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Dimitrios Zavantis
Hasselt University

Fatma Outay
Zayed University

Youssef El-Hansali
Hasselt University

Ansar Yasar
Hasselt University

Elhadi Shakshuki
Acadia University

See next page for additional authors

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Author First name, Last name, Institution
Dimitrios Zavantis, Fatma Outay, Youssef El-Hansali, Ansar Yasar, Elhadi Shakshuki, and Haroon Malik

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Autonomous Driving and Connected Mobility Modeling: Smart Dynamic Traffic Monitoring and Enforcement System for Connected and Autonomous Mobility

Dimitrios Zavantis[a]*, Fatma Outay[b], Youssef El-Hansali[a], Ansar Yasar[a], Elhadi Shakshuki[c], Haroon Malik[d]

[a]*Transportation Research Institute (IMOB), Hasselt University, Diepenbeek, Belgium*
[b]*Zayed University, Dubai, UAE*
[c]*Acadia University,Wolfville, Canada*
[d]*Marshall University, Huntington, USA*

Abstract

In recent years, autonomous vehicles (AVs), connected vehicles (CVs) and all relative technology have been in the spotlight, being intensively researched and developed. There is high anticipation on the benefits of automation and the overall reform it will bring to the transport sector, with some optimistic estimates considering it as a reality within the next few years. Evidently, AVs and CVs are attracting considerable attention and are developed very rapidly, cultivating great expectations for traffic safety improvements. While their potential is enormous and undeniable, benefits are not automatically guaranteed as there are parameters that currently appear unforeseen. This paper investigates the ways that monitoring and enforcement of autonomous vehicles can be improved and serious problems such as tailgating and crashes can be mitigated. This paper's result could provide useful conclusions about human factor, the effectiveness of existing monitoring and enforcing systems and possible future systems regarding enforcement and monitoring of autonomous vehicles (AVs).

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Keywords: AVs; Safety of AVs; Tailgating; Monitoring; Enforcement

* Corresponding author. Tel.: +306979774436
E-mail address: dimitrios.zavantis@uhasselt.be

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1. Introduction

Mobility is at cross-roads. There have been many significant steps forward over the last century in road transport. But mobility is now crossing a new – digital – frontier with increasing automation and connectivity allowing vehicles to "talk" to each other, to the road infrastructure, and to other road users. These developments, that benefit from the progress in the field of Artificial Intelligence [2], open up an entirely new level of cooperation between road users which could potentially bring enormous benefits for them and for the mobility system as a whole, including making transport safer, more accessible and sustainable [1].

Driverless vehicles will change our lives, just as steam trains and motor cars did before them. They will shape the future of road transport and could lead to significantly reduced transport costs. They could pave the way for new services and offer new ways to respond to the ever-increasing demand for mobility of people and goods [1]. Once the current teething problems have been properly addressed – and they must be, driverless vehicles could significantly improve road safety since human error is estimated to play a role in 94 percent of accidents [3]. Driverless vehicles could bring mobility to those who cannot drive themselves (e.g., elderly or disabled people) or are under-served by public transport [1].

However, we cannot expect such technological changes alone to solve the challenges of congestion, transport emissions and road fatalities. We need to properly manage the long transition phase and make sure future vehicles are embedded in a transport system that favors social inclusion, low emissions and overall efficiency [1]. We need to strengthen the links between vehicles and traffic management, between public and privately-owned data, between collective and individual transport and between all transport service providers and modes [1].

Initial studies show that a majority of European citizens have a good acceptance of driverless cars with 58% willing to take a ride in a driverless vehicle [4].

In other words, driverless mobility promises great benefits but also poses serious questions. We are in a global race to reap the benefits and answer the questions raised, as this provides a major opportunity for growth and jobs [1]. The new market for automated and connected vehicles is expected to grow exponentially and large economic benefits are expected, with for instance revenues exceeding EUR 620 billion by 2025 for the EU automotive industry and EUR 180 billion for the EU electronic sector [5]. Automated mobility could therefore support the EU ambition for a stronger and more competitive industry [6], creating new jobs and boosting economic growth.

In this paper we will try to research how we can improve the monitoring and enforcement of AVs and intelligent mobility in order to mitigate problems like traffic accidents and tailgating behavior.

2. Background

Literature review about tailgating issues, safety and security of AVs, AVs development and monitoring and enforcement systems are provided below.

2.1. Autonomous vehicles Development and Deployment Predictions

Most innovations follow a predictable deployment pattern, often called innovation S-curve. Autonomous vehicles are currently in development and testing stages. Many current vehicles have Level 2 and 3 technologies such as cruise control, hazard warning and automated parallel parking [7]. Tesla's *Autopilot* offers automated steering and acceleration in limited conditions, although deployment was delayed after it caused a fatal crash in 2016 [7]. Several companies have Level 4 pilot projects, which are testing autonomous vehicles in certain conditions, but despite this progress, many technical improvements are needed before vehicles can operate autonomously under all normal conditions [7].

Autonomous vehicles technologies will need to go through several more stages to become widely commercially available, reliable and affordable, and therefore common in the vehicle fleet. Because vehicles can impose significant external costs, such as congestion and crash risks, they have higher testing and regulation standards than most other technological innovations such as personal computers and mobile phones [7]. Under optimistic conditions testing and approval will only require a few years, but if the technology proves to be unreliable and dangerous, for example, if autonomous vehicles cause high-profile crashes, it may take longer. It is likely that different jurisdictions will impose different testing, approval and regulations, resulting in varying rates of deployment [7].

2.2. Traffic Safety and Security

Optimists claim that, because human error contributes to 90% of crashes, autonomous vehicles will reduce crash rates and insurance costs by 90% [8], but this overlooks additional risks these technologies can introduce:

- Hardware and software failures. Complex electronic systems often fail due to false sensors, distorted signals and software errors [7]
- Malicious hacking. Self-driving technologies can be manipulated for amusement or crime [7]
- Increased risk-taking. When travelers feel safer, they tend to take additional risks, called offsetting behavior or risk compensation [18]
- Platooning risks. Many potential benefits, such as reduced congestion and pollution emissions, require platooning (vehicles operating close together at high speeds on dedicated lanes), which can introduce new risks, such as human drivers joining platoons and increased crashes severity [7]
- Increased total vehicle travel. By improving convenience and comfort autonomous vehicles may increase total vehicle travel and therefore crash exposure [19]
- Additional risks to non-auto travelers. Autonomous vehicles may have difficulty detecting and accommodating pedestrians, bicyclists and motorcycles [20]

These new risks will probably cause crashes, so autonomous vehicles will not really achieve the 90% crash reductions that advocates predict [7]. Analysis of factors that contributed to traffic crashes concluded that by improved sensing and response, autonomous vehicles could prevent up to 34% of crashes, and more if the technology eliminates all traffic violations, but predictions of 90% crash reductions are exaggerated [7].

Autonomous vehicles currently have high operational failure rates. [7]. In 2019 the best test vehicle experienced one disengagement (when human drivers overrode automated systems) per 16,666 miles, but most were more frequent [7]. Many disengagements involved non-critical risks and occurred on lower-speed surface streets, and disengagement rates have declined, but this indicates that in 2020 autonomous vehicle operating technologies are not ready for implementation, particularly in mixed urban traffic [7].

2.3. Evaluation of Existing Systems for Tailgating Avoidance

Tailgating is generally considered a form of aggressive driving. The National Highway Traffic Safety Administration defines “aggressive driving” as “an individual committing a combination of moving traffic offenses so as to endanger other persons or property” [21]. While many driving patterns are considered aggressive, tailgating is among the most dangerous ones and is a major cause of rear-end crashes [8]. Out of about 5.9 million police-reported automobile accidents in the United States during the year 2006, rear-end collisions ranked the highest, with more than 1.8 million cases (30.4%), and resulted in more than 2,100 fatalities and approximately 500,000 injuries [21]. Data from the Federal Highway Administration (FHWA) indicate that each year, approximately 2.2% of total licensed drivers in the United States are involved in rear-end crashes [22]. Two factors are primarily responsible for rear-end crashes: inattention and tailgating, while the latter is the major contributing cause with a deadly consequence [21].

Some past researchers showed that a wide range of factors such as drivers’ behavior, traffic condition, road condition, roadway design, state law and regulation, and even personality had effects on vehicle headway [8]. Based on these factors, various car following models were developed to describe the interaction between individual vehicles or the whole traffic dynamic. However, none of them compared these factors and identified factors that have major effects on vehicle headway [8].

While driving on highways, a driver’s reaction time varies from 0.5 second for simple situations to 4 seconds for complex situations and the reaction time in braking is about 2.5 seconds [8]. Simple reaction time was often less than one second while decision reaction time could take much longer. According to this, quantified safe following distance has been written into rules of the road [8]. It varies from state to state, but is mostly in the form of a "two-second rule." Drivers are advised to keep a vehicle headway of at least two seconds from the vehicle ahead driving in the same direction. Rear-end crash risk increases as vehicle headway decreases. When vehicle headway reduces to zero, a rear-end crash occurs [8].

2.4. Human Factor on Automated Driving

Automated driving technology has the potential to fundamentally change road transportation and improve quality of life. Automated vehicles (AVs) are anticipated to reduce the number of accidents caused by human errors, increase traffic flow efficiency, increase comfort by allowing the driver to perform alternative tasks, and ensure mobility for all, including old and impaired individuals [23].

Along this accelerating evolution of road vehicle automation, Human Factors (HF) research scientists have warned for a long time that the mere fact that you can automate does not mean that you should [24]. As early as 1983, Bainbridge presented several 'ironies of automation' and explained that "the more advanced a control system is, the more crucial may be the contribution of the human operator [9]." Similarly, Parasuraman and Riley in 1997 explained the importance of studying how humans may misuse, disuse, and abuse automation technology, and also argued that humans tend to be poor supervisors of automation [25]. With respect to AVs in particular, up to Level 4 automation, human drivers will be a key component, because they should operate the vehicle in conditions not supported by the automation, and will be expected (Level 4), even if not liable (Ref for Volvo), or even required (Levels 2 and 3) to resume manual control when needed [9].

Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved [9]. Such challenges include the impact of automated systems on drivers' mental workload and situation awareness, as well as the human drivers' levels of acceptance, trust, and reliance on the automated systems [9].

Further challenges are associated with potential changes in human drivers' behavior due to automation, the necessary skills that the humans should retain to perform the driving task manually, and the role of the humans in the case of an emergency such as when automation fails or exceeds its functional limits [9]. In addition, research has yet to clarify the required level of supervisory control and cooperation (who is performing what part of the driving task) between human drivers and automated systems [9].

2.5. Traffic Accidents with Autonomous Vehicles

According to Petrovic et al. [10], despite the great expectations regarding the positive effects of AVs on road safety, all papers have found that traffic accidents with an AV occur more often than accidents with a conventional vehicle (CV). Considering a small sample of traffic accidents with AVs in the conducted analyzes did not put special emphasis on the type of collisions, maneuvers and errors for the occurrence of accidents [10].

Favarò et al. [11] found that the most frequent type of collision is rear-end – front bumper of CV and rear bumper of AV. Also, it was found that in most cases the vehicle speed was less than 10 mph [11]. Applying advanced software packages, some authors analyzed the impact of the introduction of AV in everyday traffic on the number and types of collisions [12].

Simulating introduction of AV (10% - 50% in traffic flow) on 4 roundabouts in Croatia recorded an increase of rear-end type crashes [12]. Authors found that with the increase in the share of connected AVs in traffic flow noted decreasing in the number of conflicts, but the share of rear-end conflict increased. Hence, we can notice that the involvement of AVs is prone to rear-end traffic accidents both in reality and simulation packages [12]. However, AVs will have more significant effects on road safety when increasing their participation in traffic. Authors have found that positive effects on road safety in arterial segments can be expected with a share of more than 30% of this type of vehicle. Similarly, positive effects on road safety in intersections can be expected with a share of more than 40% [12]. Morando et al. [13] analyzed the impact of autonomous vehicles on the number of conflicts at the signalized intersections and roundabouts. In this paper, it is found that a share of 50% of autonomous vehicles in traffic can reduce the number of conflicts at signalized intersections by 20% and roundabouts by 29% [13]. By contrast, maneuvers and errors for the occurrence of accidents with AVs still have not been the subject of research [10].

2.6. Evaluation of ITS on-Road Safety

The seriousness of road traffic accidents in terms of personal injuries, fatalities, and property damage, has been recognized by the World Health Organization as a social and public health problem, based on advanced telecommunication and information technology, offer a great potential for improving the road safety situation for all types of road-users [14]. In this report we see the identification of ITS and its benefits and after that they present the importance of ITS in-road safety parameters and investigate how ITS can influence all of the key macroscopic variables of the road safety problem, for example the severity of an accident [14].

ITS are advanced applications which provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks [14]. Although ITS may refer to all modes of transport, EU Directive 2010/40/EU of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport defines ITS as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport [26]. ITS is a collective name for a number of technology- based approaches that are designed to improve the quality, safety and efficiency of transport networks. These approaches could be categorized by application areas such as traffic management control, tolling, road pricing, road safety and law enforcement, public transport travel information and ticketing, driver information and guidance, freight and fleet management and vehicle safety [14].

2.7. Autonomous Vehicles: A Gradual Transition

Low levels of car automation (e.g., Levels 1–3) are already in place, offering capabilities such as parking assistance, autonomous emergency braking, lane tracking/entering and adaptive cruise control. Fully autonomous Levels 4 and 5 will give the drivers back time from daily commuting and transform driving into opportunities to work, enjoy entertainment and socialize with fellow passengers [15].

Automotive experts anticipate that the transition to autonomous vehicles will be gradual, as the benefits (in safety, congestion and parking, etc.) can only be realized after the reduction of "corner cases"—those outside of normal operating parameters—that vehicle AI must consider when it needs to anticipate the behavior of human-driven vehicles [15]. Adoption is likely to start with closed environments—for instance airports, campuses, and dedicated traffic lanes—and expand to selected public roads. Collaboration across many digital supply chain partners will be required to test out these scenarios [15].

Comparing regions, the U.S. legislative environment and road infrastructure are the most supportive of autonomous driving, while continental Europe lags because of limited testing activity and older road infrastructure. According to a study by KPMG, Autonomous Vehicles Readiness Index, the U.S. has been ranked above all European countries (excluding the Netherlands) for a combination of four success factors for autonomous driving: policy and legislation, technology and innovation, infrastructure, and consumer acceptance [27]. California, Nevada and Arizona now allow for driverless testing of autonomous cars with remote monitoring only. California has been a preferred choice for autonomous vehicle testing (with 1M+ autonomous miles driven from 2014 through 2017 by 20 companies). Autonomous vehicle testing in Europe has been moving more slowly and is more regulated (with tests being conducted on private roads and/or in low-speed areas) [27].

2.8. Monitoring of Automated Vehicles

One of the biggest challenges is the monitoring of automated and connected vehicles. Remote control systems can act as an economic and safety backup of automated systems [16]. In remote control, one person can manage multiple AVs, take actions upon request, and take over the control after system failures. Inspired by the control tower in aviation control, the AVTCT can be a potential solution to control and manage AVs in various scenarios [16]. It should be noted that remote control from a control tower is not the same as remote driving of the vehicle. The control tower could be a solution to integrate vehicle, human and dynamic situations to fulfill real transport assignments in an efficient, safe and reliable way. In the control tower, human operators are prepared, when necessary, support is needed. AVTCT can perform the traffic control from a holistic level to a specific individual level for fleet management, commercial services and personal travel [16].

An AVTCT has the potential to control vehicles when the ADS control fails. Decision-making can then be more proactive, reactive and responsive because information is processed more efficiently based on a holistic view of situations like weather data, traffic information, and movements of other vehicles [16]. AVTCT does not only serve as a safety control center but also as a platform for handling requirements from various actors, and makes the whole transport system more efficient and intelligent. Cooperation among stakeholders and support both from the technical side and policy side can be conducted through AVTCT [16].

AVTCT may provide various functions when it comes to fleet management and autonomous driving. First, similar to AiTC, one potential role of AVTCT is to assure traffic safety and increase traffic efficiency in dynamic situations [16]. Second, AVTCT can probably make decisions and take actions to achieve safe, reliable and efficient automated driving in teleoperation mode.

3. Methodology

Regarding the methodology, except the literature review part which is shown above, a survey and a data analysis used for this research in order to go even deeper to the problem.

3.1. Survey

In order to be able to analyze more in depth how the human factor influences autonomous mobility or how autonomous mobility influences drivers, a survey conducted. The objective of this research is to examine how the human factor (drivers) can influence autonomous vehicles and connected mobility in terms of traffic safety.

The main goal of the survey is to gain knowledge of people regarding autonomous and connected mobility. What do they know about the specific subject? What do they believe about it? Do they have any similar experience? What is their opinion about traffic safety? Will they ever feel safe inside an autonomous vehicle? How do they perceive the mixed traffic situation? Autonomous vehicles and connected mobility are not something new, but not all people are familiar with these terms. The report from the survey in combination with the literature review part will give us a clearer picture about the interaction between human factors and autonomous and connected mobility. The questionnaire consists of 19 questions, divided into 4 main parts scattered inside the survey:

- Demographic questions
- AVs knowledge questions
- Responders' perspective questions
- Traffic safety questions

3.2. Data analysis

In order to investigate how big, the tailgating problem is and if there is room for improvement, a tailgating data analysis has been performed. For that purpose, we were given data by the Vitronic company. The data retrieved from Abu Dhabi tailgating site and the considering parameters are:

- Distance variation in observance time
- Setting parameters of vehicle length, where chosen 3,5 meters

In tailgating we try to find out which is the safe distance between two vehicles. It is too difficult to measure the distance between two moving vehicles in the field, so we have to measure first the velocity at which each vehicle passes through a reference point and the time that each vehicle passes through the same reference point. So, if we multiply the velocity and the time, we can find the distance. In our case, were we have a specific reference point, we can find the distance between two vehicles by following the formula below:

$$V1 \; x \; T1 - V2 \; x \; T2 \tag{1}$$

- V1: The velocity of the first vehicle at which it passes through a reference point
- T1: The time that the first vehicle passes through the reference point
- V2: The velocity of the second vehicle at which it passes through a reference point
- T2: The time of the second vehicle passes through the reference point

4. Result Analysis

This chapter focuses on the analysis of the results of the survey and the data analysis. There is a perfect match between survey and data analysis, because both the methodologies in some point analyze the human perspective and the human behavior. The perception of the responders regarding mixed traffic is depicted in tailgating driving behavior in data analysis.

4.1. Survey analysis

In order to create the survey, collect and analyze the data, Qualtrics XM has been used. The specific software also offers analysis of basic statistics and relative percentages which are enough for this research work. The two figures below are depicting the most important survey responses and what participants prefer regarding their vehicle.

In Figure 1 is observed the level of automation that participants prefer for their vehicle. Only 14% of the participants prefer full automation for their vehicle and most of the responders, almost 30%, prefer conditional automation, which is somewhere in the middle of the levels of automation.

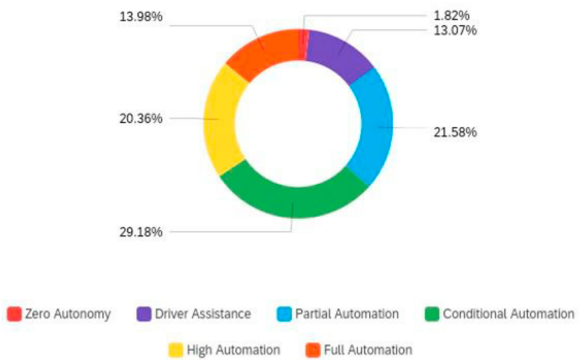

Fig. 1. Levels of autonomy participants prefer for their vehicles.

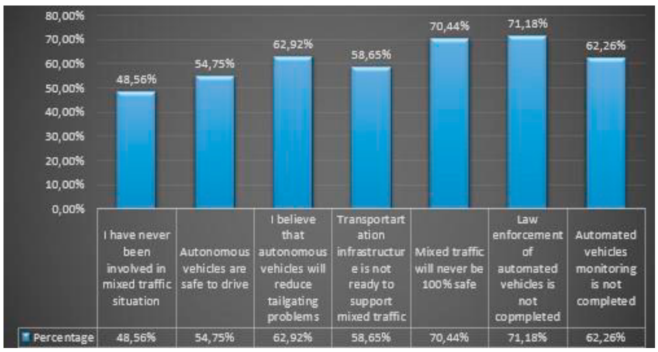

Fig. 2. Most important survey answers.

In Figure 2 the most important survey responses are depicted. Most of the responders, almost 71% believe that mixed traffic will never be 100% safe, since human factors are involved. 71.18% of the participants agreed that the law enforcement of automated vehicles is not completed and a lot of work needs to be done in order to have a fully functional system. On the other hand, 54.75% believe that autonomous vehicles are safe to drive.

4.2. Data analysis

Regarding the tailgating problem, a tailgating analysis using excel is performed. In Figure 3 we can see how big the tailgating problem is, since we know the vehicle separation based on their distance. First, we have to mention that the speed limit of the specific road is 120 km/h, so the cars below are not speeding. From a total of 34.517 vehicles, 17.675 vehicles keep distances between 4 to 100 meters. And this is really dangerous since a car that moves at a speed of 100 km/h needs almost 100 meters to come to a complete stop [17]. The driver needs 1 to 1,5 seconds to think, and this time equals 20 to 30 meters. After the brake is pushed, the car needs 70 to 80 meters to come to a complete stop [17].

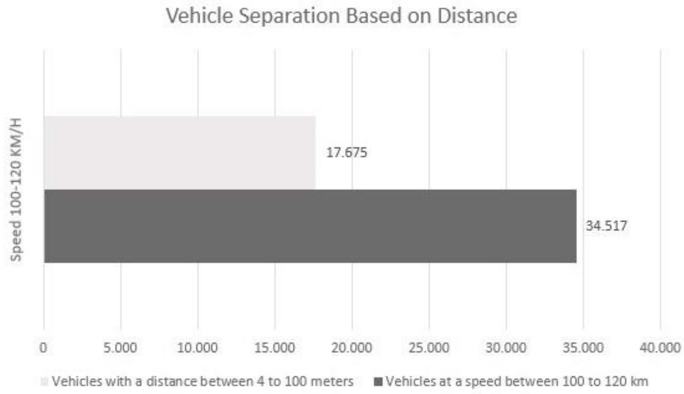

Fig. 3. Dangerous tailgating behavior.

5. Conclusions and future work

This paper presents the existing systems of monitoring autonomous and connected mobility and how these systems can be improved in order to mitigate problems such as tailgating and traffic accidents. Data analysis identified serious tailgating issues and indicated a need for countermeasures that need to be taken. Advisory signs and training of the drivers in order to change their driving behavior are some of them.

Also, the survey gave us a clearer picture about responders' perception and knowledge according to autonomous vehicles and connected mobility. Most of the responders believe that autonomous vehicles are safe to drive and will reduce tailgating and traffic safety issues, but on the other hand most of them believe that mixed traffic will never be 100% safe since the human factor is involved. The main limitation of the survey was the uncertainty of responders if they have ever been involved in a mixed traffic environment and their limited knowledge about connected mobility.

Finally, the literature review gave us the opportunity to explore the existing systems for monitoring and enforcing connected mobility but also the future steps that will be taken in all areas of connected mobility. AVs and connected mobility depend on a variety of parameters such as human behavior, mobility infrastructure, people perception, fears and laws. Also, traffic control centers and ITS could play a major role in AVs and connected mobility. Until now, a variety of efforts have been made on monitoring and enforcement of AVs, but there is still room for improvement.

This paper could provide useful conclusions about AVs and connected mobility regarding the systems for their monitoring and enforcement, but there are limitations to this approach that should be addressed in the future.

All of the methodologies could be used in further research but with some changes. The changes have to do with the 2 steps of the methodology that have been used, survey and tailgating analysis. Regarding the survey, the aim would be to involve people related to the subject and people who have experience. In this survey the most of the participants were students without any previous experience and answers weren't the best. Regarding tailgating analysis, the limitation of data was the biggest constraint. Also, there were no participants in the survey from the country where the data came from, and that couldn't give us the chance to compare the data and the survey results.

Ideally, the data and the participants should be from the same area for comparison reasons. Finally, the percentage of AVs, if any, relative to the conventional vehicles wasn't known.

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