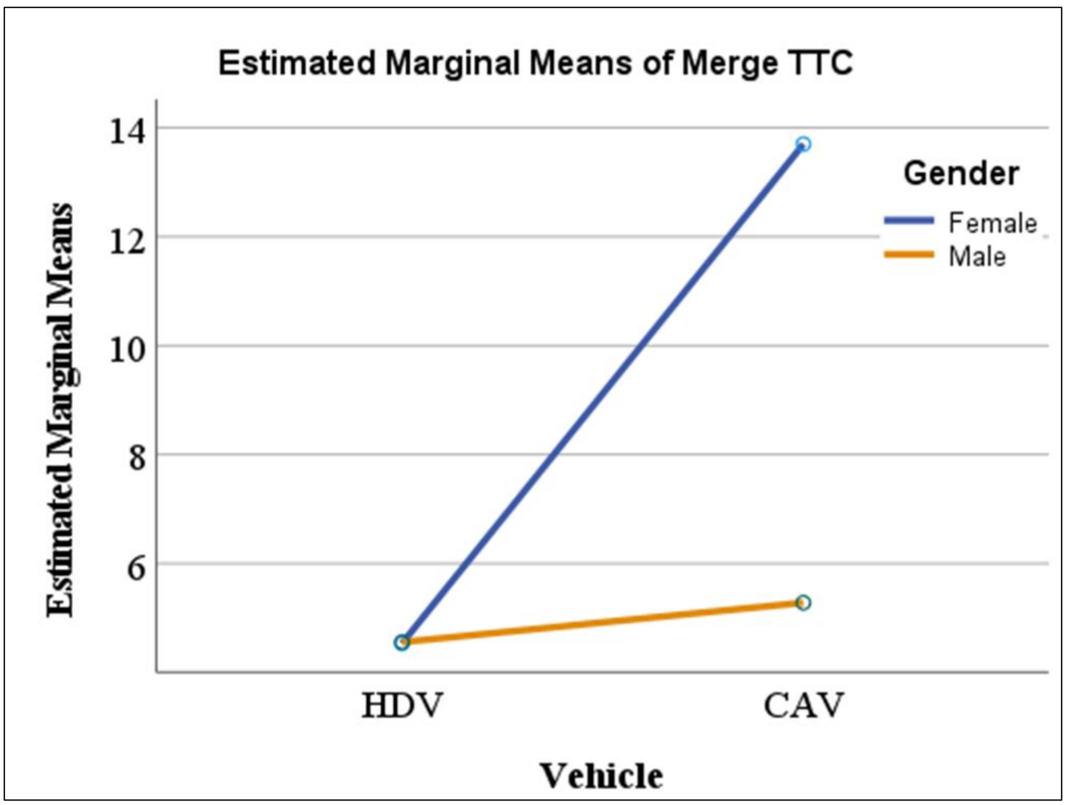


Figure 18. Interaction effect between vehicle type and gender for merge TTC.

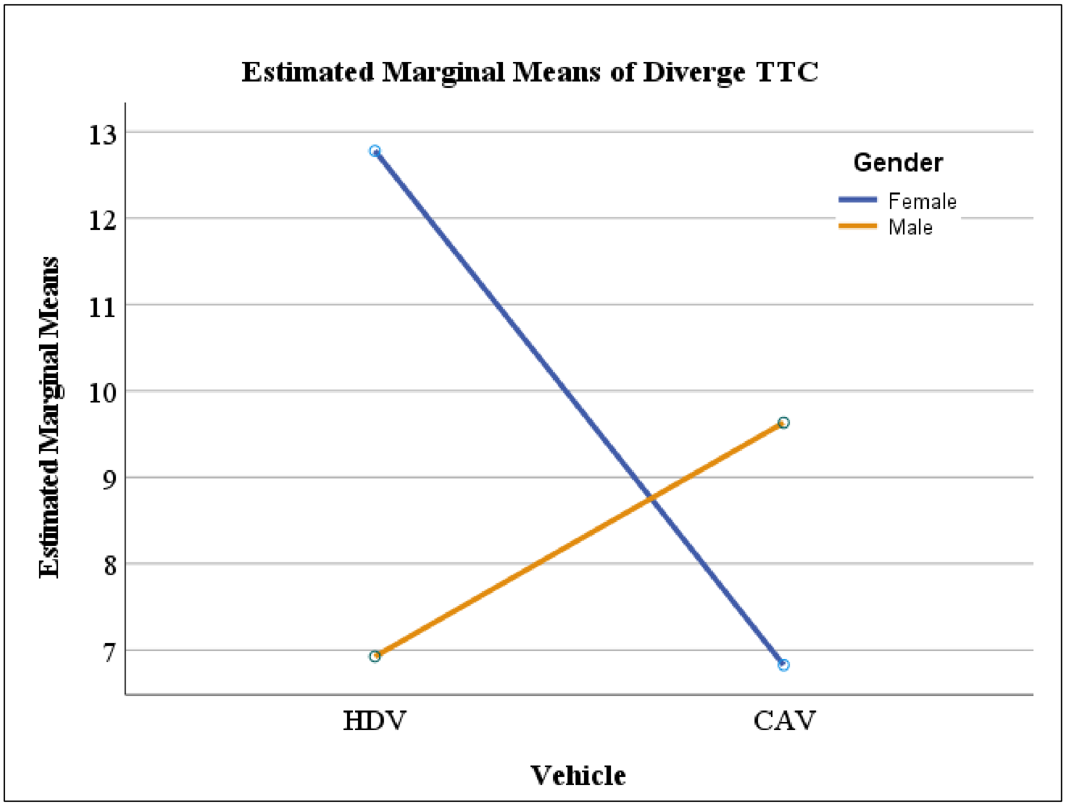


Figure 19. Interaction effect between vehicle type and gender for diverge TTC.

5.2. Interaction with CAVs on Straight Section

In this section, drivers' preference on interacting with CAV platoon of car and truck in straight section of highway will be discussed. Using an online national survey, a total of 1565 responses were collected from Americans who are at least 18 years old and have valid drivers' license. Among them, 49.5% were males and 50.5% were females. According to Table 10, 11.6% of the respondents were in age group 18-24, 26.3% in age group 25-39, 24.5% in age group 40-54, 16.8% in age group 55-64 and 20.8% were 65+ years old.

Table 10: Proportion of respondents by age and gender.

Age	Male	Female	Percentage
18-24	32	149	11.6%
25-39	182	229	26.3%
40-54	189	195	24.5%
55-64	132	131	16.8%
65+	240	86	20.8%
Percentage	49.5%	50.5%	100%

Table 11 lists other demographic characteristics of the respondents of this survey. A quarter of respondents (25.0%) reside in rural areas, compared to nearly half (47.8%) who live in suburbs.

Approximately 40% of the respondents have a high school diploma, while the next highest category of education is a bachelor's degree (24.7%), followed by an associate degree (15.8%), a master's degree (around 9%), and the other 10% fall into the categories of doctorate, no certification, and other. When these people were asked about their employment, nearly half (49.1%) reported being employed, followed by retirees (26.6%) and the jobless (14.6%). Most of the respondents (86.4%) had more than 5 years of driving experience, only around 3% being with less than 2 years of driving experience, and 10% had 2-5 years of experience.

Table 11. Respondents' demographic characteristics.

Demographic characteristics	Category	Frequency	Proportion of Respondents
Residential Area	Urban	426	27.2
	Suburban	748	47.8
	Rural	391	25.0
Total		1565	100
Level of Education	No certification	46	2.9
	High school diploma	595	38.0
	College diploma	84	5.4
	Associate degree	247	15.8
	Bachelor's degree	387	24.7
	Master's degree	145	9.3
	Doctorate degree	33	2.1
	Other	28	1.8
Total		1565	100
Employment Status	Unemployed	228	14.6
	Employed	769	49.1
	Retired	417	26.6
	Student	63	4.0
	Other	88	5.6
Total		1565	100
Driving Experience	Less than 2 years	46	2.9
	2-5 years	166	10.6
	More than 5 years	1353	86.5
Total		1565	100

5.2.1. Interaction with CAV Platoon on 2-Lane 2-Way Roads

In this section of the survey, respondents were asked about their choice of overtaking a platoon of car in a 2-lane 2-way road as shown in Figure 20 where green cars represent the CAV car platoon. Figure 21 shows the distribution of their choices for the given options. According to the Figure 21, around two-third of the respondents mentioned that they would not overtake as they would not feel safe to do so. While a little over 20% would overtake the platoon at one attempt, fewer than 15% of them would overtake the vehicles of the platoon one at a time.

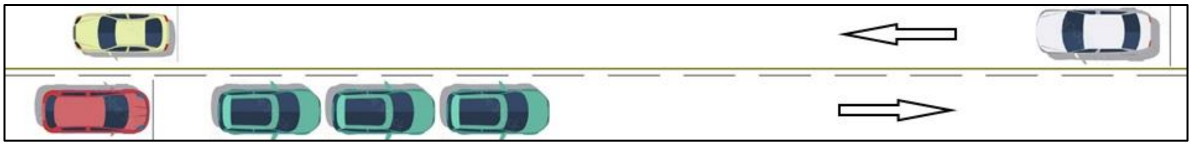


Figure 20. Interaction with CAV on a 2-lane 2-way road

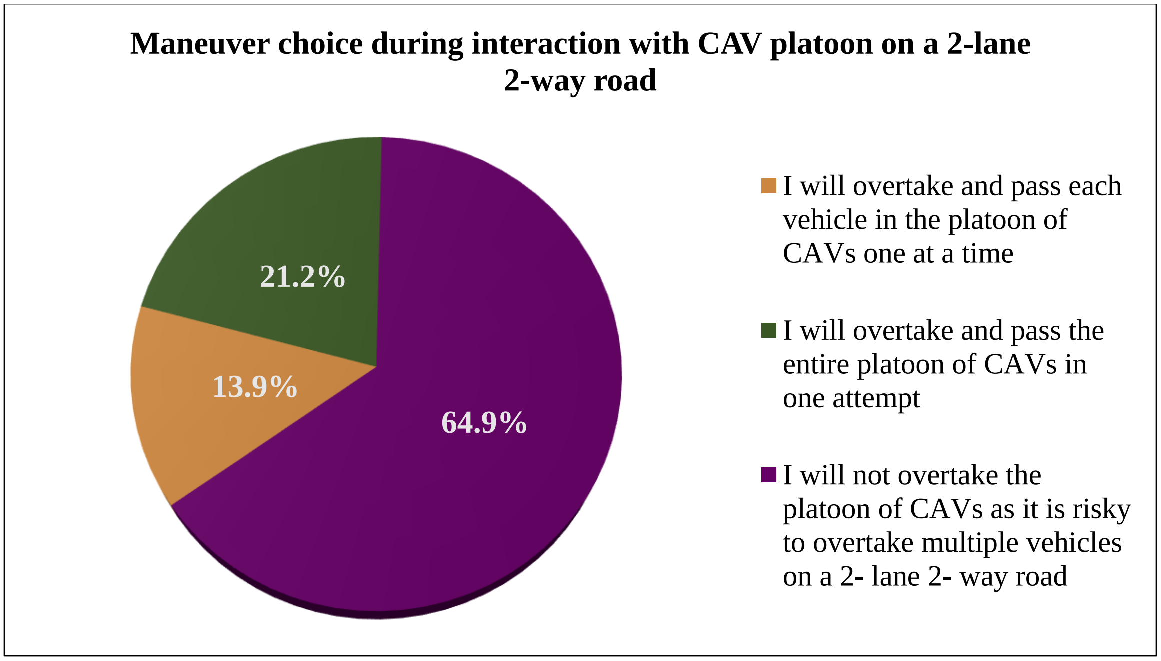


Figure 21. Participants' maneuver choice when attempting to overtake a CAV platoon on a 2-lane 2-way road.

In the case of choosing to stay behind the platoon and following them, around half of the respondents reported that they would do so if the platoon is driving at speed limit (Figure 22). From the remaining 50%, 31.6% claimed that they would continue driving behind the platoon instead of overtaking if the operating speed of platoon is 5-10 mph above the speed limit. Rest of them stated that they would follow the platoon if the vehicles in the platoon drives more than 10-15 mph above the speed limit or over 15 mph above the limit.

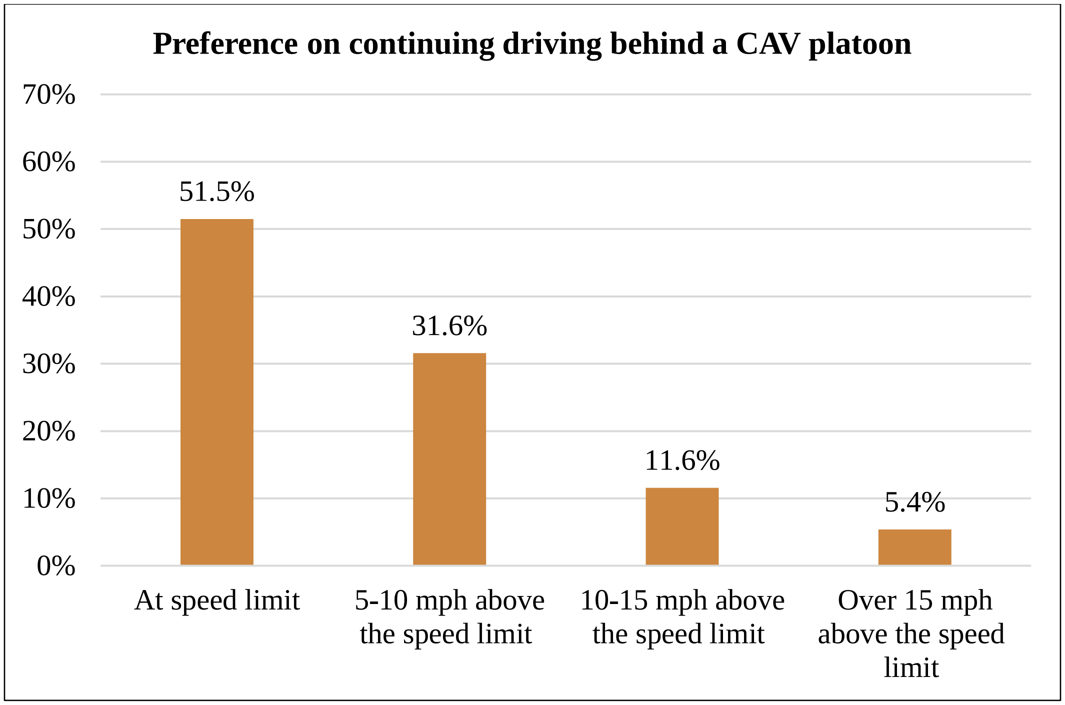


Figure 22. Drivers' preference in case of following the platoon instead of overtaking.

Though around two-third (about 65%) of the respondents mentioned they did not feel that overtaking maneuvers on a 2-lane road are safe in general (Figure 21), about 55% of them indicated that they would overtake the platoon if the CAVs could detect the overtaking cars and yield by increasing the gap between the vehicles of the platoon to allow cars to easily overtake and pass (Figure 23).

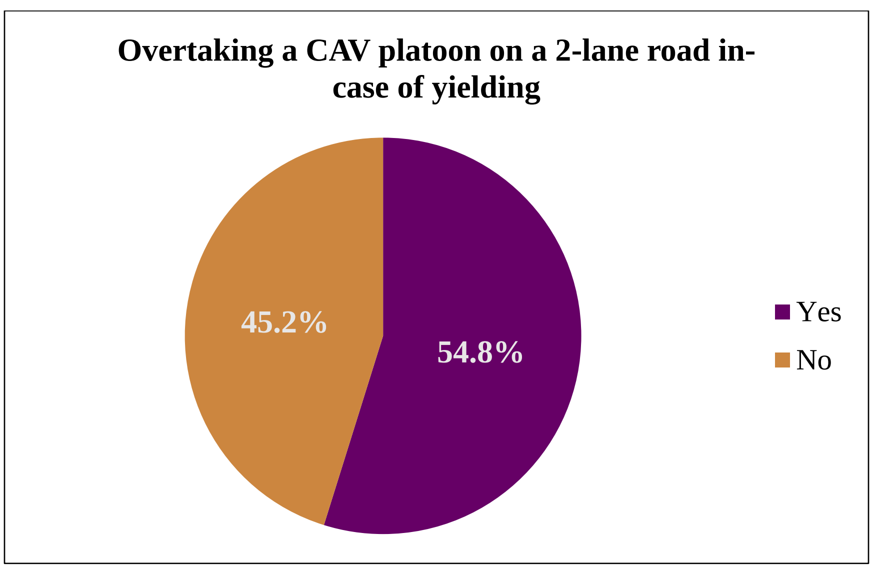


Figure 23. Drivers' opinion on overtaking in case of yielding by CAV platoon.

5.2.2. Interaction with CAV Platoon on Multilane Highways

This section discusses drivers' attitude towards following or overtaking a CAV platoon on a straight section of a highway with three lanes. Figure 24 represents the scenario that the respondents were asked about where green car demonstrates the CAV car platoon. Figure 25 shows the options given to them along with the corresponding response rates in case of CAV car platoon. Assuming to be in the middle lane behind the platoon, about 60% of the respondents reported that they would treat the situation as a normal traffic situation and overtake or change lanes to avoid being behind the platoon. The remaining 40.5% indicated that they would be comfortable continuing to follow behind the CAV platoon and not changing lanes.

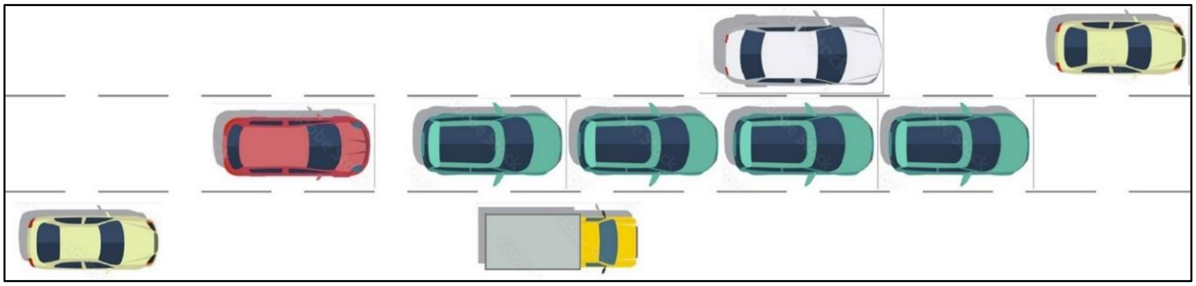


Figure 24. Interaction with CAV car platoon on 3-lane highway.

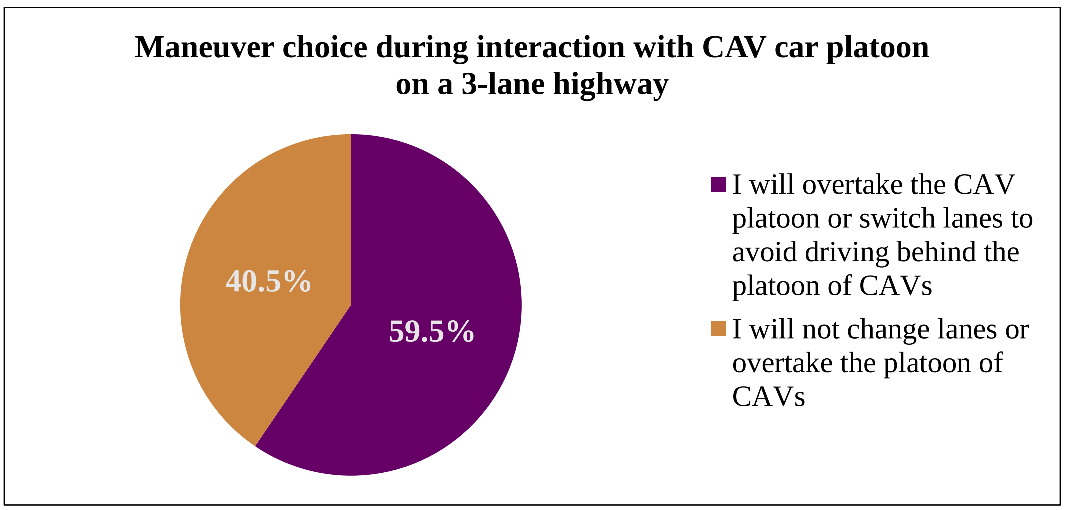


Figure 25. Participants' maneuver choice when driving behind a CAV car platoon on a 3-lane highway.

While they were asked about CAV truck platoon in place of car platoon, the response rate towards following (40.9%) and overtaking (59.1%) were almost like those in the case of a car platoon. Figure 26 shows the scenario given to the respondents to express their opinion about their interaction with CAV truck platoon on a 3-lane highway and Figure 27 shows the response rates for the given options about their maneuver choice in the presence of CAV truck platoon.

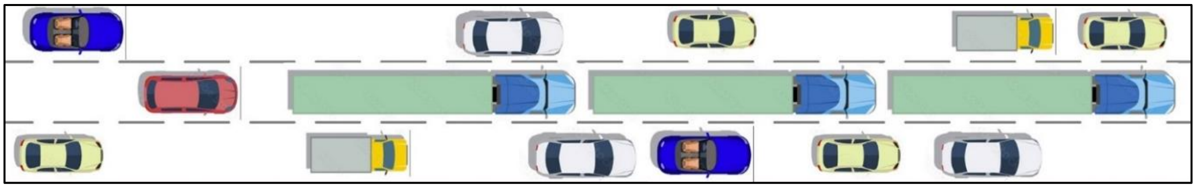


Figure 26**. Interaction with CAV truck platoon on 3-lane highway.**

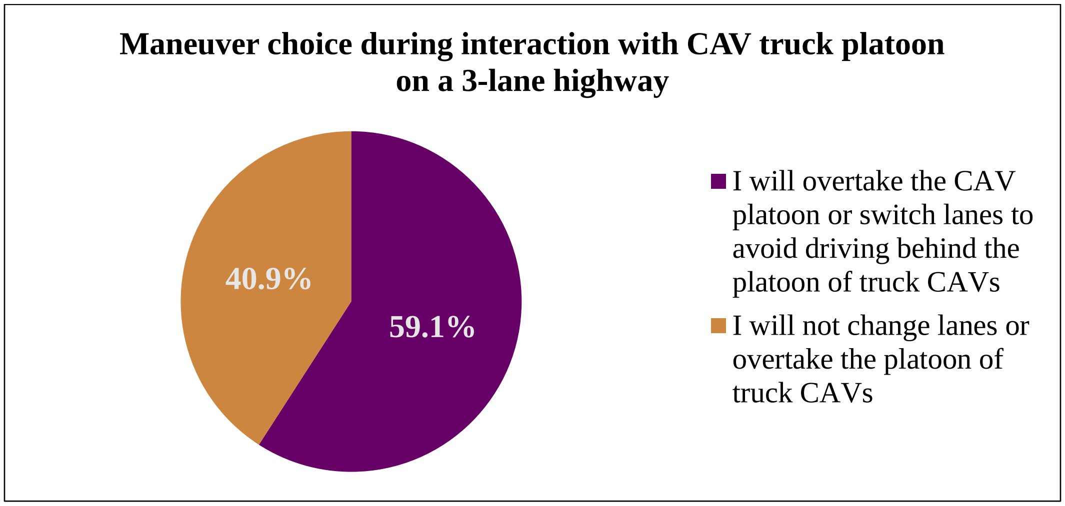


Figure 27. Participants' maneuver choice when driving behind a CAV truck platoon on a 3-lane highway.

5.3. Interaction with CAVs during Adverse Weather

Respondents were asked about their preference in case of driving in the presence of CAV car platoon during adverse weather such as heavy rain, fog etc. Figure 28 shows the scenarios that were given to the respondents to comment on their preference during adverse weather conditions in the presence of a CAV car platoon. Over half (51.8%) of them reported that they would continue without changing lane or speed. Only 21.2% of the respondents claimed that they would prefer to follow behind the platoon during the hazardous conditions and follow the speed limit. The remaining 27% stated that they would follow the speed of the car platoon but would prefer not to stay behind it in the same lane (Figure 29).

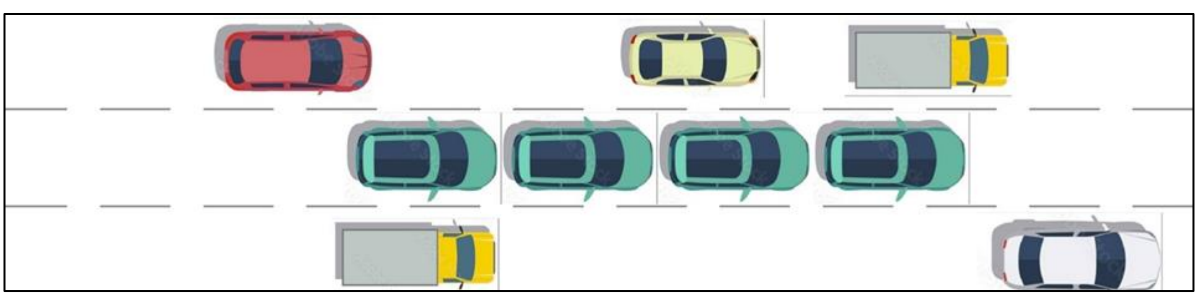


Figure 28. Interaction with CAV car platoon during adverse weather condition.

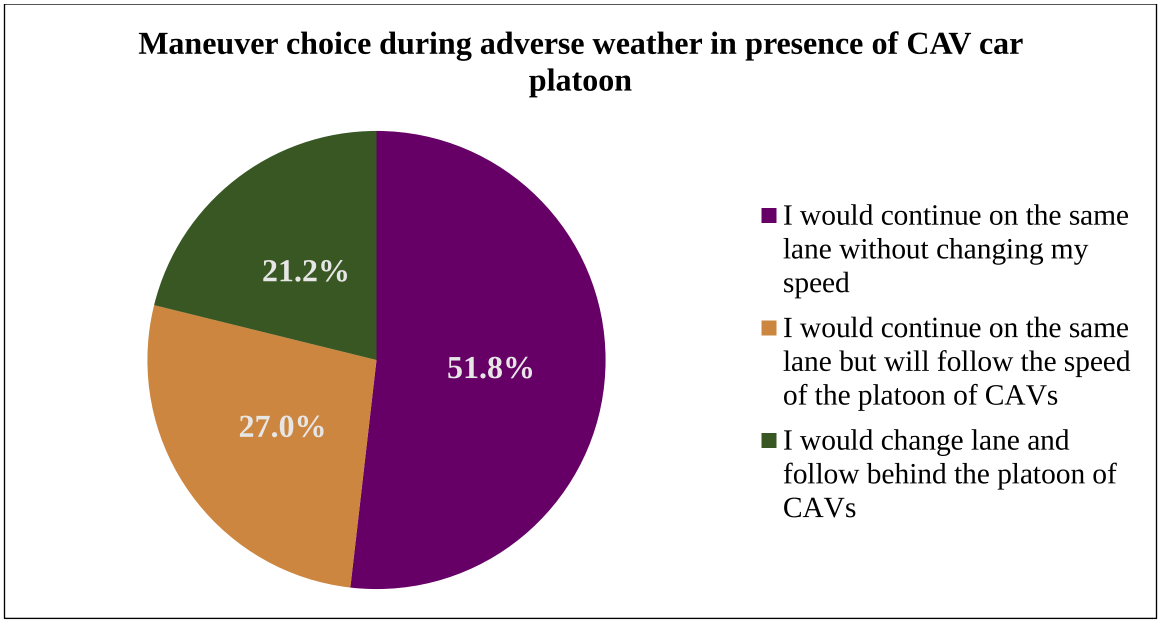


Figure 29. Participants' maneuver choice when driving during adverse weather in presence of CAV car platoon.

Figure 30 focuses on driving in severe weather conditions near a CAV truck platoon instead of a car platoon. The responses were nearly identical, 53.6% of participants reported that they would feel comfortable in their current lane and speed, 27.2% claimed that they would prefer to match their speed with the platoon's speed without following them, and 19.2% stated that they would feel safer following the truck platoon as well as copying their speed (Figure 31).

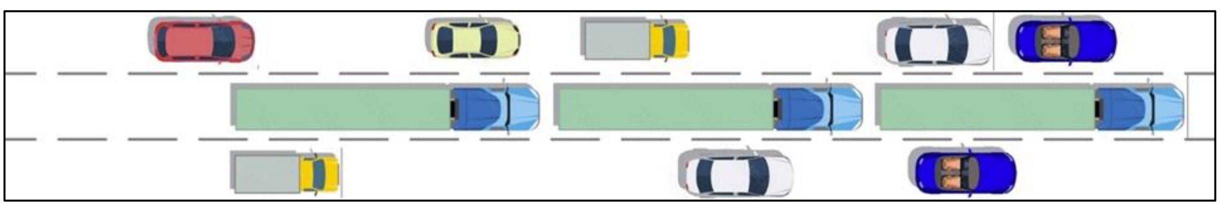


Figure 30. Interaction with CAV truck platoon during adverse weather condition.

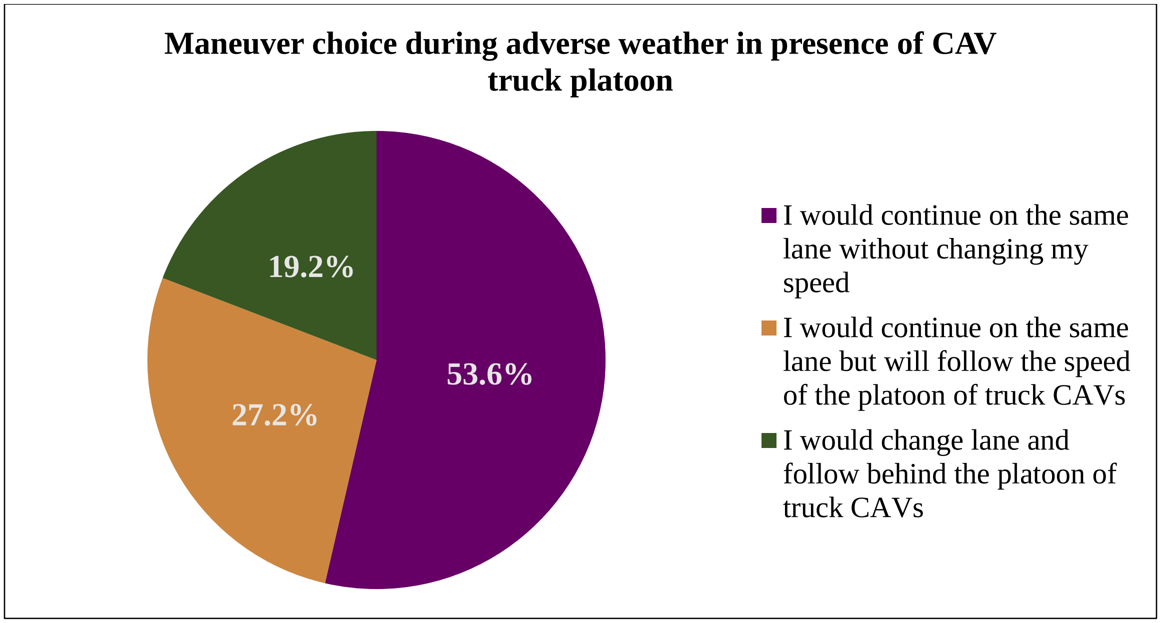


Figure 31. Participants' maneuver choice when driving during adverse weather in presence of CAV truck platoon.

5.4. Reaction to Vehicular Automation and Automation Failure

This section describes drivers' activity during automation and their reaction after the automation was disengaged and TOR was issued. To investigate drivers' reaction to the TOR, two scenarios were designed. In the first scenario, participants were asked not to use their phone but to relax as NDRT was not allowed, and in another scenario, they were informed that they may choose to either relax or doing NDRTs such as checking their phone, browsing internet etc.

5.4.1. Drivers' Activity during Automated Driving Mode

A driver's capacity to regain control safely in an emergency takeover situation depends on how actively they continue to monitor the fully automated driving mode and the surrounding road environment [65]. Therefore, drivers' activity during the automated driving mode is monitored using several cameras inside the driving simulator. To that end, drivers' eye movement in terms of monitoring driving, using cell phone, and watching surrounding environment were observed from the video recording. Also, feet placement of participants during the automated driving mode were noted. Table 12 describes drivers' activities in both scenarios while the car simulator was in the automated driving mode.

During the automated driving mode, participants were mostly monitoring how the subject vehicle itself was braking at intersection and behind other cars, accelerating to start from stopped condition, changing lane etc. However, some participants monitored the surrounding environment (roadside restaurants, gas station, grocery shops etc.) and used phone along with monitoring the automated driving mode. The percentage of drivers who looked at surroundings besides monitoring the automated driving was around 40% for both scenarios with and without NDRT. When drivers were not allowed to use phone, approximately 60% of the drivers did not pay attention to the surroundings other than monitoring the automated driving mode. On the other hand, only 21.9% of the drivers did so while they were allowed to use phone during the automated mode. In the scenario where drivers were allowed to use their phone, half of the drivers used their phone which is in line with the results of a prior study by Dogan et al. [23] where 50% of the drivers performed NDRT during level 2 automation. All the drivers who were either looking at the surroundings or using their phone were still monitoring the driving occasionally. Regarding keeping the foot closed to the brake or gas pedal, the percentage is 21.9% and 18.8% for No NDRT and NDRT scenarios, respectively. Yang et al. [36] reported that 64% of drivers in their study kept their foot close to the pedal, which is higher than the percentages in both scenarios of the current study.

Table 12. Participants' activities during the automated driving mode of the car simulator.

Activities	No NDRT	NDRT
Only Monitoring driving	59.4%	21.9%
Monitoring the surroundings	40.6%	37.5%
Foot close to pedal	21.9%	18.8%
Using phone	NA	50%

5.4.2. Performance Measures

To evaluate drivers' reaction towards the TOR due to automation failure, TTC, Take Over Reaction Time (TORt) and maximum deceleration were recorded.

Minimum TTC: The minimum TTC from the time stamp TOR is issued to the time stamp two of the pedestrians crossing the road is recorded for analyzing drivers' safety behavior toward automation failure.

Maximum Deceleration: Maximum deceleration executed (after the TOR is issued) to avoid hitting the pedestrians and to avoid running the red light.

TORt: Time taken from the moment TOR is issued to the time stamp driver regains control by pressing the brake pedal.

5.4.3. Statistical Analysis

Descriptive Statistics: Table 13 illustrates the descriptive statistics of the aforementioned three performance measures. The table shows that the minimum values of the maximum deceleration in both scenarios with NDRT and without NDRT are very small. This means that some drivers were very cautious during the automated driving mode in both cases, therefore did not have to brake hard, which is also supported by very small TORt (0.94 s) in NDRT scenario. By exploring the video files, it was found that the driver with 4.21 seconds TORt hit one of the pedestrians and drivers with more than 3.4 seconds of TORt were about to hit the pedestrians. The average TORTs were 2.6 s and 2.1 s for no NDRT and NDRT. These TORts are close enough from the results of some previous studies, such as 2.47 seconds in Jeihani et al. [13], 2.71 seconds in Radlmayr et al. [39], 2.25 seconds in Feldhütter et al. [68], 2.86 seconds in Lorenz et al [69] etc.

The minimum value of TTC (0.02 seconds) corresponds to the driver who hit the pedestrian, indicating that the driver had critical situations before taking control of the vehicle. The mean minimum TTC values were found to be 2.43 seconds and 2.98 seconds for the two scenarios considered which are closed to the minimum TTC observed in the case of take over situation in some of the previous studies. For example, Feldhütter et al. [68] reported 2.78 seconds of TTC for

5 mins automated driving and 2.51 seconds of TTC for 20 minutes of automated driving. Radlmayr et al. [39] found 1.4 seconds, 1.8 econds, 3.02 seconds and 2.64 seconds of TTC for their four different scenarios of take over process.

In terms of difference between scenarios with NDRT and without NDRT, lower deceleration, lower TORt and higher TTC were observed in NDRT scenario compared to the scenario without NDRT. This result means that although the drivers were using phone in NDRT scenario, they did not trust the automation completely and were more careful during the scenario where they were allowed to do NDRT such as browsing internet using their phone.

Table 13. Summary statistics for the variables of automation failure scenarios.

Performance measures	NDRT type	Min	Max	Mean	SD
Maximum Deceleration (ms^{-2})	No NDRT	-0.0001	-0.0697	-0.01	0.0164
	NDRT	0.00001	-0.0093	-0.002	0.0020
TORt (sec)	No NDRT	1.24	4.21	2.61	0.67
	NDRT	0.94	3.78	2.11	0.67
Minimum TTC (sec)	No NDRT	0.02	5.76	2.43	1.01
	NDRT	0.37	6.08	2.98	1.16

Figure 32 shows the box plot for deceleration in both scenarios (NDRT and No NDRT). According to the Figure 32, less variability in deceleration is noticeable in the boxplot for NDRT. Median of the maximum deceleration is higher in the scenario with no NDRT.

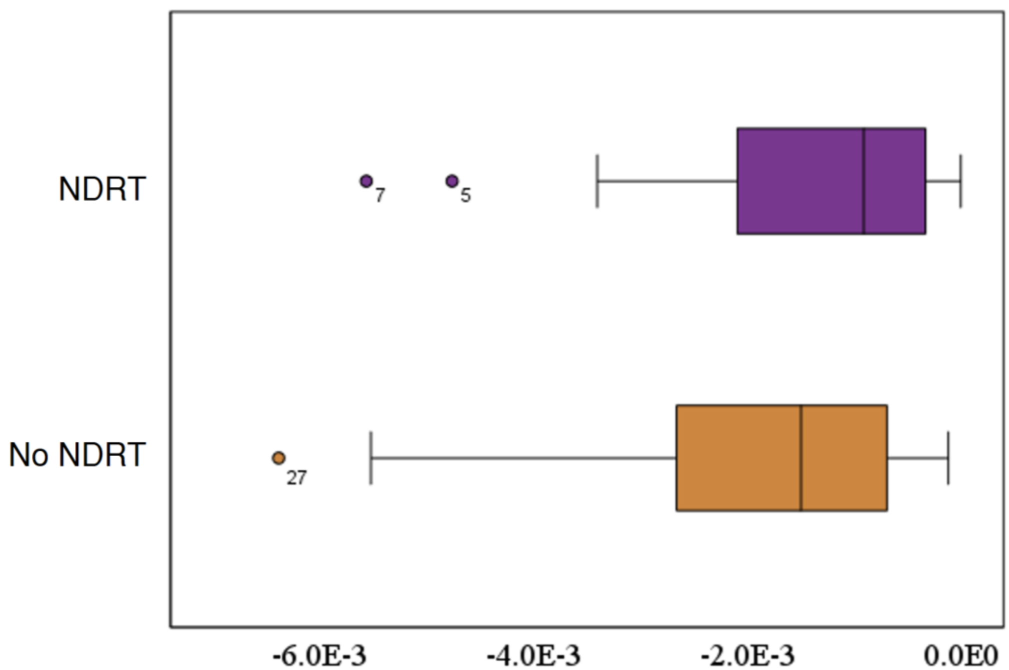


Figure 32. Maximum deceleration in two scenarios of automation failure.

Figure 33 shows median TORt is higher in the scenario where participants were not allowed to use their phone. Standard deviation for both of these scenarios is similar which is visible from the spread of the boxplots. No potential outliers are visible in any of the scenarios.

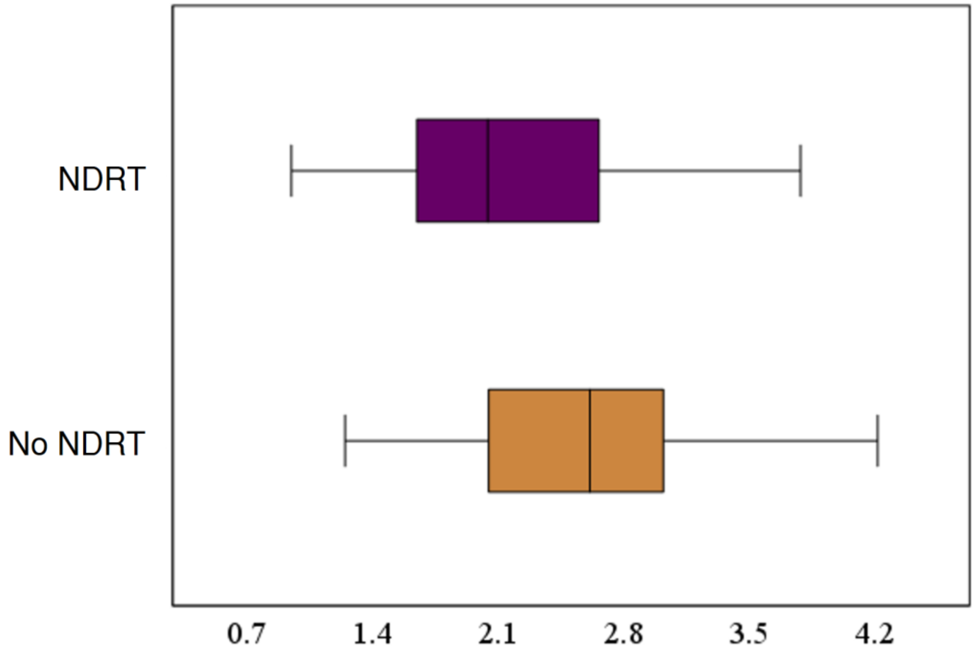


Figure 33. TORt in two scenarios of automation failure.

Figure 34 shows minimum TTC values have more variability in the scenario where participants used their phone and the median value of TTC is smaller in the scenario where they were not allowed to use their phone. This implies that people who engaged in non-driving related task such as using phone during the automated driving mode were more careful about the surroundings and therefore were able to maintain safe distance with the crossing pedestrians. As shown in the Figure 34, there are outliers in both scenarios.

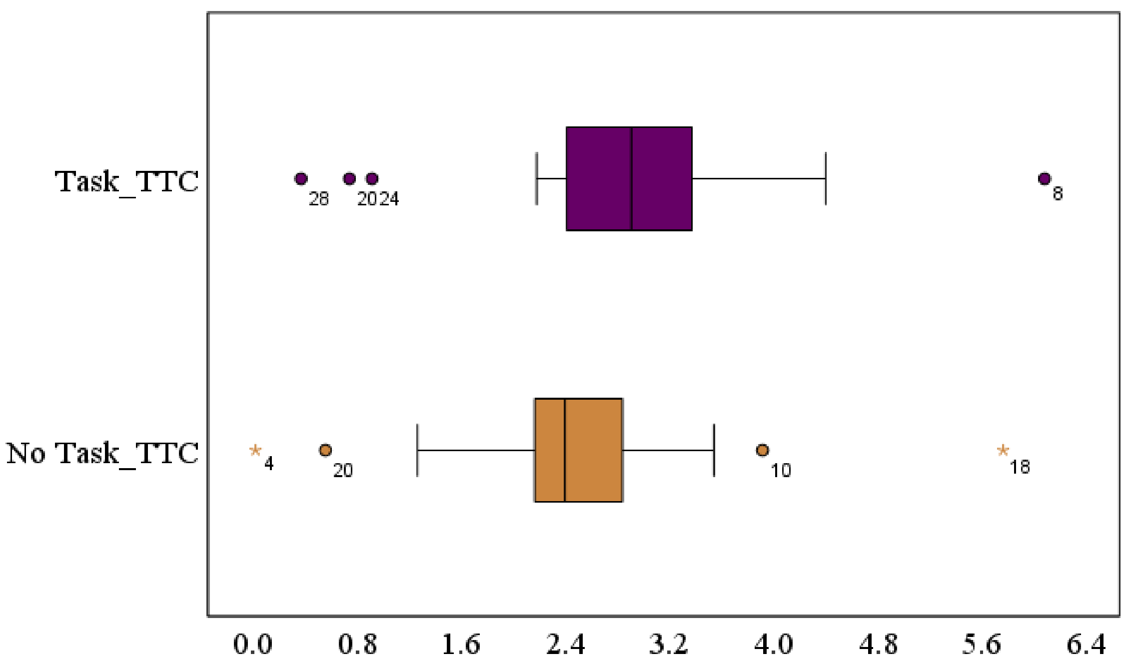


Figure 34. Minimum TTC in two scenarios of automation failure.

To investigate if any significant difference exists between the two scenarios, multivariate analysis of variance (MANOVA) with repeated measures was conducted. Dependent variables of this analysis are TTC, TORt and deceleration, whereas independent variables are NDRT type (within subject) and all the demographic characteristics (between subject).

Assumptions for Repeated Measure Analysis: After deleting the observations with missing data and extreme outliers, this analysis included 28 observations. However, two outliers (0.02 s and 5.76 s) marked as significant outliers in Figure 34 were not removed as they represent true TTC values for this study. Figure 35 indicates that all the dependent variables are approximately normally distributed in the Q-Q plot. Table 14 indicates low to medium correlation between the dependent variables, so no multicollinearity exists between these dependent variables. Therefore, MANOVA was conducted with these variables.

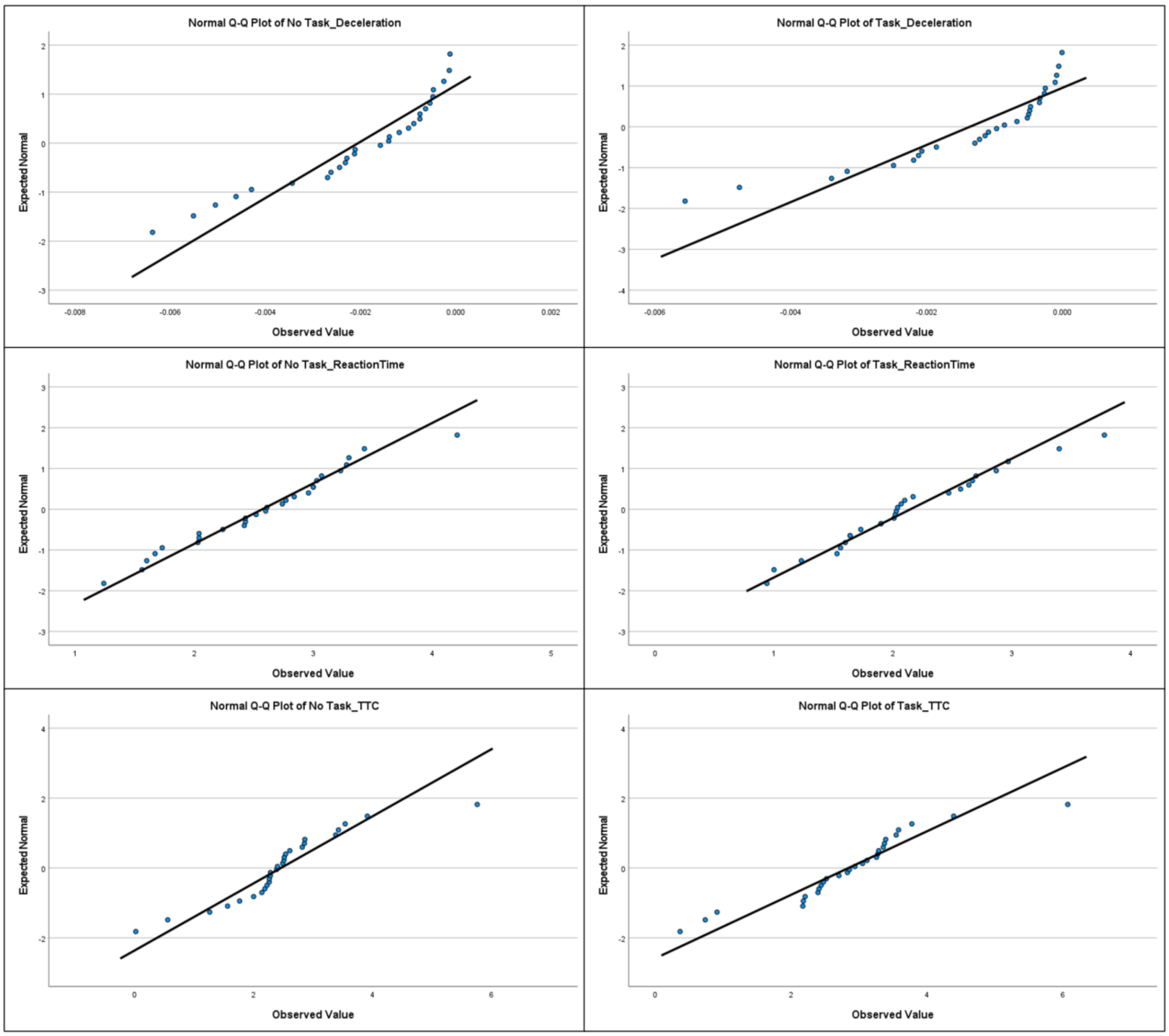


Figure 35. Q-Q plots for variables of automation failure scenarios.

Table 14. Correlation matrix for dependent variables in automation failure scenarios.

		Deceleration		TOT		TTC	
		No NDRT	NDRT	No NDRT	NDRT	No NDRT	NDRT
Deceleration	No NDRT	1					
	NDRT	0.240	1				
TOT	No NDRT	-0.304	0.050	1			
	NDRT	0.297	0.167	-0.073	1		
TTC	No NDRT	0.304	-0.066	-0.669	0.353	1	
	NDRT	-0.213	-0.309	0.091	-0.557	0.077	1

Results of the Analysis: To determine whether involving in NDRT affects drivers' behavior in terms of deceleration, TORt and TTC, and whether these behaviors are different across the demographic groups, MANOVA was conducted using GLM repeated measure. Results of the analysis in Table 15 indicates that p-value of the NDRT which refers to involvement in non-driving related task is 0.22 > 0.05. This indicates that TTC, deceleration and TORt were not influenced by the involvement in NDRT. Multivariate analysis did not show any significant difference between gender, age and other demographic groups. However, a significant interaction effect (p-value = 0.07) between NDRT and driving experience was found at 90% confidence level. Profile plot of NDRT and experience for TTC, deceleration and TORt indicates that the interaction exists in the maximum deceleration.

Table 15. Multivariate test results.

Effect		Value	F	Hypothesis df	Error df	Sig.
Between Subjects	Intercept	0.99	291.11	3	13	0.00
	Gender	0.15	0.76	3	13	0.54
	Age	0.08	0.36	3	13	0.79
	Experience	0.08	0.38	3	13	0.77
	Education	0.12	0.59	3	13	0.63
	Accident	0.20	1.09	3	13	0.39
Within Subjects	NDRT	0.28	1.69	3	13	0.22
	NDRT * Gender	0.02	0.11	3	13	0.95
	NDRT * Age	0.21	1.16	3	13	0.36
	NDRT * Experience	**0.41**	**2.96**	**3**	**13**	**0.07**
	NDRT * Education	0.24	1.34	3	13	0.31
	NDRT * Accident	0.16	0.82	3	13	0.51

Figure 36 denotes that people with 5 or less than 5 years of driving experience had higher deceleration in no NDRT scenarios which is decreased by almost half than in the NDRT scenario. On the other hand, experienced people who have more than 5 years of driving experience had almost similar deceleration in both scenarios.

While looking at the univariate test results for TTC, deceleration and TORt, it was found that TORt differed significantly between the two scenarios. On average, participants took longer time (2.56 s) to react to the TOR while they were just relaxing than the situation where they were using phone (2.11 s).

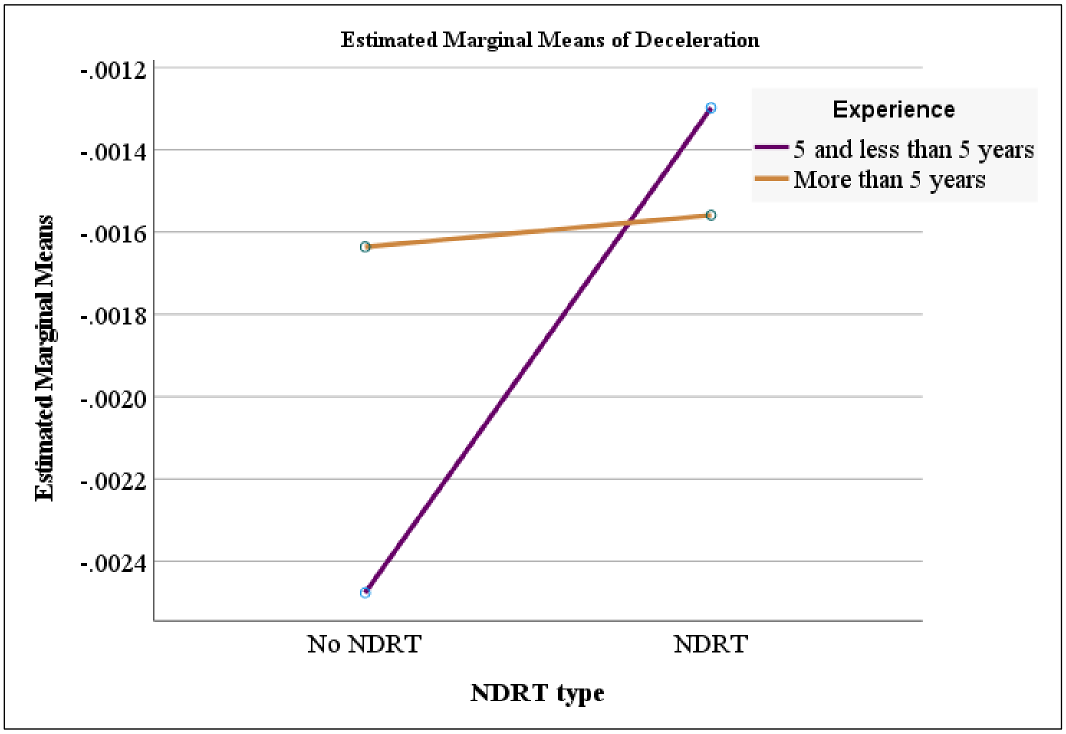


Figure 36. Interaction effect between vehicle type and experience for maximum deceleration after TOR.

5.5. Preference and Opinion Change

The objective of this section is to investigate if participants' opinions changed after driving with the CAV platoon of trucks in the driving simulation experiment. To achieve this objective, participants were provided with the following information before starting the experiment.

- Definition of an automated vehicle,
- Definition of Connected and Automated Vehicle (CAV),
- How the CAV platoon is formed and how they operate.
- How CAVs can be recognized in the experiment.

After receiving this information, participants were asked to give their opinion regarding the following two aspects.

1. Do they think that merging and diverging on a highway in the presence of CAVs would be challenging or similar to when interacting with regular vehicle or easier?
2. How strongly they agree or disagree that CAV platoons should be on a dedicated lane on highways?

After participating in the experiment, they were again asked about their opinion on the above two aspects to compare the differences in road users' challenges and preferences toward CAVs before and after taking part in the driving simulator experiment. Figure 37 shows the number of participants who viewed driving with CAV platoon near entry and exit as easier, challenging, and similar as with regular vehicle before and after the experiment. In this figure, purple-colored bars represent the opinions before participating in the experiment and orange-colored bars represent the opinions after participating in the experiment. According to Figure 37, over half of the drivers claimed that driving in presence of CAV platoon near the entry and exit of a highway would be challenging, whereas only one-quarter of them had a similar opinion after they completed the experiment. This indicates that even though drivers anticipated it would be difficult for them to interact with the CAV while merging or diverging from the highway, most of them did not find it challenging.

Another option that participants were given to choose was whether they thought merging and diverging in the presence of CAV platoon would be similar as merging or diverging with a regular vehicle. Only 37.14% of participants reported that it would be similar to a regular vehicle; this percentage changed to 57.14% after the experiment. Also, the percentage of participants who mentioned that it was easier to merge or diverge with the CAV platoon and who found it similar to a regular vehicle was 74.3% after participating in the experiment. This supports the conclusion in the previous paragraph that most drivers did not find it difficult and similar to driving with a regular vehicle. However, although only around 5% of the participants thought it would be easier to merge and take exit while there is a CAV platoon near entry and exit of a highway, more than 15% of the participants marked the navigation as easier.

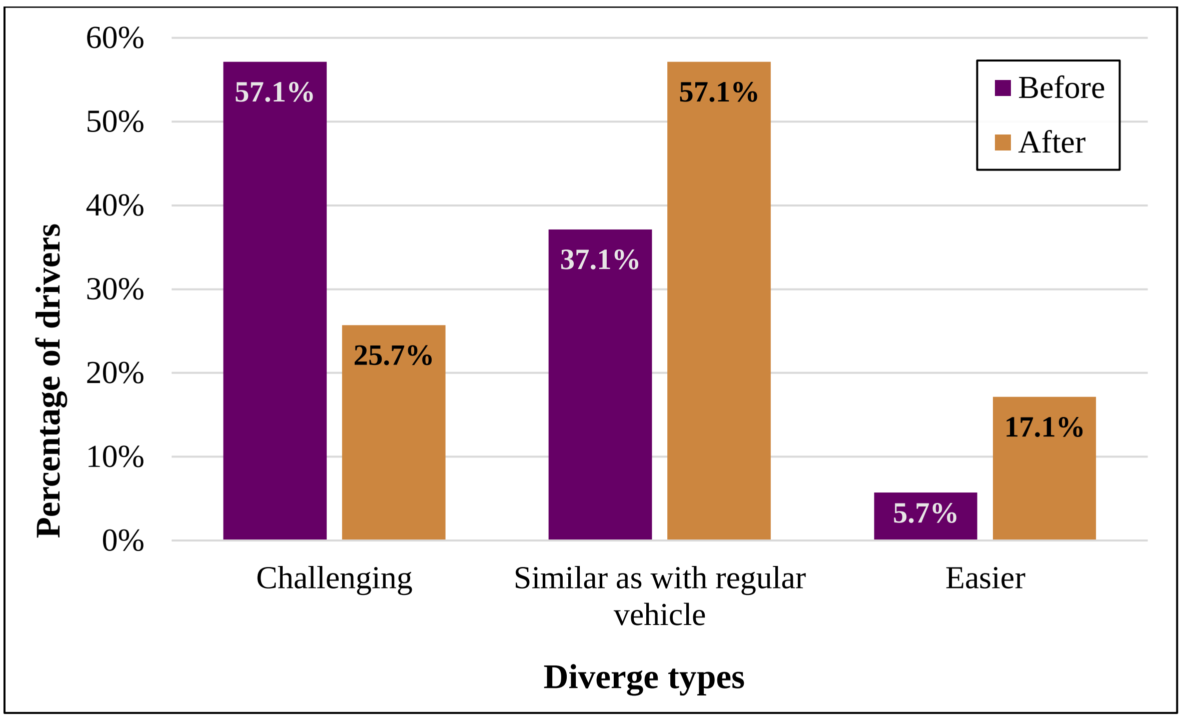


Figure 37. Drivers' opinion on driving with CAV platoon near on-ramp and off-ramp.

On the second question, participants' preference about "whether *CAV platoon should be on a dedicated lane*" before and after participating in the experiment was determined. Figure 38 shows the result of this question where the bars represent before (purple) and after (orange) response for five options (strongly agree, agree, neutral, disagree and strongly disagree). Before participating in the driving simulation experiment, around 65% drivers agreed that CAV platoons should be on a dedicated lane of the highway. Around 22% of these drivers strongly agreed about CAV platoons being on a dedicated lane. Around two-third of the drivers agreed with this aspect before the experiment, whereas more than 70% of them agreed to this aspect after they finished the experiment. This indicates that although drivers felt driving with CAV similar to driving with HDVs, they wanted the platoon to be on a dedicated lane to reduce interaction with them. Only around 6% drivers strongly disagreed about this aspect after the experiment and none of them disagreed before the experiment.

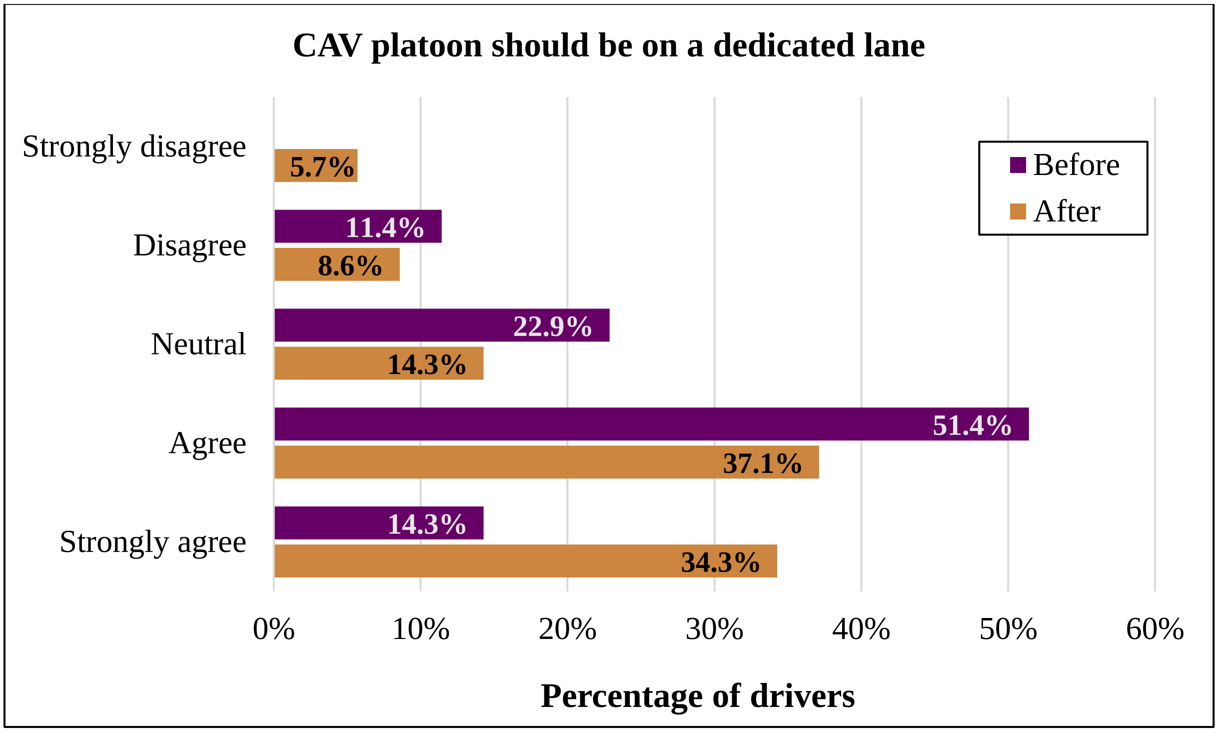


Figure 38. Drivers' preferences on CAV platoons' being on a dedicated lane.

In terms of feeling stressed during driving, only a quarter of the drivers mentioned that they felt stressed while merging with highway from on-ramp and diverging to off-ramp from highway in presence of CAV platoon in the rightmost lane (Figure 39).

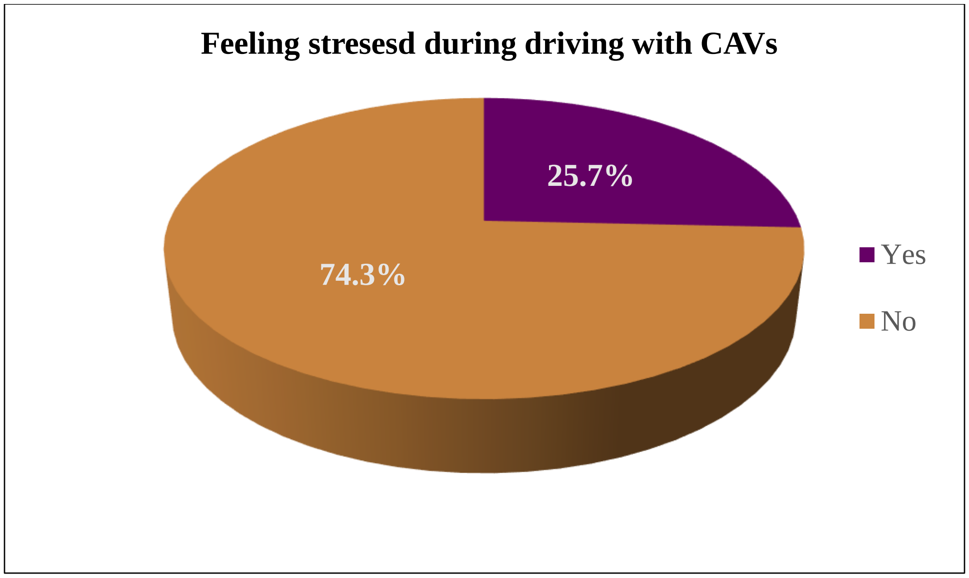


Figure 39. Drivers' opinion on feeling stressed while driving with CAVs.

6. CONCLUSIONS

The primary objective of this study was to investigate driver's behavior to connected and automated vehicles (CAVs). Underlying this objective, this study aimed to examine (1) drivers' behavior and interaction with CAVs platoon of trucks and other transitional vehicles near entry and exit of highway as well as on straight section of highways, (2) their reaction to failure in the automated driving mode, and (3) changes in their preferences and opinions about CAVs after participating in the driving simulation experiment.

6.1. Interaction with CAVs

For investigating the interaction with HDVs and CAV platoon near on-ramp and off-ramp, four scenarios were designed in the driving simulation experiment. These scenarios were merge with human driven vehicles (HDVs), merge with CAV truck platoon, diverge in presence of HDVs and diverge in presence of CAV truck platoon. Following are the main findings from this experiment.

- While interacting with closely spaced HDVs and CAV truck platoon near entry and exit of a highway, over 50% of the drivers preferred to merge in front of the CAV platoon. Contrarily, nearly two thirds of participants opted to diverge from the highway and head toward the off-ramp by staying behind the platoon (65.7%) and HDVs (60%). A potential future research direction is to include both CAV platoon of cars and trucks to investigate difference in behavior of cut-ins, merging behind and merging front etc.
- Though 8 cut-ins happened during the merge scenario, only 2 cut-ins happened during exit to the off-ramp. Among these, 6 cut-ins happened during interaction with HDVs, remaining 4 cut-ins happened during interaction with CAV platoon. As most cut-ins happened during the interaction with HDVs, it can be concluded that drivers were more comfortable to merge with the HDVs compared to merging with CAVs. For HDVs, cut-ins happened only during merge, whereas both on-ramp and off-ramp cut-ins were observed for HDVs.
- At 95% confidence level, none of the performance metrics (average merge speed, average diverging speed, the maximum acceleration and the maximum deceleration for both on-ramp and off-ramp) were significantly impacted by the vehicle type. However, with 90% confidence level, the results indicate that drivers merged with CAV at an average speed that was about 8% higher than the speed during merge with HDVs. Also, while taking the exit in the presence of platoon of CAVs trucks on the most right lane of the highway, the maximum deceleration was approximately 27% lower than that for HDVs. This demonstrates that although drivers merged in front of the CAV platoon with higher speed than the HDV scenario, they were less aggressive during off-ramp maneuvers with the platoon, resulting in lower maximum deceleration values while exiting behind the platoon.
- An interaction effect between type of vehicle and involvement in accident was found. This indicates that during diverge in the presence of HDVs, drivers who had previously involved in a traffic collision had faster speed compared to the speed in the presence CAV platoon. On the contrary, drivers with no prior accident involvement had higher speed in case of CAVs.
- The mean minimum time-to-collision (TTC) value was higher when leaving a highway than when entering highway, indicating that diverging activities were safer for participants than merging operations. When comparing the differences between HDVs and CAV platoon during merging, it was noticed that the latter had a larger (safer) TTC (7.6 s) than the former (5.1 s).

- In general, female drivers had 85% higher TTC compared to the male drivers during merge. Regarding interaction effect between gender and vehicle type (HDVs and CAV truck platoon), female driver's TTC was higher by 9.2 seconds during the interaction with CAVs compared to the interaction with HDVs during merge whereas it was higher by only 0.7 seconds for male drivers in CAV scenarios compared to HDV scenarios. However, during diverge scenarios, male drivers had 40% higher TTC in CAV scenario compared to the HDV scenarios and female drivers' TTC decreased by 40% from HDV to CAV scenario. As male drivers' TTC increased while interacting with CAV in both on-ramp and off-ramp scenarios, it indicates that male drivers' driving behavior was more consistent in terms of traffic safety in presence of CAV truck platoon.

Regarding participants' attitudes and preferences while driving with CAV platoon of trucks on straight section of the highway and during adverse weather conditions, an online national survey was designed and distributed among 1565 Americans. The main findings from the survey are:

- Nearly 65% of the survey respondents claimed that they would not overtake a CAV car platoon on a two-lane two- way road for safety reasons, whereas 20% of them reported that they would pass the platoon at one attempt.
- When asked about their preference in case of following a CAV platoon of trucks in the middle lane of a 3-lane multilane highway, around 60% of participants stated that they would prefer to change the lane to avoid staying behind the platoon. Interestingly, their preference was almost similar in case of a CAV truck platoon.
- Over 50% of the respondents would neither change the lane to follow a CAV platoon of car or truck nor will change their speed to imitate the platoon speed during adverse weather conditions such as heavy rain, fog etc.

6.2. Reaction to Vehicular Automation and Automation Failure

To investigate driver's reaction to automation failure in the automated driving mode, a take-over request (TOR) was issued after 2.2 miles of driving in automated mode. Following are the findings from analysis of drivers' activity during automation and their reaction to automation failure.

- When the subject vehicle was in automated mode, all the participants were mostly attentive towards monitoring the driving task. In the scenario with no phone allowance, 60% of the participants solely focused on monitoring the automated driving, whereas this percentage was only around 22% in the scenario with phone allowance. This is because 50% of the participants were using phone besides monitoring the driving in the scenario with phone allowance. In both scenarios, around 40% of the participants paid attention to the surroundings of the driving simulator during the automated mode of the subject vehicle. Implementing more automated driving times before issuing the take-over requests might help to get more comprehensive results regarding drivers' behavior during the automation mode.
- Maximum deceleration after the TOR was higher in the scenario where no NDRT was allowed, indicating that drivers were more careful about the driving task and were able to take back the control of the vehicle at lower deceleration while they were allowed to do non driving related tasks. This behavior was also reflected in lower Take Over Reaction Time (TORt) for non-driving related task (NDRT) scenario than no NDRT scenario. Average TORt for no NDRT scenario was 2.61 seconds which was around 24% higher

than the TORt in NDRT scenario. The mean minimum TTC was also around 22% lower in no NDRT scenario than NDRT scenario. All these three performance measures indicate that drivers were careful enough to respond to the TOR due to automation failure in a scenario where they were allowed to use their phone to browse internet or for other purposes. This might be because they were not very comfortable to trust the automation and thus were frequently monitoring the driving.

6.3. Preference and Opinion Change

Participants of the driving simulation experiment were asked about their opinion and preferences about driving with CAV platoons. Though before participating in the experiment, less than half of the drivers mentioned it would be either easier or similar to driving with regular vehicle near highways' entries and exits, more than 70% of participants indicated that driving with CAVs is easier or similar. On the other hand, number of participants who thought it would be challenging decreased after participating in the experiment and the number of individuals who thought it would be easier increased after they experienced driving with CAVs in the driving simulator.

Though a big part of the drivers mentioned driving with CAV easier or like driving with a regular vehicle, 70% of them stated that they would prefer to have CAVs on a dedicated lane of a highway. This indicates that drivers prefer to have less interaction with CAVs while driving. Before participating in the experiment, none of the drivers strongly disagreed about CAVs being on a dedicated lane. However, around 6% drivers did so after participating in the experiment.

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