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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

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

Dimitrios Zavantis

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

SUPERVISOR :

Prof. dr. ir. Ansar-Ul-Haque YASAR

MENTOR :

Mevrouw Hana GHARRAD

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PREFACE

During the Master of Transportation sciences at Hasselt University, I gained knowledge in various aspects of transportation. Knowledge that helped me discover my work even more. I have been working at a motorway management centre in Greece since 2009 and I am very experienced in motorway management and safety issues. During all these years I have been taught about different modes of transport, human behavior, transport planning etc. This was, important and helped me to become more efficient in my work. The university studies helped me a lot to strengthen my problem-solving skills and made me think more scientifically.

During all these years, hearing frequently about connected and intelligent mobility. These definitions were new for me. How difficult is it to monitor and enforce that kind of systems? What are the main challenges of that kind of systems? How difficult is it to have mixed traffic? Is it possible to apply that kind of systems in Greece? Really challenging questions for me and that was an important factor of selecting the specific topic to research.

With these thoughts and with Prof. Yasar guidance, I have started reading about these systems and I was impressed with what the possibilities could be for these systems. I also want to search all possible potential issues or problems of these systems.

People that are working on a motorway management centre know that traffic safety is the most important daily task. Our job is to protect the people that are using the motorway and keep traffic moving smoothly through any work or incident zone. In order to succeed, we use a cutting-edge equipment and plenty of systems. But how difficult is it to keep the traffic moving smoothly in case of a mixed traffic, since we know that the human factor is the one of the most important factors causing a traffic accident. This is really challenging for me.

At this point I would like to thank my parents for their support all these years, but especially my wife and my two little kids who are by my side in all my decisions. Also, a special thanks to my Prof. Ansar Yasar for all his guidance and supportiveness all these years. I could not accomplish even half of what I have done without his guidance.

SUMMARY

This master thesis elaborates on autonomous driving and connected mobility and more specifically on the smart dynamic traffic monitoring and enforcement system for connected mobility. There are many challenges that I faced, but I will try to analyze as best as I can how to overcome these kinds of challenges.

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 few next years. However, since it is still an emerging technology, its impacts on several aspects are still unclear (ERSO, 2018).

One such aspect, probably amongst the most critical from a social, economic and scientific point of view, is traffic safety. There is considerable uncertainty regarding the repercussions that will occur when AVs and CVs start operating in real traffic conditions, and several pertinent questions have reasonably arisen:

- Will there be an impressive reduction in crashes when full automation is reached?
- Could vehicles be freely repurposed when there is no need for human hands-on driving?
- What do we have to change from the current state to reach safe automation?
- Where does the fault or liability lie in the event of a crash?
- What will happen during the transition phase, when human drivers share the road with artificial intelligence algorithms?
- What kind of system is needed to monitor and enforce connected and intelligent mobility?

Researchers, authorities and stakeholders have strived to provide respective answers, which, however, do not always seem to agree. This report aims to provide a synthesis of current knowledge and a discussion on current and future challenges of connected and autonomous vehicles regarding traffic safety, by analyzing relative research from scientific, governmental and industrial viewpoints and commenting on general directions for future advancement and overcoming of challenges (ERSO, 2018).

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. Increased efforts and participation of all stakeholders will be required to ensure a smooth and lengthy transition period, where safety and public acceptance of AVs will be tested in earnest. AV progress will not be confined by a lack of preparation on any front; rather all interested parts should anticipate their arrival beforehand.

Conventional traffic safety has improved by leaps and bounds ever since the operation of the first motor vehicles, with considerable advancements in contemporary road operations, and even more ambitious targets. One such target is the Vision Zero initiative that originated from Sweden, which states that “it can never be ethically acceptable that people are killed or seriously injured when moving within the road system”. Traffic and road safety practices have been implemented to save lives by halting the increase of road traffic fatalities against an ever-rising population. The still occurring fatalities, however, suggest a lot of untapped potential and margin for safety improvements, since they are mainly caused by the very high human error in road crashes, which is estimated at over 90%. These improvements will reduce the lessening of the respective burdens on society in human and economic terms as well (ERSO, 2018).

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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, 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.

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. 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 per cent of accidents. Driverless vehicles could bring mobility to those who cannot drive themselves (e.g., elderly or disabled people) or are under-served by public transport. They could encourage car-sharing schemes and 'mobility as a service'3 (i.e., selling rides, not cars). They could also accelerate vehicle electrification and electro-mobility4. Ultimately, driverless vehicles could free up the space wasted in parking and revolutionize urban planning (European Commission, 2018).

The EU is one of the largest exporters of vehicle technologies. Its businesses stand to benefit from the dynamic growth of the sector. High levels of investment will be needed and new jobs will be created to develop new technologies and services. The EU automotive industry, with its expertise in developing vehicle technologies, is well-positioned to seize this opportunity6. Moreover, automated vehicles will also have spill-over effects on many other sectors in the value chain (e.g., semiconductors, processing technologies, digital maps) and the new business models enabled or facilitated by driverless mobility (e.g., electronic commerce, 'mobility as a service').

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. 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.

Initial studies show that a majority of European citizens have a good acceptance of driverless cars with 58 per cent willing to take a ride in a driverless vehicle7. However, as the latest accidents in the United States have shown, in order for automated mobility to gain societal acceptance only the highest safety and security standards will suffice. New risks such as overreliance on, and misuse of, technology should be addressed.

New questions such as the level of infrastructure support for driverless vehicles and how this infrastructure should interact with the vehicles should be tackled. Ethical issues related to transferring the responsibility of driving to vehicles must also be addressed. This includes our expectations for how a vehicle should react when an accident cannot be avoided and criteria used to determine a vehicle's decision. Relatedly, to this we need to ask ourselves who is liable when a driverless vehicle is involved in an accident (European Commission, 2018).

It is also essential to find the right balance between sharing public and private data, enabling fair and effective competition for innovative solutions, and data protection. As we share more data and as the

number of players involved increases, it is necessary to ensure that Europe remains competitive in all phases of driverless mobility, up to and including bringing these final services to our citizens and our businesses. Finally, the disruptive effect of driverless mobility on the labor market will have to be addressed, particularly the need for skilling and reskilling (e.g., professional drivers would initially gain freedom to perform additional tasks but could in the long-term no longer be needed in the vehicles).
Provided the regulatory and enabling framework is in place to address all these issues the first vehicles driving themselves under specific driving conditions could be available on a commercial basis by 2020, and they could become commonplace by 2030 (European Commission, 2018).
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. 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 sector8. Automated mobility could therefore support the EU ambition for a stronger and more competitive industry9, creating new jobs and boosting economic growth.
With this communication, the commission proposes a comprehensive EU approach towards connected and automated mobility setting out a clear, forward looking and ambitious European agenda. This agenda provides a common vision and identifies supporting actions for developing and deploying key technologies, services and infrastructure. It will ensure that EU legal and policy frameworks are ready to support the deployment of safe connected and automated mobility, while simultaneously addressing societal and environmental concerns which will be decisive for public acceptance (European Commission, 2018).

1. PROBLEM DEFINITION, OBJECTIVES, RESEARCH QUESTIONS, METHODOLOGY

1.1. Problem Statement

Urbanization increases the problem of density. More people live in less space and all demand mobility. However, due to geographical constraints, the expansion of the mobility infrastructure is limited. Therefore, intelligent mobility services are considered to be key to support citizens and commuters in their daily lives in future smart cities. These services rely on data, which is currently gathered but mostly stored in legacy systems that operate in isolation.
The lack of digital support leads to inconvenience for citizens and commuters when they are looking for free parking lots, car sharing vehicles or public transportation. Furthermore, raising needs for private transportation due to the lack of effective mobility services result in more congestion and pollution in the cities, which contradict the vision of building smart, sustainable and green cities.
The smart traffic management system, a speculative informational, clever, effective and mingled new transport framework that works to expand the productivity of transport foundation by new age data innovation, data communication transfer technology, electronic control technology and computer processing technology.
The creative energy of smart cities is inconceivable without utilizing smart traffic management systems. The smooth and fault free activity development is the key to smart cities. Traffic congestion is the result of poor infrastructures, low speed and violation of traffic rules. Although many traffic management and control strategies utilized on interurban systems are legitimate, with some traffic administration designs close key conurbations coordinating the interface to urban systems, urban

traffic administration mainly includes traffic signal administration and coordination, need and enhancements to open transport and a more exhaustive portability administration approach, given specifically that a considerably more noteworthy extent of journeys in urban ranges are normal trips (e.g., driving). These days, the quantity of vehicles has expanded exponentially, however the bedrock limits of streets and transportation frameworks have not created a comparable approach to productively adapt to the quantity of vehicles going on them. Because of this, street sticking and activity connected contamination have expanded with the related unfriendly societal and budgetary impact on various markets around the world. A static control framework may square crisis vehicles because of roads turned parking systems. WSNs have increased expanding consideration in movement location and maintaining a strategic distance from street blockage. WSNs are exceptionally popular because of their quicker exchange of data, simple establishment, less support, smallness and for being more affordable contrasted with other system choices. There has been huge research on Traffic Management Systems utilizing WSNs to maintain a strategic distance from clog, guarantee need for crisis vehicles and cut the Average Waiting Time (AWT) of vehicles at crossing points. The purpose of Smart Traffic Management is mainly improvised for looking after the Set off data of a region to manage the Traffic along that area and implement various useful technologies which have been required by various persons like vehicle owners, pedestrians, police officers etc. Mainly the purpose of Smart traffic management system is to give the traffic information which road users can use in their daily life. The problems which have occurred in their presence can be solved by this Smart Traffic (Das A., Dash P., Mishra K. B., 2018).

In Greece we are ages back when we talk about connected and intelligent mobility or autonomous vehicles, so I would be very interested to research how this intelligent system works in other cities in the world. I work in a motorway management centre in Greece and I would be very interested to find out how this kind of system could be implemented on a Greek motorway and how we can gather all the information that we need to monitor and enforce intelligent mobility, in order to have a safe motorway. I would be very interested to find how intelligent mobility could fit on non-intelligent infrastructure and what interventions must be done in order to succeed.

1.2. The Objective

The objective of my thesis is first, to review what kind of systems are used in order to enforce and monitor the connected and intelligent mobility and second, what interventions must be done in terms of infrastructure and systems, in order to efficiently monitor and enforce autonomous vehicles. I will also try to analyze the available data of existing traffic issues such as tailgating behavior, in order to find out the current number of front-end crashes of that behavior and maybe the future number of those crashes after countermeasures. It is also really important to find out the key points below:

- Monitoring and enforcement of mixed traffic
- Traffic safety
- Drivers' interaction with autonomous vehicles (human factor)

As I mentioned above, I work in a motorway management centre (MMC) and I really want to find out how intelligent mobility can be monitored and enforced through the MMC.

1.3. The Key Research Questions and Sub Questions

With the advent of autonomous vehicles, road safety issues began to appear on the horizon causing many problems. The mixed traffic is a difficult situation and especially the human factor contributes to this difficulty. One of these difficulties is tailgating, which is a dangerous driving behavior and a leading cause of most rear-end crashes.

This thesis will try to give answers on the following main questions:

- *What systems (onboard and outboard of the smart vehicle) must be used concerning the improvement of monitoring and enforcement of intelligent mobility, in order to mitigate problems like traffic accidents due to tailgating?*

To facilitate an answer to this question, the below sub-questions are proposed:

- *How can we improve the efficiency of an existing tailgating system, based on available data? Is there room for improvement?*
- *How can the human factor(drivers) influence autonomous and connected mobility?*
- *How systems for monitoring and enforcing mixed traffic can be made more effective?*
- *Is it possible to enforce, control and monitor autonomous and connected mobility by a traffic control center?*

1.4. Scope of the Study

As the use of autonomous vehicles is growing every day, road safety issues are rise and uncertainty grows. People must feel safe either as an autonomous car driver, or in case of mixed traffic, while driving their conventional vehicle. The first part of the study consists of a literature review, regarding autonomous vehicles in terms of their history, safety issues, evaluation of the existing enforcement systems, ways of monitoring AVs, limitations and future of mobility.

The second part consists of a survey. 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. After the survey is finished useful conclusions are expected to be drawn. Since we are still years away from fully autonomous mobility, people's perception and ability to drive in a mixed traffic environment are crucial mobility ingredients.

The third and last part consists of data analysis. As we know, tailgating is a dangerous behavior in terms of traffic safety. Most rear end crashes are due to tailgating. Here also we have to deal with human factor, human behavior. Are autonomous vehicles capable of reducing or even eliminating the specific human behavior and making our trips safer? The specific answer will be answered since all the three parts are finished and all available data will be analyzed.

From the different methods I have used, I must highlight the two delineations of my study. The first one is the people's participation in my survey. From the beginning of my research, I knew that survey's participant will be only students and some of my colleagues, so participation is limited. As we know in research, the greater the participation in it the better its results.

The second one is the limited available data for analysis. For my own analysis, I had at my disposal data for only one day so the analysis may not be so representative of reality. In each case, many useful conclusions can be drawn. Furthermore, the objective of this research is to highlight the smart dynamic traffic monitoring and enforcement system for connected and intelligent mobility and describe the future and the limitations of that system.

1.5. Methodology

To answer the main question: "What systems must be used concerning monitoring and enforcement of intelligent mobility, in order to mitigate problems like traffic accidents and tailgating", a few sub-questions are proposed. Finding answers to these sub-questions cumulates to an answer to the main research question.

The first sub-question "How can we evaluate the efficiency of existing tailgating systems, based on available data? Is there room for improvement?" tries to investigate how big is the tailgating problem and if there is room for improving the specific traffic behavior. To acquire all the necessary information, a tailgating analysis using excel must be performed, in order to figure out how big the tailgating problem is. Also, for the second sub-question a literature review must be performed.
The second sub-question "How the human factor(drivers) can influence autonomous and connected mobility?" it has to be done with the human factor. Human factor is a really important factor on traffic safety and a literature review must be performed also in order to see the interaction between people and intelligent mobility. I can definitely say for sure that the human factor is the number one factor of traffic accidents and tailgating behavior, and this conclusion comes from my experience at the motorway management centre. According to the literature "Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved" and this is really a challenge, in order to see what to expect for now and for the future. Also, I believe that in order to have a clear picture, a survey must be conducted. It is really important to know how the drivers, in case of mixed traffic, can coexist safely with autonomous vehicles in order to increase traffic safety and avoid tailgating accidents. This survey should target a variety of categories of drivers including young novice and older experienced drivers. It is really important to answer the specific sub-question about human behavior, if we want to solve traffic safety issues.
The third sub-question" How can it be done more effectively the monitoring and enforcement of mixed traffic?" it has to be done with the effective monitoring and enforcement of mixed traffic. What kind of systems will allow us to efficiently monitor and enforce mixed traffic? Since the human factor and autonomous vehicles are involved, the monitoring and enforcement of traffic becomes a challenge. In order to answer the above sub-question a literature review must be performed. According to the literature we saw that the use of drones is something new and I strongly believe that drones can be successfully used in the future.
Finally, the fourth sub-question" Is it possible to enforce, control and monitor autonomous and connected mobility by a traffic control center "it is relevant to my job. In order to monitor and enforce intelligent mobility, we need to create a management centre where all the information is gathered and analyzed in terms of traffic safety and accidents avoidance. A literature review must be performed, in order to see how traffic centers around the world deal with intelligent mobility, and what is expected to be used in the future. In my job we are not familiar with those kinds of systems and this is something that I really want to research. How are the developed countries dealing with this problem or what are they planning to do in the future in order to succeed in total control of intelligent mobility? When the answers to all these sub-questions are cumulated, the main research question will have been answered.

2. LITERATURE REVIEW

2.1. Brief History and Current State of Autonomous Vehicles

While futurists have envisioned vehicles that drive themselves for decades, research into AV technology can be divided into three phases. From approximately 1980 to 2003, university research centers worked on two visions of vehicle automation. The first were automated highways systems where relatively "dumb" vehicles relied on highway infrastructure to guide them. Other groups worked on AVs that did not require special roads. From 2003 to 2007, the U.S. Defense Advanced Research Projects Agency (DARPA) held three "Grand Challenges" that markedly accelerated advancements in AV technology. The first two were held in rural environments, while the third took place in an urban environment. Each of these spurred university teams to develop the technology (Anderson J.M., Kalra N., Stanley K. D., Sorensen P., Samaras C., Oluwatola O. A., 2016).

More recently, private companies have advanced AVs. Google's Driverless Car initiative has developed and tested a fleet of cars and initiated campaigns to demonstrate the applications of the technology—for example, through videos highlighting mobility offered to the blind. In 2013, Audi and Toyota both unveiled their AV visions and research programs at the International Consumer Electronics Show, an annual event held every January in Las Vegas. Nissan has also recently announced plans to sell an AV by 2020.

Google's vehicles, operating fully autonomously, have driven more than 500,000 miles without a crash attributable to the automation. Advanced sensors to gather information about the world, increasingly sophisticated algorithms to process sensor data and control the vehicle, and computational power to run them in real time has permitted this level of development (Anderson J.M., et al, 2016).

In general, robotic systems, including AVs, use a "sense-plan-act" design. In order to sense the environment, AVs use a combination of sensors, including lidar (light detection and ranging), radar, cameras, ultrasonic, and infrared. A suite of sensors in combination can complement one another and make up for any weaknesses in any one kind of sensor. While robotic systems are very good at collecting data about the environment, making sense of that data remains probably the hardest part of developing an ultra-reliable AV.

For localization, the vehicles can use a combination of the Global Positioning System (GPS) and inertial navigation systems (INS). Challenges remain here, as well, because these systems can be somewhat inaccurate in certain conditions. For example, error of up to a meter can occur in a 10-second period during which the system relies on INS. At this point, it is not clear what combination of sensors is likely to emerge as the best combination of functionality and price—particularly for vehicles that function at Level 3 and higher.

In order to permit autonomous operation without an alert backup driver at the ready, the technology will need to degrade gracefully, in such a way that a catastrophe is avoided. For example, if some element of the system fails in the middle of a curve in busy traffic, there must be a sufficiently robust back-up system so that even with the failure, the vehicle can maneuver to a safe stop. Developing this level of reliability is challenging.

The role of vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication in enabling AV operation also remains unclear. While this technology could ease the task of automated driving in many circumstances, it is not clear that it is necessary. Moreover, V2I might require substantial infrastructure investments—for example, if every traffic signal must be equipped with a radio for communicating with cars (Anderson J.M., et al, 2016).

Partly as a result of all of these challenges, most (but not all) stakeholders anticipate that a “shared driving” concept will be used on the first commercially available AVs: Vehicles can drive autonomously in certain operating conditions—e.g., below a particular speed, only on certain kinds of roads, in certain driving conditions—and will revert to traditional, manual driving outside those boundaries or at the request of a human driver.

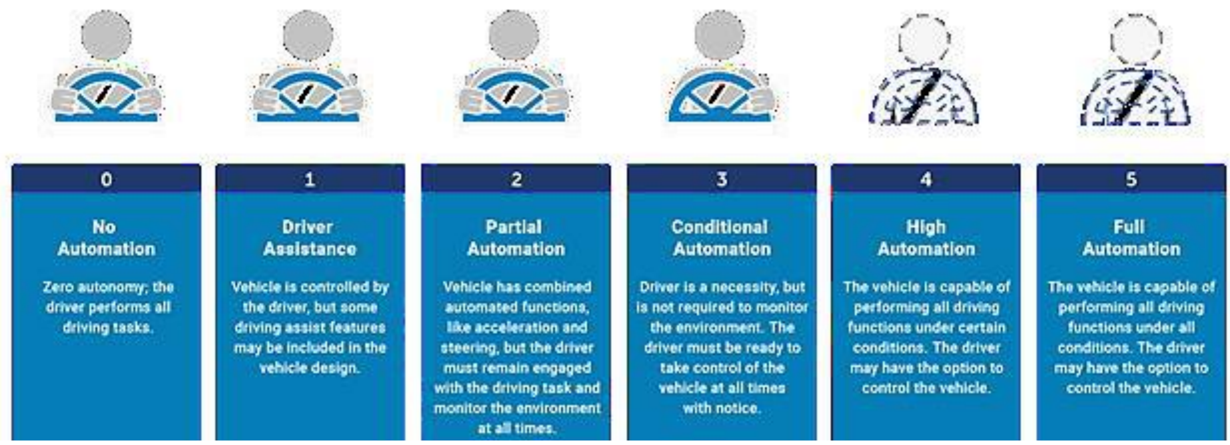
Human driver reengagement will pose another key challenge. To experience the greatest benefits of the technology, human drivers will need to be able to engage in other tasks while the vehicle is driving autonomously. For safety, however, they will need to quickly reengage (in a matter of seconds or less) at the vehicle’s request. Cognitive science research on distracted driving suggests this may be a significant safety challenge. Similarly, developing the appropriate mental models for human-machine collaboration may be a challenge for a technology widely available to the public (Anderson J.M., et al, 2016).

Software upgrades also could pose challenges, as they might need to be backward-compatible with earlier models of vehicles and sensor systems. Moreover, as more vehicle models offer autonomous driving features, software and other system upgrades will have to perform on increasingly diverse platforms, making reliability and quality assurance all the more challenging. System security is also a concern, so that viruses or malware are prevented from subverting proper functioning of vehicles’ systems.

State transportation departments may need to anticipate the use of vastly different kinds of AVs operating on roadways. This may pose challenges for the registration and requirements necessary for the vehicles to operate and for the level of training particular operators must have. One short-term action that might improve safety is requiring stricter conformance to road signage requirements, particularly those that involve construction or some alteration to the roadway. This would both aid human drivers and ease some of the perception requirements for AVs (Anderson J.M., et al, 2016).

2.2. Autonomous Vehicles Operational Models

The picture below describes the five levels of autonomous driving. Level 4 offers autonomous mobility under some conditions and Level 5 offers autonomous mobility under all normal conditions.



PICTURE 1. Automated Driving Levels. Source: Victoria Transport Policy Institute (2021)

On the picture 1 we saw the five different automation levels and on the table 1 below we can see the distinguish between four vehicle operating models.

	Private Human-Driven Vehicles	Private Autonomous Vehicles	Shared Autonomous Vehicles	Shared Autonomous Rides
	Motorist own or lease and drive a vehicle.	Households own or lease self-driving vehicles.	Self-driving taxis offer serve individuals.	Micro-transit serves multiple passengers.
Advantages	Low costs. Always available. Users can leave gear in vehicles. Pride of ownership.	High convenience. Always available. Users can leave gear in vehicles. Pride of ownership.	Users can choose vehicles that best meet their needs. Door to door service.	Lowest total costs. Minimizes congestion, risk and pollution emissions.
Disadvantages	Requires driving ability, and associated stress.	High costs. Users cannot choose different vehicles for different uses. Likely to increase vehicle travel and associated costs.	Users must wait for vehicles. Limited services (no driver to help passengers carry luggage or ensure safety.	Least speed, convenience and comfort, particularly in sprawled areas.
Appropriate Users	Lower- and moderate-income suburban and rural residents.	Affluent suburban and rural residents.	Lower-annual-mileage users.	Lower-income urban residents.

TABLE 1. Operating Models Compared. Source: Victoria Transport Policy Institute (2021)

2.3. Autonomous Vehicles Development and Deployments Predictions

New technologies generally follow an S-curve development pattern, as illustrated below. An initial concept usually experiences development, testing, approval, commercial release, product improvement, market expansion, differentiation, maturation, and eventually saturation and decline. Autonomous vehicle technology will probably follow this pattern (Victoria Transport Policy Institute, 2021).

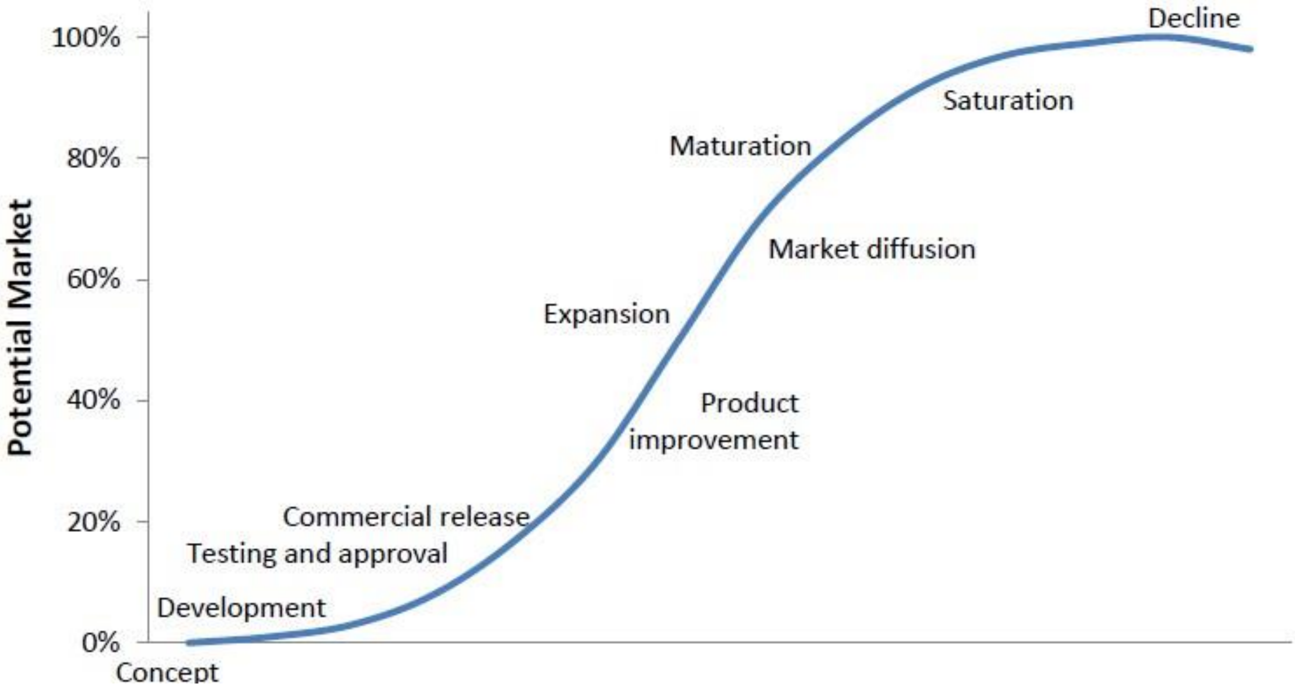


FIGURE 1. Innovation S-Curve. Source: Victoria Transport Policy Institute (2021)

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. Tesla's *Autopilot* offers automated steering and acceleration in limited conditions, although deployment was delayed after it caused a fatal crash in 2016. 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 (Victoria Transport Policy Institute, 2021).

Autonomous vehicle 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. 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 (Victoria Transport Policy Institute, 2021).

In 2015, autonomous vehicle expert Chris Urmson famously predicted that his son would never need a driver's license because self-driving would be ubiquitous by the time, he reached driving age in 2019, but in a 2019 interview he predicted a much more modest, "hundreds or maybe thousands of self-driving vehicles on the road within five years" (The Economist, 2019). Although current technologies allow vehicles to operate autonomously on grade-separated highways, in good weather, achieving 95% operability (vehicles are unable to reach desired destination a few times each month) will be difficult. Achieving 99.9% operability (vehicles are unable to reach desired destinations only about once a year) will be far more difficult still (Victoria Transport Policy Institute, 2021).

Operating a vehicle on public roads is complex due to the frequency of interactions with often unpredictable objects including potholes, vehicles, pedestrians, cyclists and animals. As a result, autonomous vehicles require orders of magnitude more complex software then aircraft, as we can see in the picture below. Producing such software is challenging and costly, and it is sure to have errors. There will almost certainly be system failures, some causing severe accidents.

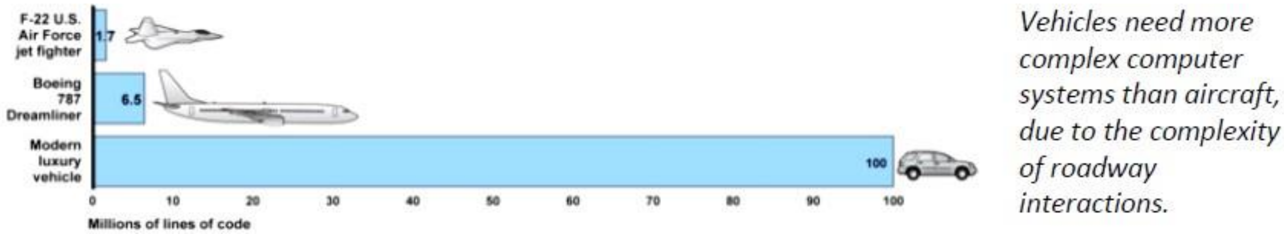


FIGURE 2. Aircraft and Automobile Software Code Compared. Source: Victoria Transport Policy Institute (2021)

Consider one challenge. For safety's sake motorists are advised to drive defensively, which means anticipating potential risks, such as wild animals and playful children. To do this, autonomous vehicles will need a database that categorizes, for example, fire hydrants as low-risk, pets on leashes as medium risk, and wild animals, such as kangaroos, as high risk. In addition, children sometimes dress in animal costumes, and adolescents in zombie variations. Most drivers can understand such risks. If I warn, "Watch out for teenagers dressed in zombie kangaroo costumes," you could probably understand the threat since you too were once a playful youth, but a computer would be flummoxed: such an unusual situation is unlikely be in its database so the vehicle would either miss-categorize the risk, perhaps treating costumed fun-seekers as injured crash victims or a riotous mob, or stop and wait for human instructions. These systems can self-learn, and so could understand such behaviors and costumes if

they become common, but cannot anticipate new conditions, and each new set of instructions will further increase system complexity and therefore potential risks and delays.
In addition to technological progress, market deployment depends on consumer demand: travelers' willingness to pay for autonomous mobility. Surveys indicate significant consumer concerns. Travelers will face access anxiety if their vehicle cannot reach all desired destinations (Victoria Transport Policy Institute, 2021).
Although optimists predict that most vehicles will operate autonomously by 2030 (Johnston C., Walker J., 2016; Keeney T.,2017; Kok I., Zou Y. S., Gordon J., Mercer B., 2017), most of them have financial interests in autonomous vehicle industries, and base their predictions on experience with electronic technologies such as digital camera, smart phones and personal computers rather than motor vehicle innovations. For example, the widely-cited report, "Rethinking Transportation 2020- 2030" was written by RethinkX, "an independent think tank that analyzes and forecasts the speed and scale of technology-driven disruption and its implications across society." Mobility As-A-Service: Why Self-Driving Cars Could Change Everything, was published by ARK Investment Management, and written by an analyst who has little apparent experience with transportation innovation. Automotive Revolution – Perspective Towards 2030: How the Convergence of Disruptive Technology-Driven Trends Could Transform the Auto Industry, was published by the McKinsey business management firm. Although their predictions are often qualified – autonomous vehicles "could" or "might" change everything – their conclusions are often presented with unjustified certitude.
Such reports are primarily oriented toward investors, and so focus on the autonomous vehicle sales potential; policy makers and planners are interested in their fleet penetration and travel impacts. Motor vehicles are durable and expensive; consumers seldom purchase new vehicles simply to obtain a new technology, so innovations generally take decades to fully penetrate vehicle markets. Optimists argue that benefits will be large enough to justify premature scrapping of vehicles that lack autonomous driving capability, but that seems unlikely under realistic assumptions of their benefits and costs (Victoria Transport Policy Institute, 2021).
Most objective experts acknowledge that Level 5 automation will require many more years for development and testing (Mervis J., 2017). For example, Michigan Mobility Transformation Center director Huei Peng said that, "it may be decades before a vehicle can drive itself safely at any speed on any road in any weather". Similarly, Toyota Research Institute CEO, Gill Pratt stated that autonomous driving, "is a wonderful goal but none of us in the automobile or IT industries are close to achieving true Level 5 autonomy". Uber self-driving vehicle lab director Raquel Urtasun said that, "Having self-driving cars at a smaller scale, on a small set of roads, we are fairly close …Nobody has a solution to self-driving cars that is reliable and safe enough to work everywhere" (Victoria Transport Policy Institute, 2021).
Artificial intelligence expert Yoshua Bengio said that, "I think people underestimate how much basic science still needs to be done before these cars or such systems will be able to anticipate the kinds of unusual, dangerous situations that can happen on the road". Chris Urmson, CEO of Aurora, a leading autonomous vehicle development firm, in 2015 hoped that self-driving cars would eliminate the need for his son to obtain a driver's license when he became eligible in 2019, but that year admitted that only "hundreds or maybe thousands of self-driving vehicles" will operate on public road by 2024 (Victoria Transport Policy Institute, 2021).
What we understand from all the above is that the future is bright but with many problems and obstacles that need to be solved.

2.4. 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% (Kok I., Zou Y. S., Gordon J., Mercer B., 2017), 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. Self-driving vehicles will certainly have failures that contribute to crashes, although their frequency is difficult to predict.
- Malicious hacking. Self-driving technologies can be manipulated for amusement or crime.
- Increased risk-taking. When travelers feel safer, they tend to take additional risks, called offsetting behavior or risk compensation. For example, autonomous vehicle passengers may reduce seatbelt use, and other road users may be less cautious (Millard-Ball A.,2016), described as "over-trusting" technology.
- 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.
- Increased total vehicle travel. By improving convenience and comfort autonomous vehicles may increase total vehicle travel and therefore crash exposure.
- Additional risks to non-auto travelers. Autonomous vehicles may have difficulty detecting and accommodating pedestrians, bicyclists and motorcycles.
- Reduced investment in conventional safety strategies. The prospect of autonomous vehicles may reduce future efforts to improve driver safety.
- Higher vehicle repair costs due to additional equipment. Additional sensors and control systems, and increased quality control, are likely to significantly increase collision repair costs.

These new risks will probably cause crashes, so autonomous vehicles will not really achieve the 90% crash reductions that advocates predict. Analysis of factors that contributed to traffic crashes Mueller, Cicchino, and Zuby 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. Sivak and Schoettle conclude that autonomous vehicles will have crash rates similar to an average driver, and total crashes may increase when autonomous and human-driven vehicles mix. Groves and Kalra argue that autonomous vehicle deployment is justified even if they only reduce crash rates 10%, but total crashes can increase if autonomous operation increases total vehicle travel, for example, if they reduce per-mile crash rates 10% but increase vehicle travel 12%, total crashes, including risks to other road users, will increase (Victoria Transport Policy Institute, 2021).

Autonomous vehicles are vulnerable to hacking. In one experiment, researchers demonstrated that adding graffiti-like marks to a roadside stop-sign caused software to read an inaccurate "Speed Limit 45". There will be an on-going arms race between hackers and software designers over autonomous vehicles control, which will add costs and risks (Victoria Transport Policy Institute, 2021).

Autonomous vehicles currently have relatively high operational failure rates. In 2019, the best test vehicles experienced one disengagement (when human drivers overrode automated systems) per 16,666 miles, but most were more frequent. 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 (Victoria Transport Policy Institute, 2021).
Shared autonomous vehicles can reduce crashes by providing more affordable alternatives to higher-risk drivers. Efforts to reduce higher-risk driving, such as graduated driver's licenses, special testing for senior drivers, and anti-impaired driver campaigns, can be more effective and publicly acceptable if affected groups have convenient and affordable mobility options. For example, parents may purchase autonomous vehicles for their teenagers, and travelers may use autonomous vehicles after drinking alcohol or taking drugs (Victoria Transport Policy Institute, 2021).
Many factors will affect these impacts, including how vehicles are programmed, and how they affect total vehicle travel. For example, to increase travel speeds autonomous vehicles can be programmed to drive faster, use shortcuts through neighborhoods, and take more risks; to minimize traffic problems they can be programmed to drive slower, be more cautious, and avoid driving on congested roads or neighborhood streets (Victoria Transport Policy Institute, 2021).

2.5. Evaluation of existing systems for tailgating avoidance

In order to emphasize the tailgating behavior problem, we have to assess drives (human factor) and the role that advisory signs play. Tailgating is a dangerous driving behavior and a leading cause of most rear-end crashes. It is critical to many traffic management authorities to understand tailgating and to explore means to mitigate drivers' tailgating behavior, especially on urban highways with high-speed and high-volume traffic. Properly designed advisory signs could reduce tailgating and related motor crashes. To assess drivers' behavior with regards to tailgating, a questionnaire survey was developed and given to a number of subjects with daily highway driving experience. The survey is designed to identify causes of tailgating and drivers' perceptions and engagements on tailgating behavior. Drivers' driving behaviors were further assessed through driving simulation under different traffic conditions. To help mitigate tailgating behavior, advisory signs and an educational video were developed. The effectiveness of these proposed counter tailgating measures was assessed in the driving simulation (Song M., Wang H. J., 2011).
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". While many driving patterns are considered aggressive, tailgating is among the most dangerous ones and is a major cause of rear-end crashes. 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. 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. Two factors are primarily responsible for rear-end crashes: inattention and tailgating, while the latter is the major contributing cause with a deadly consequence (Song M., Wang H. J., 2012).
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. 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 (Song M., Wang H. J., 2012).

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. 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. 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 (Song M., Wang H. J., 2012).

2.5.1. Tailgating Treatments

Hutchinson in 2008 conducted an in-depth investigation in Australia of rear-end crashes, tailgating, and the correlation between them. Calculations about how tailgating could lead to rear-end crashes were presented in his study and the results proved that a safe vehicle headway should be at least two seconds. Although he mentioned that inattention in various forms is a more frequent cause than tailgating as shown from some rear-end crash investigations, inattention could naturally lead to tailgating. Measures to counter tailgating such as advisory signs, pavement markings, and enforcement by the police could help reduce rear-end crashes and were recommended in his study (Song M., Wang H. J., 2012).

Rama and Kulmala conducted a field study in Finland and investigated the effects of two variable message signs (VMS) on drivers' car-following behavior. The signs warned of slippery road conditions and to keep a minimum following distance. It was performed as a before-and-after experiment at three test sites. Results showed that the slippery road conditions sign reduced the mean speed by one-two km/hour in addition to the decrease caused by the adverse road conditions. The minimum following distance sign reduced the proportion of cars with following distance of less than 1.5 seconds, in addition to a speed reduction of one km/hour.

To help drivers gauge their following distances, research was conducted to assess the effects of regularly-spaced markings on highway pavement. Lertworawanich conducted a study to estimate safe car-following distance according to speed limit, and developed the "dot" treatment pavement markings. Headways in term of distance were examined before and after the implementation of "dot" markings. He found that headways were increased after the marking implementation at a given flow rate and the likelihood of rear-end collisions was reduced at the study site. Arrows spaced 131 feet apart, implying a gap of about three seconds at 60 miles per hour, were painted on a U.K. motorway in a study by Helliar-Symons, Webster, and Skinner. They found that, because of the markings, crashes were reduced by 56% at the study site (Song M., Wang H. J., 2012).

A few tailgating treatment programs were pilot-tested in several states such as Pennsylvania, Minnesota, and Maryland. PENNDOT's Tailgating Treatment Program (Safety Improvements) was considered the most successful and was honored in 2001 with the National Highway Safety Award. On a portion of US Route 11 that previously experienced high rates of tailgating, aggressive driving and tailgating has dropped a significant 60% after equipping with reflective dots on the roadway, pavement markings, and signs that help motorists gauge their distance behind moving vehicles. Before the implementation, there were 135 crashes a year costing approximately $1.9 million. After the implementation, yearly crashes decreased to 60 at a reduced cost of $1.3 million. The cost of implementation in the first year is estimated at just over $11,000, including enforcement. After eight to nine months, statistics indicated that crash reductions remained fairly constant, pointing to the success of the program (Song M., Wang H. J., 2012).

Given the successes, relatively low implementation cost, and the measurable benefits of the PENNDOT program, Minnesota DOT and Public Safety piloted a similar project in 2006. The project was viewed as a tool to educate motorists on how to identify and maintain a minimum safe following distance, and to ultimately reduce rear-end crashes. Minnesota used similar engineering elements from the Pennsylvania program: elliptical pavement dots, informational signs, and a strong public information campaign. A section of State Highway 55 in Wright County was painted with 94 elliptical dots, spaced 223 feet apart, along a two-mile single-lane segment of the rural roadway with a 55-mph speed limit. Vehicle headway data collected prior to and after the treatments showed that the average headway increased from 2.36 to 2.62 seconds, or 22.89 feet at the mid-point of the test site (Song M., Wang H. J., 2012).

Michael, Leeming, and Dwyer in 2000 implemented a method to collect tailgating data in an urban setting and assessed the effectiveness of two hand-held roadside signs admonishing drivers not to tailgate. One was “Please Don’t Tailgate” sign and the other “Help Prevent Crashes Please Don’t Tailgate”. Data collected from over 25,000 drivers were studied. They found that the latter had a significantly positive impact on drivers' tailgating behavior compared with the former sign, increasing the average headway by 0.18 seconds.

Advisory signs could be part of tailgating treatments to help mitigate tailgating behavior. However, improper use of advisory message signs could distract drivers and cause inattention leading to rear-end crashes. To reduce the risk of distracting drivers, the use of graphical images to convey the meaning on roadway signs has been employed in many European countries. It is found in many studies that graphically presented information allowed faster responses than information presented by words. A pioneer study conducted in 2007 from Wang, on the use of graphics on the dynamic message sign (DMS), a 1024x270 full matrix tri-color LED overhead message sign that is capable of displaying pre-programmed text and graphic messages. They found that most drivers preferred graphics over text and responded faster to graphic-aided messages than text-only messages. Due to these findings, proper graphics need to be designed and integrated into advisory signs in the development of feasible tailgating treatment systems (Song M., Wang H. J., 2012).

Regarding the above we can clearly see that a lot of studies conducted in different places all around the world, and different measures tested. The signage is the main countermeasure that has been taken through the years. Also, we see that equipment like VMS belongs to a motorway management centre equipment and that’s why I fully believe that MMC will always play an important role in traffic safety issues such as tailgating. Finally, in order to acquire all the necessary information, a software analysis in Vissim will be performed later on, in order to figure out how big the tailgating problem is in mixed traffic.

2.6. 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 (Kyriakidis M., et al, 2019).

As I mentioned above, AVs can be classified according to their technological capabilities and human engagement, ranging from manual driving, where the human driver executes all of the driving tasks, to fully automated driving where no human interaction occurs.

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.

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.” 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. 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 (Kyriakidis M., et al, 2019).

Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved. 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.

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. 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 (Kyriakidis M., et al, 2019).

Research challenges also comprise the estimation of the minimum time required by human drivers to resume manual control when instructed by the automated system and the interaction between AVs and other vehicles and road users.

One empirical question that necessitates vital research at this present time is the establishment of appropriate epidemiological baselines for the dimensions of current, manually-operated vehicle performance such as transit time efficiency, system downtime, injury and fatality.

Therefore, HF research can critically contribute to the development and deployment of AVs, by working towards a synergy between the human driver, vehicle, and environment. This paper presents the findings of an interview study with twelve researchers in the field of HF and automated driving (Kyriakidis M., et al, 2019).

2.6.1. Human Factors Issues

Driver inattention and distraction: Although automation is usually intended to lighten driver workload, this is not necessarily beneficial for driving and does not always lead to increased road safety. If the workload on the driver is too little during periods of automation, the driver may experience passive fatigue, which is argued to stem from situations in which cognitive load is low and there is a lack of direct control over the task at hand. Moreover, research has shown that passive fatigue can degrade overall driver performance. For example, increased vehicle automation is associated with reduced driver vigilance indicated by increased braking and steering reaction times in response to a sudden critical event. In the realm of HAD, this reduced vigilance and inattention may pose problems for drivers required to manually intervene during critical automation failures as these critical events may impose such a sudden increase in demand on the driver that may have difficulty dealing with it, and possibly crash (Cunningham M., Regan A. M., 2015).

Conversely, boredom may also proliferate from low workload in periods of automated driving. As a result, drivers may seek to engage in other activities (e.g., a task that is more entertaining) as opposed to monitoring and supervising the autonomous driving. Two recent studies conducted in driving simulators support this premise, showing that drivers are more likely to engage in secondary activities and spend more time looking away from the forward roadway at higher levels of driving automation. In essence, these findings suggest that drivers may be more vulnerable to distractions during periods of driving automation, posing a safety issue by compromising the ability of the driver to suddenly regain control of the vehicle when required. Several studies have demonstrated the adverse effects of secondary task demands on take-over time and quality in automated driving (Cunningham M., Regan A. M., 2015).

Situational awareness: Situational awareness (SA) is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Colloquially, SA is operators' dynamic understanding of what is happening around them. When drivers divert attention away from the automated driving task (i.e., distraction) or attention is diminished in the absence of a competing activity, their level of SA will likely diminish as attentional resources are not being devoted to maintaining awareness of the vehicle state and road situation. This reduction in SA in periods of automation can be dangerous as automation actions and alerts will likely be unexpected and come as a surprise to the driver. For example, a driver that is occupied in some secondary tasks may fail to notice the autonomous vehicle navigating through foggy conditions (i.e., SA is low). In this instance, an alarm sounding to notify the driver that the automated systems are struggling in these conditions will come as a surprise to the driver. On the other hand, a driver that is paying attention to the road context (i.e., SA is high) will observe the onset of the foggy conditions and be ready for any automated failure alerts. Automation surprises can be detrimental to driver re-engagement time and quality as they may erratically increase driver workload, briefly rendering the driver unable to respond as a result (Cunningham M., Regan A. M., 2015).

An insufficient level of driver SA can also lead to mode confusion. Mode confusion is a phenomenon that refers to a discrepancy between how the vehicle driver believes the vehicle to be operating and how the vehicle is actually operating. In lay terms, there is a sense of confusion concerning which aspects of vehicle performance is controlled by the driver and which are controlled by the automation at a particular instance. If a driver is unaware of the state of the automated vehicle, he or she could make decisions based on the (incorrect) belief that the vehicle is in a certain state or in control of a certain aspect of driving when it currently is not. For example, a driver may reverse without looking with the (incorrect) assumption that operation of the vehicles' reverse collision sensors would warn of potential hazards.

Overreliance and trust: As automated systems take over control of many driving tasks, drivers may learn to overestimate and over-rely on automation performance. Overreliance occurs when a driver does not question the performance of automation and insufficiently counter checks the automation status. The phenomenon is synonymous with a sense of over-trusting automated systems, in which an operator's trust in the automation exceeds its actual capabilities, resulting in the operator over-utilizing it. However, too little trust may result in the technology being ignored and negating associated benefits with its use. Therefore, trust in the system must be at an optimal (moderate) level (Cunningham M., Regan A. M., 2015).

The problem with overreliance and excessive trust in automated driving systems is that drivers may wrongly assume that the technology will warn them and intervene to prevent failure if and when necessary. With this in mind, drivers may feel it is safe to engage in other activities, which will increase the propensity to become distracted (an issue for driver re-engagement), and adopt more hazardous driving behaviors (e.g., shorter headways) as the driver perceives the automation to be more capable than it actually is. These consequences of over-reliance on automation are known as negative behavioral adaptation effects and can be detrimental to safe driving (Cunningham M., Regan A. M., 2015).

Skill degradation: Drivers that over-rely on highly automated driving systems may fail to use their manual driving skills over long periods of time. The neglect of manual driving skills may, in turn, may degrade both the psychomotor dexterity and cognitive skills required to manually complete a task successfully and safely. Ironically, this loss of skill may further encourage reliance on automation. The consequences of this skill degradation may be exacerbated in situations of automation failure as the driver may have difficulty resuming manual control of driving. In addition to the predicted long-term effects recent research has demonstrated that periods of automated driving may also impose more transient skill degradation. For example, a simulated driving study by Skottke, Debus, Wang, and Huestegge in 2014 found that even brief periods of highly-automated driving were sufficient in impairing driving performance in a subsequent manual driving task, as evidenced by shorter headway times and increased variability of lateral position (Cunningham M., Regan A. M., 2015).

Motion sickness: A relatively unexplored, yet important, human factors issue in the realm of automated driving is that of an increased propensity for motion sickness of vehicle occupants. Motion sickness is a condition marked by symptoms of nausea, dizziness, and other physical discomfort and can be associated with various modes of transportation. The condition is most frequently caused by a conflict between visual and vestibular inputs, loss of control over one's movements and reduced ability to anticipate the direction of movement. Interestingly, Sivak and Schoettle in 2015 purport that up to 10% of American adults are expected to experience motion sickness often in autonomous vehicles. The authors also contend that remedies for motion sickness in the form of the design of the automated vehicle are limited as the crux of the issue is that automation controls the drivers' direction of motion, not the driver themselves, which may present issues of driver acceptance (Cunningham M., Regan A. M., 2015).

2.6.2. Traffic accident with autonomous vehicles

According to Petrovic et al. (2020), 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, manoeuvers and errors for the occurrence of accidents. Favarò et al. (2018) 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. Applying advanced software packages, some authors analyzed the impact of the introduction of AV in everyday traffic on the number and types of collisions (Tibljaš A., Giuffre T., Surdonja S., Trubia S, 2018). Simulating introduction of AVs (10% - 50% in traffic flow) on 4 roundabouts in Croatia recorded an increase of rear-end type crashes (Tibljaš et al., 2018). 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 increase. Hence, we can notice that the involvement of AVs is prone to rear-end traffic accidents both in reality and simulation packages. However, AVs will have more significant effects on road safety when increase 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%. Morando et al. (2018) 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%. By contrast, manoeuvers and errors for the occurrence of accidents with AVs still have not been the subject of research (Petrovic D., Mijailovic R., Pesic D., 2020).

2.6.2.1. Type of Collision

Analyzing the effect size, we noted the most significant difference in the type of collision “rear-end”. Namely, the share of traffic accidents of this type of collision is higher in accidents with AVs (64.2%) as opposed to accidents with only CVs (28.3%). The assumption for this difference is that drivers of the CVs are not accustomed to the driving style of AVs in the convoy. AVs absolutely comply with traffic regulations. Speeding, aggressive driving, overcompensation, inexperience, slow reaction times, inattention and various other CV drivers’ shortcomings are rare to occur with AVs. On the other hand, the self-reported percentage of speeding of the CV drivers in the settlement in 38 countries of the world is 61%. In reality, this percentage is higher. It is assumed that the initial introduction of AVs contributes to reducing the traffic flow and occurrence of congestion (Petrovic D., Mijailovic R., Pesic D., 2020).

Consequently, the errors of the CV drivers due to aggressive driving in the convoy lead to the occurrence of traffic accidents “rear-end” type. This finding is consistent with Favarò et al. (2018).

The smaller effect size is observed within types of collision “broadside” and “pedestrian”. These two types of traffic accidents represent a total of 5.7% of accidents with AVs versus 42.1% of accidents with only CVs. The main reason for these results is the assumption that AV is more carefully approaching the intersections (Smith, 2012), in these locations “broadside” collisions most frequently occurred. Also, AVs are prone to frequent stops to let pedestrians right of way. Using complex systems for perceiving the environment (LiDAR - Light Detection and Ranging System, sensors, cameras), AV is able to locate and track stationary and moving objects in a very large area (Petrovic D., Mijailovic R., Pesic D., 2020). Combs in 2019 estimated that the use of these systems can reduce the number of traffic accidents with pedestrians up to 90%. Also, we can assume that these systems can provide very good sight distance at intersections for AVs. Although some authors have concerns about the impact of AV on the vulnerable road user’s safety, we assume that the introduction of AVs will have a positive impact on their safety. In other types of collision, we did not find statistically significant differences between traffic accidents with AV and accidents with only CVs. However, it should be noted that some types of accidents were merged into the category “others” and their differences could not be examined. In general, it can be noticed that the introduction of AVs has a positive impact on the distribution of types of collision, because the share of accidents that often have severe consequences (“broadside” and “pedestrian”) decreases, while the share of accidents that usually have only damage consequences (“rear-end”) increases (Petrovic D., Mijailovic R., Pesic D., 2020). In the figure 3 we can see the traffic accidents distribution by type of collision comparing CVs and AVs.

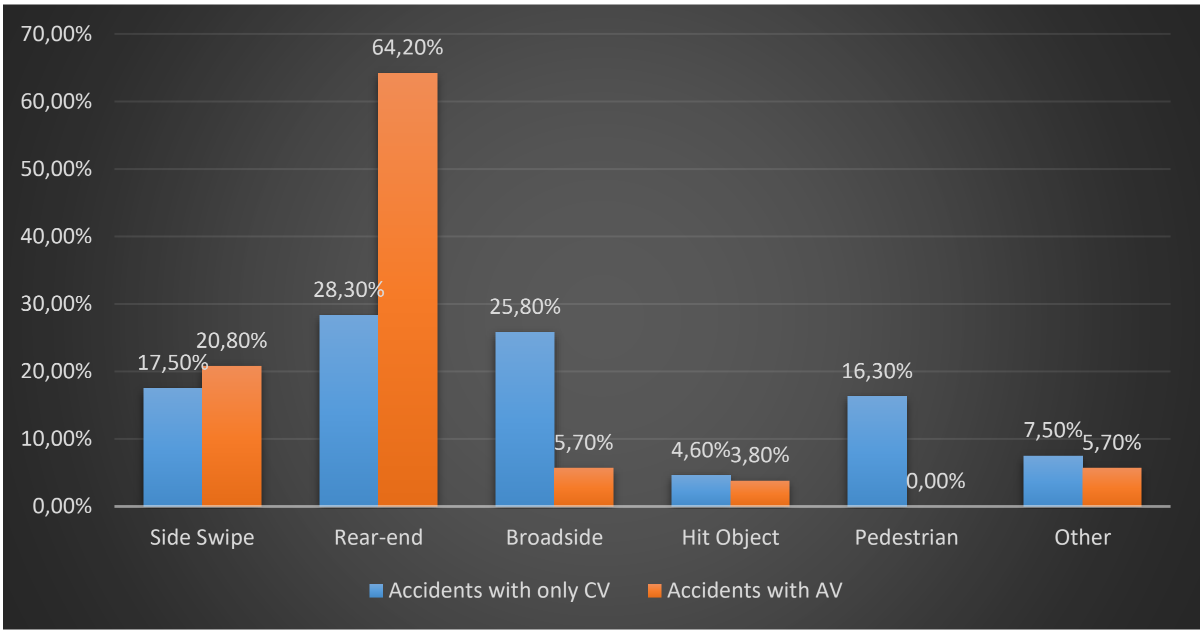


FIGURE 3. Traffic Accidents Distribution by Type of Collision. Source: Petrovic D., Mijailovic R., Pesic D., 2020

2.6.2.2. Manoeuvers of the Drivers CVs

Within so far conducted research, manoeuvers of the drivers' CVs were not in the focus of the authors. Based on analysis of the manoeuvers of the drivers' CVs, we noticed that there is no significant difference in the manoeuvers depending on whether drivers of CVs were involved in the accident with AV. This finding was expected, considering the small number of AVs on the roads and lack of adjustment driving task of CVs drivers for AVs movement. Also, this fact can be enjoyed by companies testing AVs, because it shows that drivers of CV did not take more specific manoeuvers when they were involved in accidents with AV (Petrovic D., Mijailovic R., Pesic D., 2020). In the figure 4 we can see the traffic accidents distribution by manoeuvres of the drivers comparing CVs and AVs.

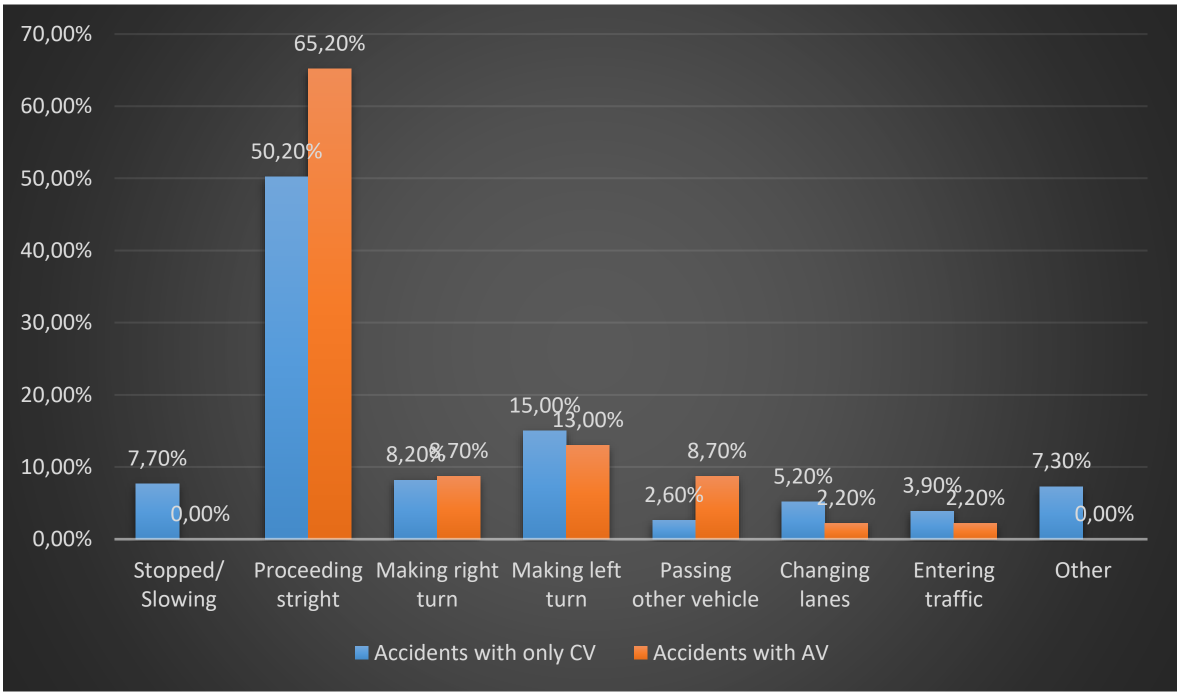


FIGURE 4. Traffic Accident Distribution by Manoeuvres of the Drivers CVs. Source: Petrovic D., Mijailovic R., Pesic D., 2020

2.6.2.3. Errors of the Drivers CVs

Generally, there are significant differences in errors of the drivers' CVs depending on whether they are involved in accidents with AV. The biggest effect size was observed within the error of the drivers' CVs "following too closely". Namely, this error of the drivers' CVs is significantly more frequent in accidents with AV. Similar results are noted for the error of the drivers' CVs "unsafe speed" with smaller effect size. The reason for these results is that drivers are not sufficiently accustomed to moving AV in the convoy, and consequently a higher rate of "rear-end" accidents is reported with AV. Namely, AVs gently accelerate and decelerate in order to provide greater comfort to their passengers while drivers of the CVs have a more aggressive driving style. In terms of traffic accident occurrence, the critical activity of AV is acceleration that is lower in comparison with the acceleration of CV. During the movement in a convoy, AV slowly starts the movement so drivers of CV are at risk of causing a "rear-end" traffic accident due to a more aggressive start of the movement (Petrovic D., Mijailovic R., Pesic D., 2020). In the figure 5 we can see the traffic accidents distribution by errors of the drivers comparing CVs and AVs.

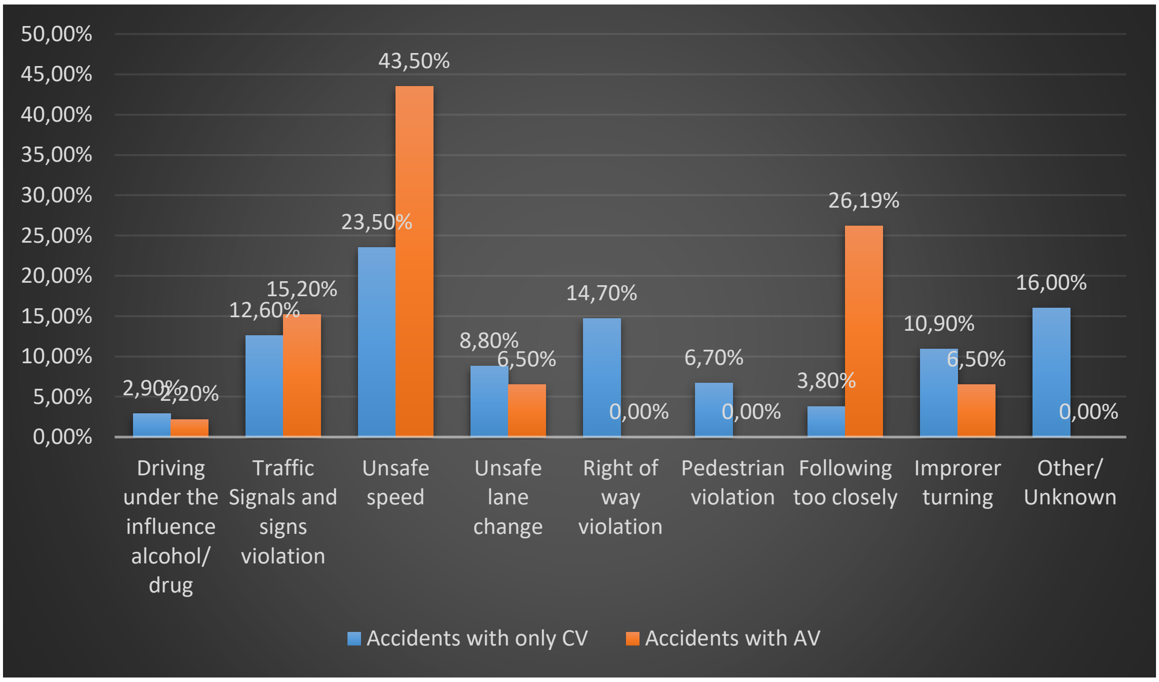


FIGURE 5. Traffic Accidents Distribution by Errors of the Drivers CVs. Source: Petrovic D., Mijailovic R., Pesic D., 2020

A smaller effect size is observed in error of the drivers' CVs "right of way violation". This error of the drivers' CVs is significantly lower in accidents with AV. This finding shows that AVs with their defensive driving style are able to compensate for errors of the driver CVs "right of way violation". Although a sample of traffic accidents with AV is small, this finding is very encouraging (Petrovic D., Mijailovic R., Pesic D., 2020).

Also, significant differences are noted on the error of the driver CVs "other/unknown". This is a consequence of an incomplete and inaccurate database of traffic accidents with only CVs. Namely, for some traffic accidents with only CVs were not found an error of the driver CVs that led to the accident. The reason for this is the existence of traffic accidents where one of the participants left the scene of a traffic accident or the official did not want to define an error. By contrast, based on the Reports of Traffic Collision Involving an Autonomous Vehicle, if there were an error of the driver CV, we always determined it (Petrovic D., Mijailovic R., Pesic D., 2020).

Within the other errors of the driver CVs, we did not find statistically significant differences between traffic accidents with AV and accidents with only CVs. However, it should be noted that no traffic accidents with AV were caused due to the specific error “pedestrian violation”. This finding shows that AVs satisfactory compensates both errors of the driver CVs and errors of pedestrians. On the other hand, it is noticed more often error of the driver CVs “traffic signals and signs violation” in a traffic accident with AV. This finding suggests that the AVs worse compensate risk for the other road users if at the same time is a defined traffic signalization (Petrovic D., Mijailovic R., Pesic D., 2020).

2.7. Smart Dynamic Traffic Monitoring and Enforcement System

According to my experience, I strongly believe that traffic control centers play a key role in monitoring and enforcement of mobility and they will also play a key role in monitoring and enforcement of autonomous driving and connected mobility. In this part I will try to analyze different types of monitoring and enforcement systems.

2.7.1. Variable Speed Limits (VSL)

Enforcement of traffic rules and regulations involves a wide range of complex tasks, many of which demand the use of modern technologies such as VSL, VMS (Variable Message Sign), LCS (Lane Control Sign) etc. VSL control is to change the current speed limit according to the current traffic situation based on the observed traffic conditions.

Various control strategies have been proposed in the past to solve the problem of continually increasing traffic congestion. These strategies include diverting traffic from congested areas, imposing constraints, reducing speed limits, and adding additional lanes where expanding the road network is feasible. Recently, significant emphasis is being put on the application of communication technologies and advanced information on the basis of the intelligent transportation systems (ITS). The main idea of ITS technologies is to improve the efficiency, safety and environment of transportation system without the need of changing existing highway infrastructure (Yasar A., El-Hansali Y., Outay F., Farrag S., Shoaib M., Imran M., Awan H. H., 2020).

A wide range of ITS has been implemented in vehicles such as Advanced Travelers Information System (ATIS), or combined into the highway infrastructure such as Motorway Control System, (MCS). Since the previous decade, connected vehicle (CV) systems have become common and are acknowledged as a vital component of ITS (Yasar A. et al, 2020).

The term “connected vehicle” refers to the vehicles that can communicate and share their information such as location and speed with high accuracy. CV technologies enable infrastructure and vehicles to share aggregated information about traffic and individual vehicles in real time. Various vehicle automation and communication systems have been introduced that can be utilized for the development of new control strategies, such as variable message sign, route guidance, and ramp metering. VSL control is one of the most popular and recommended CV applications that uses vehicle motion behavior transmitted into vehicles to optimize traffic operations.

Although ITS technologies have shown significant potential in improving the effectiveness of traffic enforcement, still there is a wide range of issues that need to be addressed before their implementation in the field. Some of them are related to the infrastructure’s improvement and installation, database development, and support agencies. Other problems are related to road user acceptance and finally, the enforcement technologies require a wide range of testing to ensure road users’ safety (Yasar A. et al, 2020).

2.7.1.1. VSL Background

Variable speed limit (VSL) control systems are based on estimated traffic conditions such as traffic speed and traffic flow collected in real time by sensors through vehicle—infrastructure communication. These data are used as the basis for traffic information provided to road users through dynamic variable message signs. Road users then adjust their behavior i.e., speed and lane positioning in response to the provided information.

Recent studies have shown the benefits of VSL control systems such as releasing highway congestion, improving safety, and reducing greenhouse gas emission, and fuel consumption in multiple situations. Several studies have investigated the impacts of VSLs on safety and traffic flow. Much of the focus of VSL evaluation has been on safety. For example, lower speeds ensure that vehicles travel at more consistent speeds, reduce lane changes, which leads to fewer traffic conflicts, and reduce noise and pollution. According to another study, VSL systems on freeways are beneficial in suppressing shockwaves at both non-recurrent and recurrent

bottlenecks and relieving adverse weather impacts. VSL control can also be used to reduce the chance of secondary accidents by displaying lower speed limits when there has been an accident on the freeway. Due to these benefits, the use of VSL controls have been encouraged in various countries such as the Netherlands, Sweden, England, Japan, and Turkey. VSLs can also help drivers to adapt their speed to match traffic, environmental, or weather conditions (Yasar A. et al, 2020).

There are few studies that focused on the potential impact of VSL control systems in improving traffic flow efficiency. They found that generally the VSL improves traffic flow and the obedience to VSLs is an important factor for better results. They found that speed reduction between 80 to 70 km/h and 80 to 60 km/h can easily solve traffic congestion. Also, (Farrag et al., 2020) used VSL control system to resolve the problem of nonrecurrent traffic congestion they found that using VSL control system improve traffic mobility through increase traffic flow during incident by 7.8% and 11% during AM and PM respectively, and reduce fuel consumption by percentage varies between 3.5% and 46.5% (Yasar A. et al, 2020).

VSL systems consist of a series of VSL signs and connected detectors to measure the traffic conditions to change the current speed limit according to the current traffic situation. The suitable speed limit is decided by the VSL algorithm. Previous studies have categorized the traffic control algorithms to major four types which are: rule based, fuzzy-logic based, analytical and control-theory based.

Different research compared these algorithms, their impact, condition of their using, etc. they found that the limitations of rule-based strategies can be mainly attributed to its reactive attribute while the other strategies are considered as a proactive, preventing meaning dynamically preventing a problem before it actually happens (Yasar A. et al, 2020).

2.7.2. Smart Traffic Incident Management Framework (STIMF)

Daily traffic incidents such as accidents, tailgating, congestion etc., may seriously impact the performance and operation of a traffic system. Reacting quickly and in a uniform and structured way is vital. In particular, choosing the appropriate response strategy with only a short delay may mitigate the impact of incidents, improve traffic efficiency, and increase safety in the transportation system. According (Farrag G. S., Sahli N., El-Hansali Y., Shakshuki M. E., Yasar A., Malik H.,2020) STIMF is a strategy that can lead to traffic efficiency and traffic safety. STIMF Is a smart traffic incident management framework to reduce the burden on traffic incident operators by assisting them in selecting the most appropriate response strategy when an incident occurs. STIMF includes two software systems: (a) a simulation environment used to evaluate traffic incident management strategies and (b) a fuzzy-logic inference system that allows the traffic operator to get prompt recommendations on the best response strategies based on the current context and conditions. Moreover, the STIMF framework also describes the process of preparing and building the simulation environment (Farrag et al, 2020).

The smart traffic incident management framework (STIMF) is here to assist operators of traffic control centers in choosing the best strategies to address traffic incidents on highways. STIMF is based on a microsimulation of the network that allows different response strategies to be evaluated according to specific criteria given a certain traffic situation (modelized by a predefined set of factors and indicators). Also, another major contribution of STIMF is the use of fuzzy logic to interface between the human operator and the simulation-based system (Farrag et al, 2020).

2.8. Intelligent Traffic Monitoring System

Daily traffic problems as for example traffic jams seek for a solution. With the rise of standard of living, the number of vehicles is increasing at an exponential rate. In response to this, much research is being done in developing an intelligent traffic system (ITS), i.e., a traffic system which interacts more with all the components of a traffic including vehicles, drivers, and even pedestrians. It not only provides safety at intersections and prevents traffic jams, but manages the traffic as a whole (Roy P., Mukherjee A., Dey N., Biswas P. S., 2015). Developed countries like America, Japan, and the U.K. have already implemented ITS on their roads and still many research works are going on to make traffic systems more advanced and suitable for developing countries also. Apart from surveying various research works on ITS, this report proposes a model which follows a simple algorithm based on the length of traffic on each lane. The length of traffic on the other lanes affects the time allotted to the current lane. Proximity sensors instead of WAN (Wide Area Network) are to be used to determine the length of the traffic. The proposed idea can reduce the traffic in all lanes proportionately reducing the chances of congestion without the use of WANs. Besides, it also manages the occurrence of any emergency vehicles such as ambulance, fire brigade, etc. in any lane and also provides the mechanism to detect the route of a vehicle. Once implemented, it does not require any human assistance for its working (Roy P., Mukherjee A., Dey N., Biswas P. S., 2015).

2.9. Evaluation of ITS in 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. 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 (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

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. 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. 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. (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012):

- Traffic Management and Control
- Tolling
- Road Pricing
- Road Safety and Law Enforcement
- Public Transport Travel information and ticketing
- Driver Information and guidance
- Freight and fleet management
- Vehicle safety.

2.9.1. Benefits of ITS

Through its use of information technology, ITS offers advantages that are not available in convent transportation systems. Basically, ITS provides two kinds of benefits. One kind is the resolution of traffic problems, including traffic congestion, air pollution, and traffic accidents. The other kind is improved services for users and increased efficiency of the transportation system and its operators. The introduction of ITS can bring about the following benefits (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

2.9.1.1. Resolution of Traffic Problems

Mobility: ITS includes many approaches to enhance the mobility of people and freight in all transportation modes. Traveler Information helps travelers avoid congestion and can help improve traffic conditions. Traffic Management, e.g., the more effective timing of traffic signals, can help increase traffic efficiency. Demand Management, e.g., road and access pricing can help relieve heavily congested urban areas. Commercial Vehicle Management helps to increase security and efficiency not only for carriers but also for related public agencies. There are many more examples as well (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Traffic Congestion: Traffic congestion is a serious problem in all parts of the world. The problem is growing fastest in developing countries where urbanization and the use of motorized vehicles is increasing most rapidly. Congestion causes delays and uncertainty, wastes fuel, results in greater air pollution, and produces a larger number of crashes. ITS can help to mitigate congestion by helping people plan travel better, by suggesting alternate routes and travel times, by keeping travelers well informed, by leveling traffic loads on roadways, and by helping to respond to and clear incidents more rapidly (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Environmental Impact: Maintaining air quality was once viewed as a luxury of developed countries, which could more easily bear the cost of technology to keep emissions under control. However, the impact of poor air quality, especially on health and productivity, is now recognized as a large cost to all national economies, including developing and transitional economies. ITS helps reduce the environmental impact of road travel by optimizing trips, reducing congestion and crashes, improving vehicle and driver performance, and helping to manage the transportation system well (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Reducing Fatalities and Car Severity: Traffic accidents around the world continue to claim hundreds of thousands of lives each year and cause millions of injuries. The personal tragedy of each death is magnified by the economic and social costs of these losses. The World Health Organization estimates that nearly 1.2 million people worldwide died each year as a result of road traffic accidents. Low-income and middle-income countries have significantly higher traffic fatality rates than high-income countries. 90% of road accident deaths are in low-income and middle-income countries. ITS is helping to shift the safety focus from minimizing the consequences of crashes (through the use of seat belts, head rests, impact absorbing front ends, etc.) to the use of technology to make crashes less severe and to prevent them altogether. The EU has set a goal of "zero traffic fatalities" by 2020 and ITS America has adopted a "Zero Vision" for future surface transportation: zero fatalities, zero delays (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Managing the Transportation Infrastructure: Modern transportation systems are more complex and their parts are more interdependent. The effective management of modern transportation systems requires better, faster, more comprehensive information about the current and future state of the system, and better management and control tools. One specific intent of ITS is to help provide information and tools of this kind. For example, sensors built into the infrastructure and sensors in automobiles can help continuously monitor pavement conditions. By doing so, developing pavement problems can be diagnosed and repaired early before they become worse, cause problems, and require more expensive repairs. Better infrastructure management systems can also help contain costs by more effectively allocating and scheduling maintenance resources. These systems can also provide a more accurate and comprehensive picture of the financial aspects of road asset management (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

2.9.1.2. Improve Services for Users and Increase Efficiency of the Transportation System and Its Operators

Reducing Travel Uncertainty: One of the interesting insights realized by transportation planners in recent years is that a major benefit of their programs has been to provide greater reliability and predictability in transport, and not just to get more people to their destinations faster. An unfortunate aspect of most current transportation systems is that travel times, both for people and for freight, can vary widely from day to day. This can be due to weather, demand, traffic incidents, or a large number of other external factors. This uncertainty means that travelers and shippers must allow extra time for worst case possibilities or risk being late at least some of the time. This is disagreeable and expensive. ITS can help reduce travel uncertainty by smoothing traffic (and therefore reducing travel time variance). ITS can also provide improved real-time and predictive information that allows travelers to plan trips better and allows shippers and carriers to plan shipments better. Public transport agencies can stay on schedule better and provide their riders with current and advanced information about travel times and connections. In-vehicle navigation systems can incorporate real-time traffic information to dynamically adjust driving routes to optimize trips based on current information (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Increasing Security: A particular transportation-related concern has grown significantly in the last few years. This concern surrounds the security of the transportation system (vehicles and infrastructure) and the security of cargo and people in transit. Containerized freight has been recognized as a particular concern, since containers may be loaded and sealed in far off locations. Improperly managed containers could contain dangerous materials (explosives, biohazards) intended to cause terrorist destruction in another country. Even legitimate hazardous materials could be hijacked or otherwise misused. Similarly, travelers are potentially at risk, particularly at travel terminals (bus and train stations) and on high-occupancy vehicles (buses and trains). ITS provides technology to address these concerns through the use of GPS (or other positioning technology), wired and wireless communications, and improved sensors and information systems. ITS can monitor the contents and locations of containers, monitor the cargo and routes taken by trucks, track the location and status of public transport vehicles, and generally support, simplify, and increase the visibility of transport logistics. This is an area in which increased security can facilitate increased efficiency and productivity by standardizing and integrating the processes for managing the transportation of people and cargo (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Increasing Efficiency for Operators: There are many other ways in which ITS can improve the operational efficiency of the transportation system. One of the most successful and widespread applications of ITS has been Electronic Toll Collection (ETC). With ETC, drivers establish an account with a toll agency and receive an electronic transponder that identifies their vehicle and their account. When the transponder equipped vehicle passes a toll collection point, the toll is automatically deducted from the driver's account. The advantage to the toll agency is lower labor costs, more reliable collections, a more efficient toll operation that will attract more users, and the financial benefit of float (i.e., earnings from toll fees collected in advance, when drivers establish or replenish their accounts). In the long term, ETC opens the possibility of more flexible tolls that can be varied based on time of day, level of congestion or demand, and many other factors. More generally, ITS provides transportation system operators with better and more current information about the status of the transportation system and better tools to plan, operate, and maintain the system (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

Increasing Efficiency for Users: ITS also helps travelers to be more efficient. For example, the ETC systems mentioned above have advantages for drivers as well as system operators. The immediate advantage to the driver is that there is no need to stop at a toll barrier – the toll can be paid while the car keeps moving. The indirect advantage is an overall decrease in delays at toll barriers for all vehicles, even those that are not using ETC. Similar mechanisms can help other travelers. For example, there is a growing use of smart cards to pay a variety of fees. In many parts of the world, the same smart card can be used as a public transport fare card, for parking, and for other purposes. The smart card is a convenient way for governments to provide travel subsidies to poor or elderly citizens. This can be done by electronically storing money on the smart card or by having the fare collection system adjust the amount collected depending on whose smart card is paying the fare. A very popular ITS application in developed countries is in-vehicle navigation. An in-vehicle navigation system calculates and delivers driving directions to a destination stated by the driver. In-vehicle navigation systems include a map database, location sensors, a computer, and a user interface (e.g., a touch screen). The user interface lets the driver specify a destination and lets the system deliver directions. Navigation systems can generate efficient routes and help drivers keep from getting lost. In the future, navigation systems will receive real-time traffic information and adapt routes dynamically based on current conditions. As the cost of navigation systems continues to come down, it is expected that these systems will start to appear in developing countries as well. In general, ITS can provide travelers with better and more current information about the state of the transportation system, both for drivers and for users of public transport. This information will help travelers plan their trips better, make better connections, and, as observed above, reduce the uncertainty of travel (Tatari A., Khorasani G., Yadollahi A., Rahimi M., 2012).

2.10. Key Trends in Connected Vehicle and Smart Mobility

According my opinion the future of automotive is definitely in autonomous electrical vehicles, and we are not far away from seeing them on public roads. Driverless cars will be used beyond commuting and additional services like mobile meeting rooms, will be built in.

Though the connected car has been around for over 20 years, until recently, its capabilities have been limited to emergency help, location tracking, partial remote diagnostics, and audio entertainment—all with limited revenue potential for (Original Equipment Manufacturer) OEMs and undifferentiated impact on user experience. Now advances in adjacent technologies— electrification, cloud infrastructure and mobility, vehicle communication protocols, edge processing/computing technologies, and artificial intelligence—have opened up new horizons, enabling the connected car to become a digital transportation, infotainment, retail, and communications hub. (Equinix, 2019) The vision of the connected car as a fully integrated experience as well as a mode of transportation is now within reach.

While sales of traditional cars are decreasing, sales of connected cars are increasing, signaling changing consumer preferences. Connected car adoption is accelerating from 35% in 2015 to an expected 98% of all sold cars by 2020, (Figure 6) driven by ubiquitous mobile networks plus government-required connectivity (e.g., Europe's eCall initiative and China's electric vehicle signal polling). Evolving V2X (Vehicle-to-Everything) technologies will enable vehicles to communicate with other vehicles, with pedestrians, and with the infrastructure managing roads, traffic and IT. This communication will lead to safer, less-congested roadways with an enhanced driver experience. Note that the future here is not that far ahead: By 2025 V2X capabilities for vehicles and infrastructure will gain market momentum, with the deployments expected to start in as soon as 2020 (Figure 7) (Equinix, 2019).

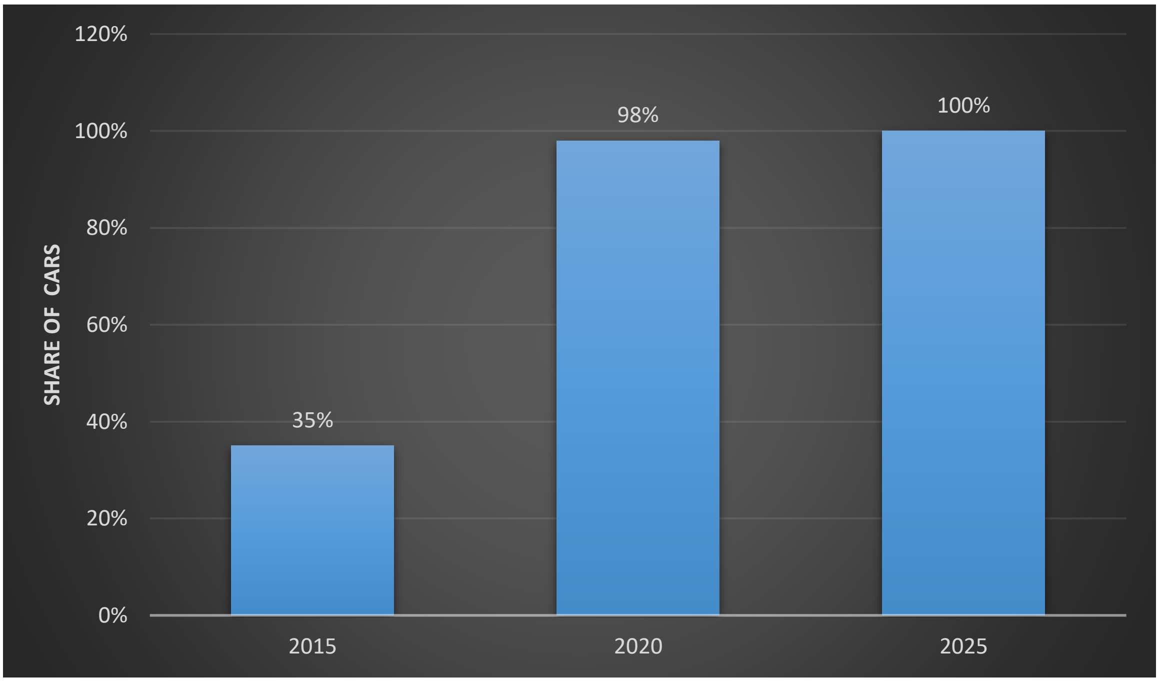


FIGURE 6. Number of Connected Cars (% of cars sold). Source: (Equinix, 2019)

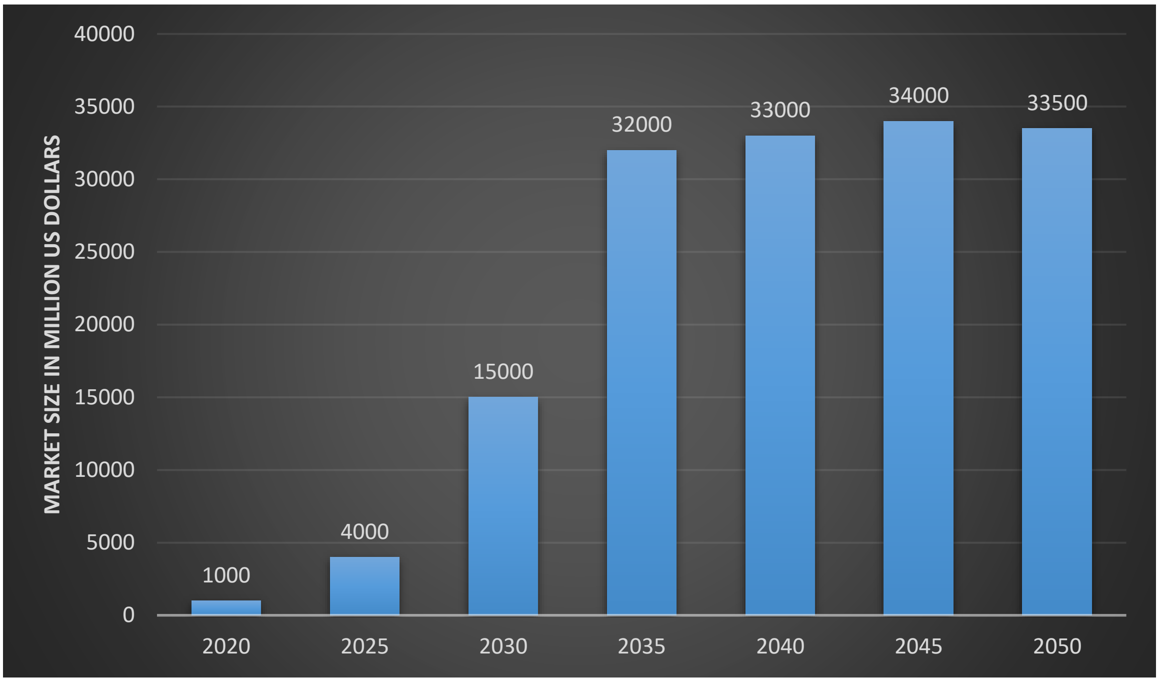


FIGURE 7. V2X market size. Source: (Equinix, 2019)

As the points above illustrate, these changes are rapidly upon us. 5G will play a role for connected vehicles by bringing high-bandwidth connectivity for over-the-air updates, advanced driver assistance systems (ADAS), high-definition (HD) and augmented and/or virtual reality (AR/ VR) infotainment, and vehicle-to-cloud data transmission. Some industry participants believe 5G will make data transfers to and from the car less expensive. However, due to the pressure on profitability and failed expectations for incremental revenues from 4G roll-outs, telcos will likely prioritize higher-return, high-density areas and premium services. A fully connected car experience relies on ubiquitous connectivity and 100% coverage, and it is unlikely that both will become available on mobile networks outside urban areas. Therefore, we expect that 5G will be an important driver for in-car infotainment, but that core system data will continue to be processed within the car, and that a car itself will increasingly become the edge data center. Multiple wireless protocols (e.g., LTE, 5G, Wi-Fi and dedicated short range communications [DSRC]) will continue to be used to exchange select data with external environments; therefore, the supporting data center infrastructure would have to be able to handle a variety of interconnection points, protocols and data dimensions (Figure 8) (Equinix, 2019).

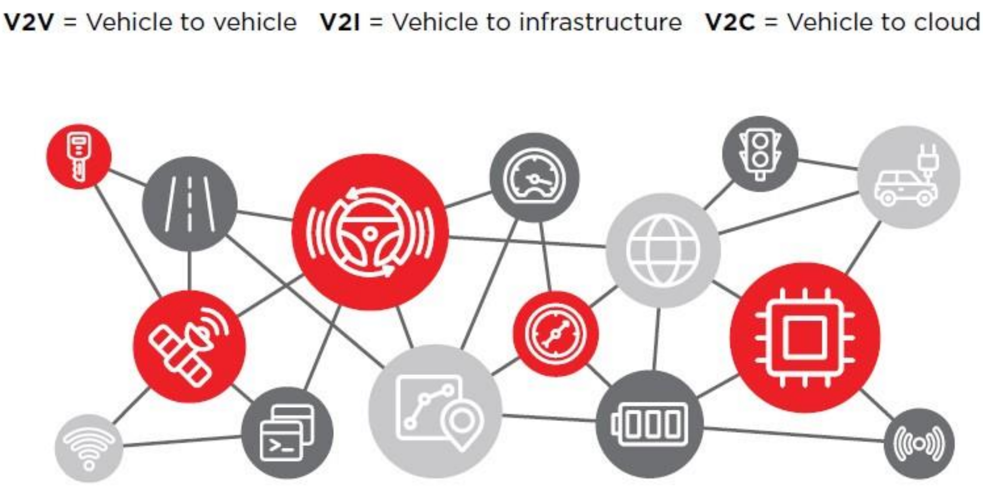


FIGURE 8. Interconnection points, protocols and data dimensions. Source: (Equinix, 2019)

According (Equinix, 2019) it's not expected OEMs to get involved in infotainment platforms in the near future. Currently users' current prefers to rely on mobile devices and their current subscription services for over-the-top (OTT) content. OEMs have struggled to bring entertainment services to the market and haven't been able to match smart devices' ease of use.

2.10.1. 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.

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. 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 (Equinix, 2019).

Autonomous technology continues to evolve. Hardware is relatively mature and includes radar, lidar, sonar, inertial measurement units (IMUs), cameras, high-performance/low-power chips, and long-lasting batteries. Software for data transmission and car guidance is still evolving. Real-time HD maps are not available as they require high-speed connectivity. Larger server capacity for storage and algorithms to interpret image data and the ever-changing driving environment are under development.

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.5 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) (Equinix, 2019).

Regulations to support testing and development of autonomous cars are in place in many geographies, with permits required for testing self-driving cars on public roads almost everywhere. In the U.S., 33 states have authorized autonomous cars on public roads. Within Europe, the U.K., Sweden, Germany and the Netherlands, regulations have been passed to allow vehicle testing.

China, despite having prominent autonomous OEMs such as Baidu and JingChi, has had a slow start, but in 2018 announced plans to designate significant areas across cities, mountains, and highways for self-driving vehicle testing starting in 2019 (Equinix, 2019).

Autonomous vehicles may change value distribution across the automotive ecosystem. Traditionally, OEMs prefer to have technology in-house; however, tech giants may be better positioned to provide some technologies. Should OEMs compete or collaborate? The software critical to driver safety will still likely be controlled by OEMs, through either the internally developed stack or acquisitions. However, the remaining systems will require multiple autotech players to collaborate on architecture and security frameworks. A key question is whether OEMs will be able to retain control over car data.

For autonomous vehicles, what is the most critical is the latency of V2I connectivity, and we don't think that even 5G will make it fast enough for critical systems; therefore, in-vehicle networking will have to support real-time data exchanges as well as provide redundancy (Equinix, 2019).

2.11. The Future of Mobility with Connected and Autonomous Vehicles

For the majority part of the 20th century, the concept of smart city was only science fiction pictured by the popular media. But very recently with considerable progress achieved in the development of computing and electronic devices, the vision that an entire city could be transformed into a smart town is becoming a reality. The idea of the smart city captured most people's attention during the last decade as a blend of beliefs on how technology in general could be used to transform how cities around the world work, while improving their competitiveness, offering new ways of solving problems linked to poverty, social deprivation, pollution and poor environmental issues. Smart cities are often seen as collections of intelligent devices installed across the city able to communicate with each other while providing constant data on the movement of people and objects. Over 50% of the world population now live-in cities and it is expected that by 2050, cities will be home for about two-thirds of the world's inhabitants. As the population in cities continue to rise, the need for mobility as well as its burdens on the environment, social stability and the economy will grow rapidly. People are attracted to cities mainly because of all the great opportunities they offer. In cities people are able to live and work, companies are able to settle, grow and recruit competitive staff, young people able to go to schools and universities. However, cities are also places for diseases mainly because in cities there are high volumes of cars, traffic, CO2 emission, high cost of living where waste production and pollution are worse. The possible applications of smart vehicles such as connected vehicles (Car2X technologies), autonomous vehicles (AVs) as well as connected and autonomous vehicles (CAVs) are wide-ranging, spanning on a variety of different sectors. CAVs appear to be a possible answer to contemporary transportation problems. Mass adoption of this emerging technology as a mode of transportation will reduce issues linked to emissions and energy consumption, while improving traffic flow, accessibility and efficiency of transportation systems, road safety, and city efficiency among other benefits. The deployment of CAVs will provide a time and space for other activities to take place from catching up on emails to watching TV. This chapter defines the concept of smart cities, it analyses connected autonomous vehicles (CAVs) as a prospective future mobility solution for smart and sustainable development. We will also identify challenges and security threats of CAVs as critical risks to the expansion of smart and sustainable cities around the world (Seuwou P., Ubakanma G., Bassini E., 2019).

PICTURE 2. A graphical Depiction of Connected Autonomous Vehicles. Source: (Seuwou P., Ubakanma G., Bassini E., 2019)

Since we discuss the future of autonomous vehicles, we can see in the picture 2 above, how the appropriate equipment is installed on cars. Video cameras are mounted near the rear-view mirror, the camera detects traffic lights and any moving objects, the Lidar positioned on the roof of the car as a rotating sensor scans the area in a radius of 60 meters for creation of a dynamic, three- dimensional map of the environment. A position estimator which is a sensor mounted on the left rear wheel measures lateral movements and determines the car's position on the map. Distance sensors made up of four radars, three in the front bumper and one in the rear bumper, measure distances to various obstacles and allow the system to reduce the speed of the car. CAVs will also be equipped with an event data recorder or EDR also referred to as automotive black box, re-cording information related to vehicle crashes or accidents (Seuwou P., Ubakanma G., Bassini E., 2019).

2.11.1. Smart Cities Concept and Challenges

In the early 1990s the expression "smart city" was coined to indicate a city that has been transformed to a modern urban landscape with the effect of globalization, extensive usage of technology and innovation. In the past few years, this concept has attracted significant attention in the context of urban development policies and from various governments interested in collecting more and more data about their population. In this setting, security agencies, law enforcement organizations, secret services and other relevant bodies will be able to monitor, collect and analyze data about the movement of people going to school, work, libraries, hospital and other community services, goods, traffic information, power plants activities, waste management, water supply networks, energy facilities in real-time. It is very important to recognize that infrastructure is a vital element for smart cities. Technology is one of the tools that make it possible but fundamental for the city to be truly smart, there should be a connection, combination and integration of all parts of the puzzle. For cities to gradually assume a critical role of leaders in innovation in sectors such as business, transportation, health in the digital economy, e-services enabled by internet and broadband network technologies are very important. Around the world, as cities continue to grow, more and more people are pursuing better lifestyles, challenges related to economic development, population growth and social progress seriously need to be considered carefully. In the reviewed literature, challenges have been identified and classified in six main city dimensions: Governance, Economy, Mobility, Environment, People and Living. They represent the specific aspects of a city upon which smart initiatives impact to achieve the expected goals of a smart city strategy (sustainability, efficiency and high quality of life). Ad-dressing the problems and development priorities of cities in a global and innovation-led world is the most important challenge of smart cities (Seuwou P., Ubakanma G., Bassini E., 2019).

Governments around the world who aspire to develop smart cities really need to change their governance models. Reduction of greenhouse gases emission, sustainable development, improvement of the energy efficiency of urban infrastructures are some other societal issues that should be ad-dressed. In smart mobility, the overall challenge is to accomplish an inclusive, sustainable and efficient transportation system of people and products. This could be achieved with the introduction of CAVs. On one hand, deploying a multimodal public transport system also known as combined transport system, making public transport accessible to all people and encouraging alternatives to car-based mobility are the three focus points that will allow improvement of connectivity, reduction of congestion and pollution in cities. On the other hand, as a follow up to the Paris Agreement adopted by consensus in 2015 on the necessity for countries to deal with greenhouse-gas-emission and achieve a sustainable development, there is a rising ecological demand for cities around the world to find ways of reducing energy consumption, CO2 emissions and pollution. Cities able to prioritize those crucial aspects and overcome the challenges listed above are crucial elements that set apart cities when it comes to good quality of life (Seuwou P., Ubakanma G., Bassini E., 2019).

2.12. Barriers to Connected autonomous Vehicles Implementation

Although CAVs offer considerable benefits, applications and opportunities in transportation, it is undeniable that their implementation will also present huge challenges to governments, car manufacturers and other related industries who will have to face and work together to overcome the challenges. The speed and the nature of CAVs mass adoption are far from guaranteed. This will depend largely on how the technology is introduced to the market, their cost, the transportation laws and regulations put in place to preserve safety and privacy of their users. The following sections outline some of the barriers to CAVs implementation. CAVs and AVs technologies are being tested in several cities across the world, global agreed standards and regulations are required and for the UK government to express their full confidence on the technology, the following challenges must be addressed (Seuwou P., Ubakanma G., Bassini E., 2019).

Consumer Acceptance: Since Norman Bel Geddes envisioned cars able to drive themselves with-out human intervention in the 1939 World's Fair General Motors exhibit Futurama, AV technologies has significantly improved. Connected Autonomous Vehicles (CAVs) will be here much sooner than most people expect and will lead to major changes to transportation, our cities and society. The car manufacturing industry used to be an area of mechanical engineering. With advances in electronics, robotic and computer science, software companies such Google are somehow leading the race. More than 50% of innovations in vehicles today are electronic. In the early 2000s, several universities took part in the Defense Advanced Research Projects Agency (DARPA) challenges in (2004, 2005 & 2007), most car manufacturers (Mercedes, BMW and Tesla) and some other technology companies (Google, UBER) are actively developing and testing AVs but there are several barriers to the introduction of this disruptive technology. At first, many consumers may be reluctant to put their lives in the hands of a robot. Recent studies and surveys have shown a split in opinion on whether people would like autonomous capability to be available in their vehicles or not. Therefore, mass acceptance of this technology could take a long time. This could be the case particularly if there are accidents involving even semi-autonomous vehicles early in the adoption phase, whether it was the fault of the autonomous system or not. The transition from hu-mans as drivers to humans as mere passengers in a car that drives itself is a major one. People generally have emotional connections with their vehicles. Therefore, are drivers willing to give up direct control over their vehicle and under what conditions? If automation of vehicles is not accepted by the users and users refrain from using the technology, the impact of automation on traffic flow efficiency, traffic safety and energy efficiency is mitigated. It is, however, not yet clear to what extent users accept automation and what the determinants of consumer acceptance of automation are. Further, societal acceptance is pending with issues like safety, trust, security, privacy concerns, etc. Therefore, mass acceptance of this technology could take a long time (Seuwou P., Ubakanma G., Bassini E., 2019).

Vehicle Costs: Highlights that the cost of most autonomous car technologies applications for military and civilians is about $100000. This is almost inaccessible for most people in the UK. Today the high-end automotive Lidar systems mounted on the roof of these cars is estimated to be about $75,000. The hope is that with mass production and notions related to Moore’s Law may also apply here to allow the prices of this technology to come closer to the conventional vehicle’s prices. J.D. Power and Associates’ survey found that 37% of persons would ‘‘definitely’’ or ‘‘probably’’ purchase a vehicle equipped with autonomous driving capabilities in their next vehicle. Nevertheless, costs remain high and is therefore a key implementation challenge, due to the current unaffordability of even some of the more basic technologies (Seuwou P., Ubakanma G., Bassini E., 2019).

Legislation Liability and Litigation: In large cities, national and local authorities and law enforcement agencies will have to act swiftly in developing laws that allow cars to drive them-selves on the streets without human intervention. Current legal systems have provision to deal with problems related to manufacturer defects. However, a framework for determining liability in a situation where an accident occurs while the vehicle is handing full control over to the human driver of the semi-automated technology. In this situation there should be more clarity in the application of current civil and criminal law to shed a light on how to deal with the problem. When AVs and CAVs become certified for safe operation by the government, the regulatory bodies and other agencies are responsible to check that new technologies are of low risk. New insurance and litigation issues should arise. Such as the persuasion of insurance companies that they will work properly in all driving environments. The reality is that even with near-perfect autonomous driving, there may be instances where accidents are inevitable. Amongst the potential implications of this, people who otherwise are not able/allowed to drive could "get behind the wheel" of AVs or CAVs, and cars could technically drive from one place to another with no occupants. If there is an accident involving an autonomous vehicle, who is liable for the consequences as the driver is still behind the wheel? because the driver is still behind the wheel and therefore ultimately liable for the safety of the vehicle. But even this point may be intensely debatable. It appears that with a possible low number of accidents in fully connected smart cities, the insurance market will be disrupted. In general, most industries will have to re-invent themselves, change their business models or disappear altogether (Seuwou P., Ubakanma G., Bassini E., 2019).

Social and Ethical Issues: Autonomous cars raise several kinds of ethical issues

- Is it possible to configure and program a CAV to react to every single imaginable situation on the road? For example, not obeying traffic light signals or speed limits when driving someone in an emergency to the hospital (A&E) or dangerous driving in order to escape from a life-threatening circumstance.
- Although it is certain that CAVs will bring substantial social and economic benefits to cities around the world, several industries will be disrupted, and many people will lose their jobs and surely must change careers.
- If an animal such as a deer jumps in front of the vehicle from nowhere, does the CAV hit the animal or run off the road? How do actions change if, instead of a deer, there is another car, or a pedestrian, a cyclist, a motor-cyclist or even a heavy-duty truck? How does the algorithm developed in these vehicles react in those situations? With a split second for decision-making, human drivers typically are not held at fault when responding to circumstances beyond their control, regardless of whether their decision was the best at the time. In contrast, CAVs have sensors, visual interpretation software, and carefully designed programs that enable them to potentially make more informed decisions. In a court of law, CAVs behavior in some scenarios may be questioned even if they are theoretically not "at fault". Other ethical questions may arise concerning the algorithm in these technologies. How do they make their decisions on who to protect most or kill in a binary situation, for example who should be protected between 5 adults and a kid crossing the road or between a disable person and an elderly pedestrian? Should the vehicle owners be allowed to adjust such settings (Seuwou P., Ubakanma G., Bassini E., 2019)?

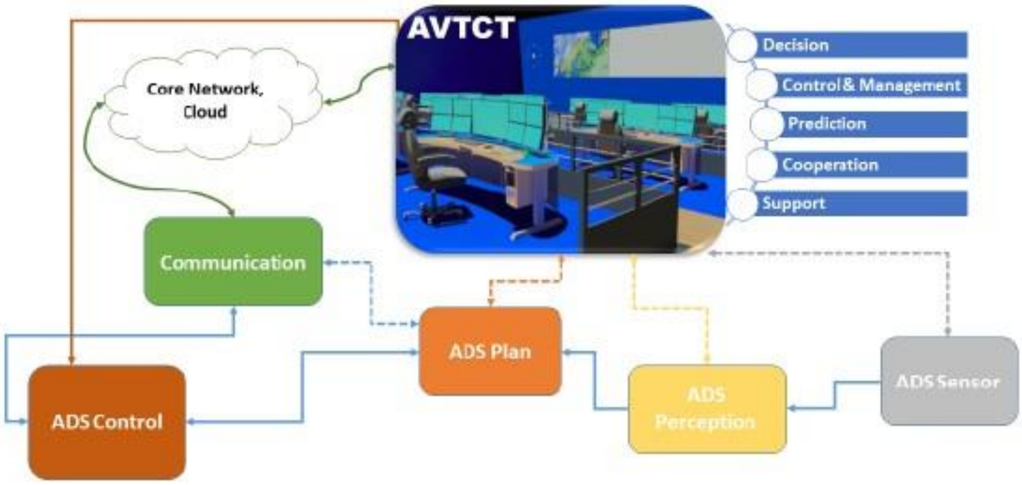
Cybersecurity, data security and Privacy Concerns: The idea that a car will be connected to the internet and able to drive itself without any human input raises several cybersecurity, data security, privacy, certification and licensing concerns as these vehicles may be subject to attack by criminals or terrorists and use for malicious purposes. These vehicles are just like computers on the road; therefore, hackers may be able to take over control of the car either to kidnap someone or a group of people remotely, purposely create an accident, terrorists may be able to guide the stolen vehicle into a crowded area to kill people or load cars with explosives as a car bomb. Gang dealers may be able to deliver drugs or weapons including firearms to remote locations without being caught. It is clear that conventional cars are being used for some of the crimes listed above, but it is also obvious that with CAVs they will be achieved a lot more easily. All countries face the same dilemma of how to fight cybercrime and how to effectively promote security to their citizens and organizations. Cybercrime, unlike traditional crime which is committed in one geographic location, is committed online and it is often not clearly linked to any geographic location. Large scale cyber security attacks by hostile nations, disgruntled employees, terrorist organizations can be mounted on the whole city transportation system, disrupting traffic and creating collisions and all kinds of accidents (Seuwou P., Ubakanma G., Bassini E., 2019). For example, a computer virus could be designed to first infect virtually the entire UK CAV fleet as a dormant pro-gram and later become active and create all kinds of disaster on the road. Therefore, a coordinated global response to the problem of cybercrime is required. According to, vice president of software security firm Vínsula, current cyber-attacks are generally acts of espionage; most attackers gain unauthorized access to systems to gather information about their opponents rather than actual sabotage. Disrupting the vehicle electronic systems and sensors will require a more complex form of attack than the one used for data gathering which is generally harder. Regardless, the threat is real, and a security breach could have lasting repercussions. Therefore, CAVs manufacturers, transportation policy makers and governments around the world should set security measures to handle these types of concerns. As CAV become mainstream and adopt-ed around the world, privacy concerns will raise several questions: Who should own or control the vehicle's data? What types of data will be stored? With whom will these data sets be shared? In what ways will such data be made available? And, for what ends will they be used? In UK, particularly in London, there are literally thousands of cameras watching us, some call London a "big brother state". From the moment you leave your home to the moment you get to work or school; you have an average of 300 cameras recording your movements. Our smartphones are equipped with location services. The reality is that privacy is almost a myth and these concepts are more likely to be transferred to CAV applications. Someone involved in a car crash may not want his vehicle's data to be shared with third parties, particularly if the person is at fault. Law enforcement could also benefit from such data. Risks such as losing privacy and/or integrity in the public cloud may prevent many decision makers from authorizing the implementation of digital services using cloud computing in a smart city. In this situation, sharing traveler data may be balanced with privacy concerns (Seuwou P., Ubakanma G., Bassini E., 2019).

Infrastructure: To get the full benefits of CAVs, new road and communication infrastructure will be required. Since CAVs are not yet completely deployed, it may be difficult to guess every single road equipment that would be required. Although AVs generally require less bespoke road infrastructure, CAV must interact with their environment, communicating with other vehicles and road side base stations in a Car2X context, they will be partially dependent on road infrastructures such as GPS mapping, road marking and strong telecom networks. The Transport Systems Catapult said that "infrastructure that is being imagined, designed, and built now, needs to have capability for future compatibility and functionality built-in from the get go". This is certainly true because they are very expensive to maintain and upgrade (Seuwou P., Ubakanma G., Bassini E., 2019).

2.13. 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. 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. 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.

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. 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 (Zhao X., Darwish R., Pernestal A., 2016).



PICTURE 3. Potential Roles of AVTCT in controlling AVs. Source: (Zhao X., Darwish R., Pernestal A., 2016)

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. Second, AVTCT can probably make decisions and take actions to achieve safe, reliable and efficient automated driving in teleoperation mode. This is not only due to a comprehensive hardware composition in AVTCT but also due to a consideration of influence from human factors and human machine interactions. Third, AVTCT could coordinate among different fleets, infrastructures, service providers and traditional road users. What is more, having AVTCT facilitating the ADS and integrating other aspects in the transport system can bring great potential to improve uptime and service accessibility, enhance fleet management, promote shared mobility services and optimize fleet utilization on a system level (Zhao X., Darwish R., Pernestal A., 2016).

2.13.1. Challenging Areas Related to AVTCT

AVTCT integrates various aspects of automated driving, and it can help decision makers and decision support systems to make safer and more efficient decisions in dynamic driving scenarios. However, the concept of AVTCT has not been discussed before in the literature, and there are still many considerations and challenges in configuring the conceptual framework to set up AVTCT. In order to set up an AVTCT, many aspects need to be taken into consideration. The areas of consideration are summarized and illustrated below in figure 9 (Zhao X., Darwish R., Pernestal A., 2016).

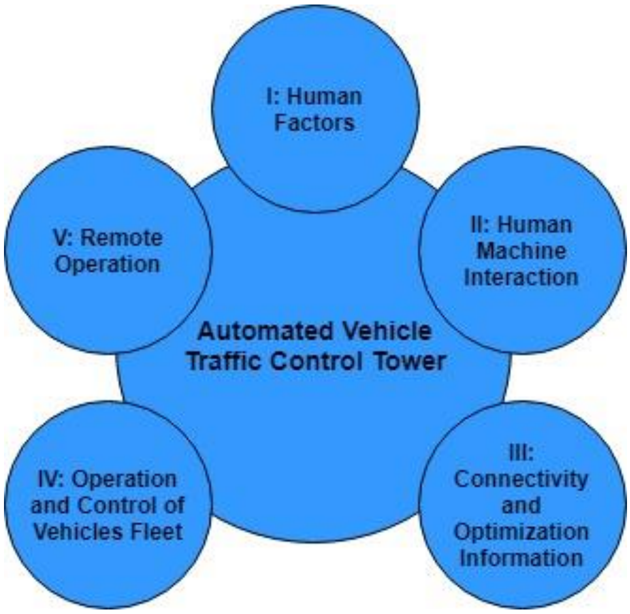


FIGURE 9. Aspects to be Considered in Setting AVTCT. Source: (Zhao X., Darwish R., Pernestal A., 2016)

These aforementioned aspects revealed several design and operational challenges. First, it is challenging to immediately identify technical solutions and to effectively transfer the critical information between the AVTCT and the AVs. Second, it is challenging for the human controllers in the AVTCT to manage all real-time traffic information accurately and effectively. Third, it is challenging to provide relevant abstractions, visualizations and interaction modalities to support the advanced decision-making capabilities required in the AVTCT. These aspects are also reflected in the different levels of abstractions considered in the definition of features and functionalities for the future AVTCT entity. At the “Macro” level, the TCT will act as a cluster-head information node, capturing the global state of the traffic network and providing monitoring and control capabilities influencing the behavior of the network as a whole. At the “Micro” abstraction level, the TCT will be required to support real-time control and monitoring information flows with each of the individual vehicles (Zhao X., Darwish R., Pernestal A., 2016).

2.14. Conclusion Literature Review

The literature review part moved around the main axes shown below:

- The history and the future of autonomous vehicles
- Safety and security of autonomous vehicles
- Serious problems such as tailgating, crashes etc. of autonomous vehicles and solutions for mitigating these problems
- Human factor
- Traffic monitoring and enforcement systems
- Monitoring of traffic safety
- Traffic centers

Autonomous Vehicles: It is very important to make a brief review of the history and the future of autonomous vehicles and how the autonomous vehicles changed and will change peoples' lives.

Many people wonder how soon autonomous vehicles will help solve transportation problems. Optimists predict that by 2030, autonomous vehicles will be sufficiently reliable, affordable and common to displace most human driving, providing huge savings and benefits. However, there are good reasons to be skeptical. Most optimistic predictions are made by people with financial interests in the industry, based on experience with disruptive technologies such as digital cameras, smartphones and personal computers. They tend to ignore significant obstacles to autonomous vehicle development, and exaggerate future benefits (Victoria Transport Policy Institute, 2021).

There is considerable uncertainty concerning autonomous vehicle development, benefits and costs, travel impacts, and consumer demand. Operating a vehicle on public roads is complicated due to frequent interactions with other, often-unpredictable animals, pedestrians, cyclists, and vehicles. Considerable progress is needed before autonomous vehicles can operate reliably in mixed urban traffic. Variety of conditions should be taken in consideration like heavy rain and snow, unpaved and unmapped roads, and unreliable wireless communication. Years of testing and regulatory approval will be required before they are commercially available in most jurisdictions. The first commercially available autonomous vehicles are likely to be expensive and limited in performance. They will introduce new costs and risks. These constraints will limit sales. Many motorists will be reluctant to pay thousands of extra dollars for vehicles that will sometimes be unable to reach a destination due to inclement weather or unmapped roads (Victoria Transport Policy Institute, 2021).

Optimistically, autonomous vehicles will be safe and reliable by 2025. A few more years will be required for testing and regulatory approval, so by 2030, autonomous vehicles may be commercially available and allowed to operate in many areas. If they follow the pattern of previous vehicle technologies, during the 2030s and probably the 2040s, they will be expensive and limited in performance, sometimes unable to reach a desired destination or requiring human intervention when they encounter unexpected situations. Customers will include affluent high-annual-mileage motorists, and businesses that use vehicles to transport equipment and goods. For the foreseeable future most moderate- and low-income households will continue to use human-operated vehicles. It will probably be the 2050s before private autonomous vehicles are affordable to most middle- and lower-income motorists (Victoria Transport Policy Institute, 2021).

Safety and Security of Autonomous Vehicles: How safe and secure autonomous vehicles are? Due to wireless communication of autonomous vehicles and new technologies, new kinds of problems have emerged. Some of them mentioned in the main part and briefly are hardware and software failure, malicious hacking, platooning risks, reduced investment, higher vehicle repair costs due to extra equipment installed on that kind of vehicles. All the above problems prevent individuals from buying an autonomous vehicle, because autonomous vehicles are not 100% safe. A lot of progress and research is still needed in order to reach 100% safe AVs. All of the above are negative factors in the purchase and use of autonomous vehicles. Car companies and all involved (government, engineers, etc.) need to solve all the problems that arise and convince users of AVs safety.

From car companies' side, a lot of efforts and tests have been done in order reduce the above-mentioned problems. I briefly mention the following:

- **Software testing:** The million lines codes in autonomous vehicle require automation functional test on source code level and also require enhanced security of permanently online safety-critical systems (Wang K., Zhu F., Yisheng L., 2016).
- **Simulation testing:** High-fidelity simulation is required in autonomous vehicle testing. The dedicated software containing mathematical representation of the subsystems should be used in order to achieve realistic system dynamic, which can be validated with hardware-in-the-loop techniques (Wang K., Zhu F., Yisheng L., 2016).
- **Driving test in real traffic:** Autonomous Vehicle driving tests can be carried out in real, open environments. Google driverless cars are mostly tested in real traffic (Wang K., Zhu F., Yisheng L., 2016).

Serious problems such as tailgating and crashes: According to our literature review, serious tailgating issues have been identified and there is a need for countermeasures taken to mitigate the problem. The use of advisory signing is a must in order drivers keep safe distances to avoid rear-end crashes. Also, drivers' behavior should also be changed and aggressive driving should be avoided. Nevertheless, other measures must be taken to further reduce the above-mentioned problems such as driver training, road safety seminars, awareness of driving risks, stricter laws etc.

Human Factor: Autonomous vehicle technology is not yet completely safe and reliable, therefore necessitating driver input when autonomous systems fail or have limited performance capabilities. Shifting the driving mode from human's manual control to automated driving with human's primary responsibility may lead to problems of inattention, reduced situational awareness and manual skill degradation. In turn, these human factors may compromise the safety of manual control in cases where autonomous systems fail.

Traffic monitoring and enforcement systems: As stated before, ITS play a key role in monitoring and enforcement of mobility, and they will also play a key role in monitoring and enforcement of autonomous driving and connected mobility. There are a lot of systems such as VMS, LCS, VSLS but also some strategies like STIMF that tries to monitor autonomous mobility. Different systems are responsible to inform drivers about the road condition, weather condition, detours etc. Information is the most important thing for a driver because it keeps the motorists informed about the possible events, accidents or road conditions and identifies the shortest route for its destination. In terms of autonomous vehicles, the same principal exists. The car needs to be updated through the various systems in order to take the shortest route or to keep the appropriate speed etc. in order to keep the drive safe.

Reading the above, we can see the efforts that have been made until now to solve the major problem called monitoring and enforcement of autonomous mobility. There is still room for improvement but so far, several steps have been taken.

Traffic Centers: They are the most important element for monitoring traffic on motorways or on rural roads. The traffic center is the heart of the system. All information gathered from various sensors is processed from operators in order to make the right choice. For example, in case of an accident the creation of a safe detour is a must. Traffic centers will also play a crucial role for monitoring autonomous mobility.

Reading all the above we can conclude that autonomous driving and connected mobility depends on a lot of parameters. These parameters must cooperate efficiently to succeed in traffic safety. Until now many steps have been taken, but a lot of work is still needed to achieve the best result.

3. RESEARCH PLAN: SURVEY SET UP

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 must be 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 This chapter describes all the steps that need to be undertaken to create and distribute the survey. This survey will target a variety of categories of drivers including young novice and older experienced drivers. The survey has been circulated on all drivers' age categories. The following chapters indicate the survey design, how the questions should be defined and why the chosen questions are the most appropriate. Also, the goal of the survey chapter, will try to document why this survey is necessary to be conducted and what are the expected outcomes of the whole procedure.

3.1. Goal of the Survey

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.

3.2. Questionnaire

The questionnaire consists of 19 questions, divided into 4 main parts scattered inside the survey. The first part gains inside the demographics of the responders, asking questions about the gender, age, living current area and country, the owning of a car and a driving license, the current profession and which means of transport is using the most by each individual. The second part tries to investigate/ explore what is the knowledge of the individual on the part of connected and autonomous mobility. The third part has to do with the perspective of each individual on the connected and autonomous mobility. What they believe about it and what they think about this new technology. The last part has to do with traffic safety. How safe autonomous vehicles are? What do people think about autonomous vehicles and traffic safety? Can these two coexist? What happens in case of mixed traffic? The survey can be found in annex 6.1.

3.2.1. Demographic Questions

Demographic questions are maybe one of the most important parts of each questionnaire. These questions help us to make the comparison between age groups, living areas, groups, gender etc. In this survey the demographic questions are crucial to distinguish the difference in perspective between age groups. Younger individuals may know the new technologies better than the older ones. In the paragraphs below, we will discuss the different demographic questions.

The first question refers to the gender of the responder. Males and females have totally different perspectives on driving and answers will be really interesting to analyze. The next question refers to age. Age is an important parameter and used to compare different perspectives between individuals. Answers can vary depending on age. Regarding the age of the participants, I decided to create 5 different age groups, and not to have and open question about the age. The age groups are separated as shown below:

- 16 – 24
- 25 – 34

- 35 – 44
- 45 – 65
- 65+

Next two questions refer to the living area of individuals in order to be able to have an idea where the responders mainly live. First a question about the country is asked. Different steps have been taken in the field of autonomous vehicles between countries. For example, ιn Greece, the technology of autonomous vehicles is at a very early stage comparing other countries, for example the UK. So, the specific question Is crucial to understand individuals' background. Second question refers to the living area of individuals. There are three choices for the respondent:

- Urban area
- Suburban area
- Rural area

These choices have been defined to get a more general overview whether the responder lives in a city or outside the city. For example, people living in a village may not have had the opportunity to get involved or just to know about autonomous mobility. Next two questions ask about the ownership of a car and the ownership of a driving license. Responders who own a car and a driver's license, are more likely to have been involved in a mixed traffic environment than individuals who do not own a car or a driver's license. For these two questions, "Yes" and "No" choices are available for the responder. Finally, the last two questions refer to the responder's profession and the means of transport that is used for his/ her everyday movement. For the first question 3 choices are available for the responder:

- Student
- Employee
- Unemployment

It is important to know the profession of each responder. For example, a student who hasn't own a car or a driver's license, but studies Transportation Sciences, knows what AVs are in contrast with someone who lives in Greece and owns a car but has never heard about AVs. For the above-mentioned, we can clearly see that we must consider multiple factors of each responder, in order to have a clearer view. Finally, a question regarding the means of transport that the responder uses has been asked. The same explanation counts as for the parameter about the "Current Profession". For this question 4 choices are available for the responder:

- Car
- Public Transport
- On foot
- Other means of transport (e.g., bicycle)

3.2.2. AVs knowledge questions

After the demographic questions, we can see the knowledge questions, to see if the responders know what autonomous mobility refers to. Also, a question is being asked about transport infrastructure. As we know, transport infrastructure is a key element when we speak about mixed traffic, where AVs and CAVs use the same movement space. For this part I used closed questions with answering categories. I preferred to use seven possible answers (Likert scale) which shown below:

- Totally disagree
- Disagree
- Rather disagree
- Neither disagree nor agree

- Rather agree
- Agree
- Totally disagree

All the questions of the specific part try to determine the level of knowledge of each participant but also their perspective on how the existing infrastructure can support mixed traffic mobility.

3.2.3. Responders' perspective questions

This part consists of most questions compared to the other parts. What people believe about additional risks that technologies can introduce, if drivers should take control in case of malfunction of a vehicle, levels of autonomous vehicles what people believe about the future of connected mobility etc. Afterwards, responders should declare what they prefer for their personal vehicles. Nonetheless, there is still the possibility to choose zero autonomy. Many individuals may see many positives on connected mobility, but not for themselves. From this specific part, very useful conclusions can be drawn regarding the perspective of the users regarding autonomous mobility. Here I also used a Liker scale with seven possible answers. The responders are able to choose between answers shown below:

- Zero autonomy
- Driver assistance
- Partial automation
- Conditional automation
- High automation
- Full automation

In this part also, responders can express their opinion about the safety of connected mobility? Do they believe that autonomous vehicles are safe to drive?

3.2.4. Traffic safety questions

In this part includes questions about traffic safety. After describing in detail safety issues that may arise, responders should answer about safety issues. I believe that the strongest question of the specific part is shown below: *"I would send my fully automated vehicle to pick up my kids from school".* This is a hard question even for the people who have a lot of experience and knowledge on connected mobility. Personally, despite my experience on the connected mobility topic, I am not sure if I would send a fully autonomous cars to pick up my kids from school. Also, in terms of law enforcement for autonomous vehicles, there are many things that need to be done, in order to feel safe inside an autonomous vehicle. Responders know the above and are asked to give their answers. For this part also, I used a Liker scale with seven possible answers, as I used for the previous parts.

4. SURVEY ANALYSIS AND INTERPRETATION OF THE RESULTS

In order to create the survey and collect 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. Also, the raw data (see annex 6. Qualtrics will help us to create additional figures in case something isn't provided from the software. In this chapter, the results from the survey are presented.

4.1. Demographics Interpretation

A total of 454 people participated in the survey. From the 454 people participated in my research's survey, only one chose not to continue further. Hereafter, the analysis of the collect responses will be presented.

From the 453 participants, 57.27% were male and 42.73% were female responders. As we can see participants almost equally distributed between male and female.

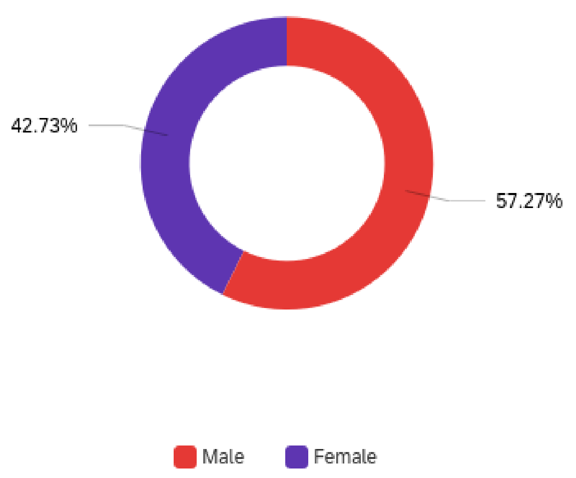


FIGURE 10. Demographics – Gender (Qualtrics, Own edit, 2021)

It is important to mention here that 75.4% of male own a driving license and 72.7% of female own a driving license also. Looking in figure 11, we see also a balance on driving license owning.

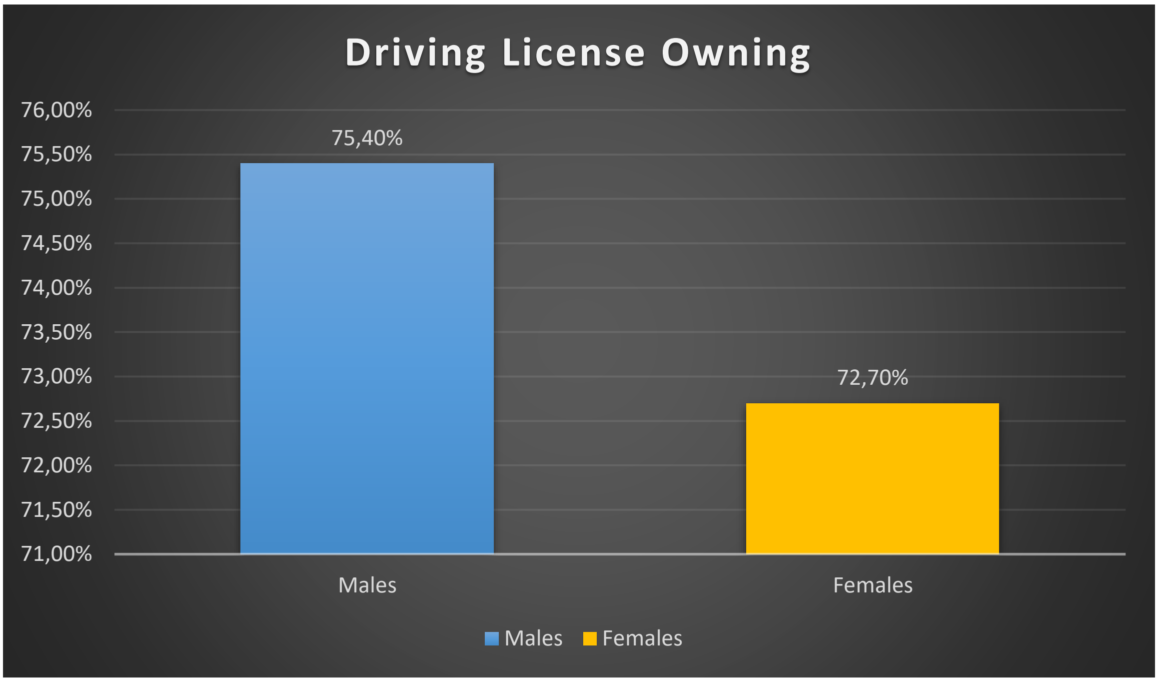


Figure 11. Demographics – Driving License Owning (Qualtrics, Own edit, 2021)

As we can observe from the following figure 12, we have participants only from the first four categories and we do not have any participant more than 65 years old. From a point of view this may be perfectly normal due to the ignorance of the subject by older people. 56.82% of the participants, belong to the first age category and this is completely logical, since the younger ones are more interested in the older ones in technology. 24.16% of the responders belong to the second age category and only 3.58% belong to the fourth age category (45 – 65). As age increases, the interest in new technologies, and especially in such a widely known mean of transport as the car, decreases.

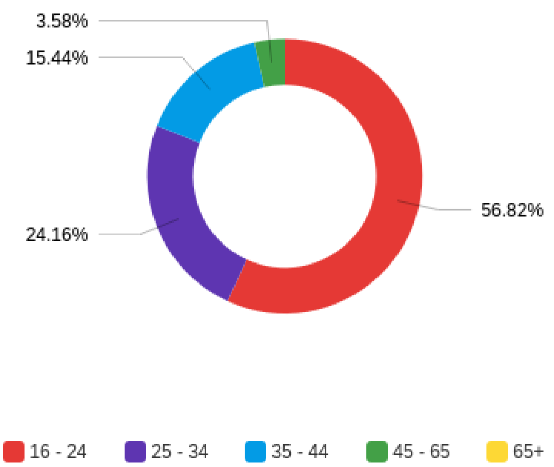


FIGURE 12. Demographics – Age Categories (Qualtrics, Own edit, 2021)

Regarding the living country I created an open question and all participants were able to write themselves about their living country. Since Qualtrics wasn't able to create any visualization, I exported the raw data on excel sheet (see annex 6.3) in order to create a graph according to my data. What I am really proud of is that the participants are scattered in 29 different countries where different perspectives dominate. Developing and developed countries have totally different perspectives regarding autonomous vehicles.

As we can observe in the figure 13 71.96% (326 people) of the participants live in Belgium, so I strongly believe that most of them are fellow students from Hasselt University. 13.68% (62 people) of the participants live in Greece and most of them are colleagues from work. The remaining participants, 14.36% (65 people) are scattered in the remaining 27 countries.

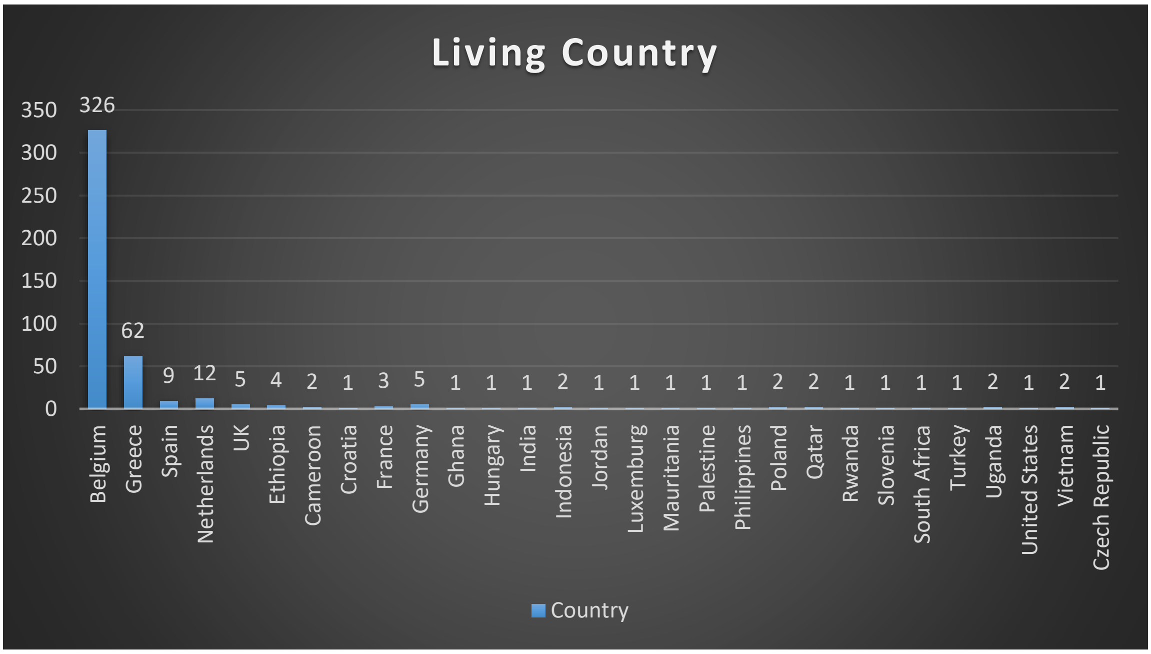


FIGURE 13. Demographics – Living Country (Qualtrics, Own edit, 2021)

Next question has to do with the living area of the responder. Observing figure 14, we see that 42.47% of the respondents live in a suburban area. 38.58% lives in an urban area and the rest 18.95% lives in a rural area. Using the survey raw data, we can create another figure that we can see the separation of gender across the living area. In figure 15 we see the gender separation across the living area.

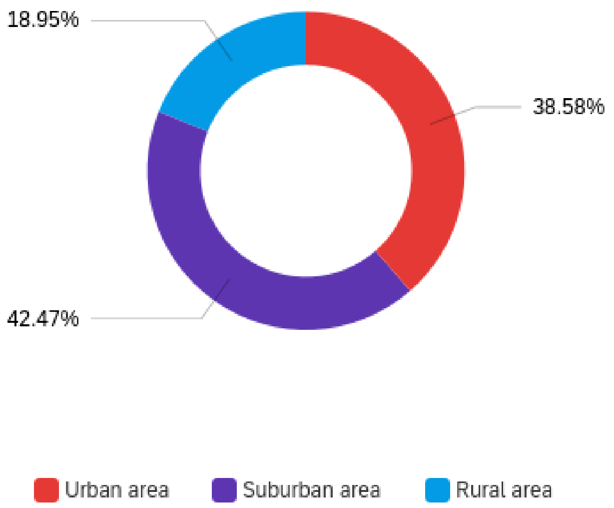


FIGURE 14. Demographics – Living area (Qualtrics, Own edit, 2021)

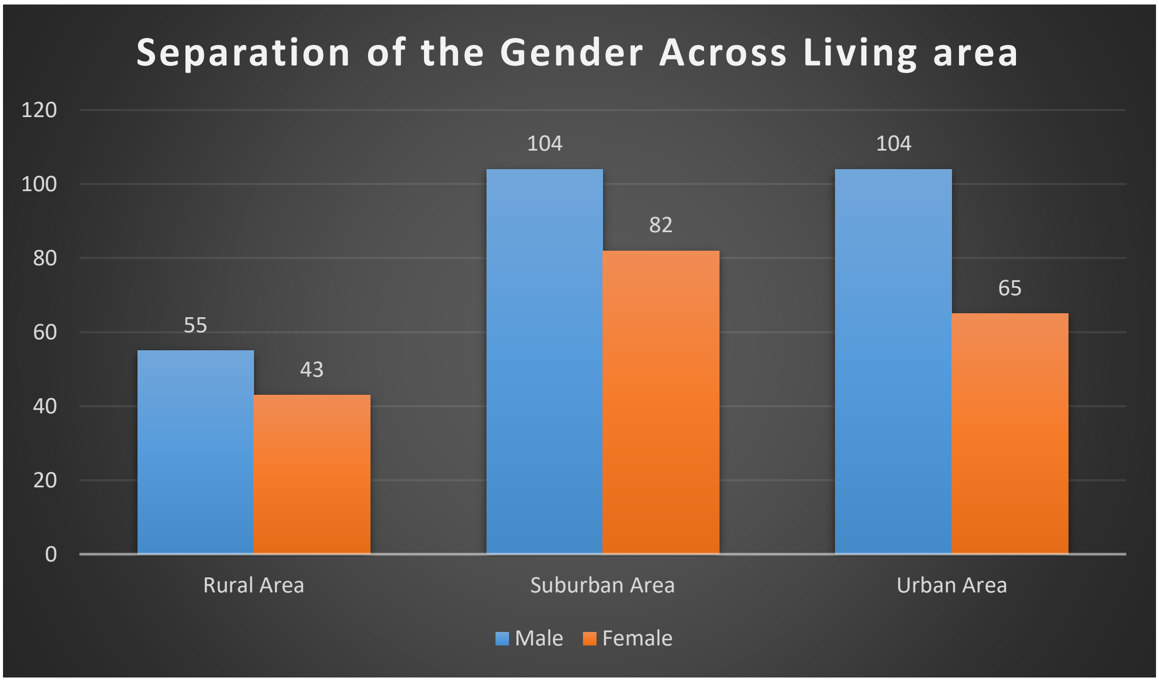


FIGURE 15. Demographics – Separation of the Gender Across Living area (Qualtrics, Own edit, 2021)

The next question has to do with owning a driving license. It is really important to know the percentage of people who own a driving license because the perspective and knowledge about autonomous vehicles could be different. According to people's answers we see that 73.68% (331 people) own a driving license and 26.32% (122 people) don't.

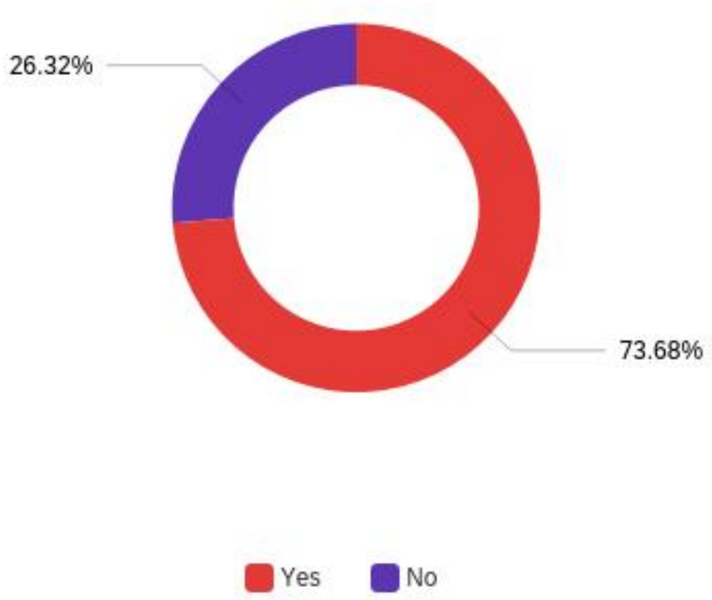


FIGURE 16. Demographics – Driving License owning (Qualtrics, Own edit, 2021)

Next question is also important and it's related to the previous one. It has to do with car ownership and despite 73.68% owning a driving license, only 50.34% owns a car. This is an interesting question because since only half the people own a car, the possibility of driving in a mixed traffic environment is reduced. So, in that case drivers experience is limited.

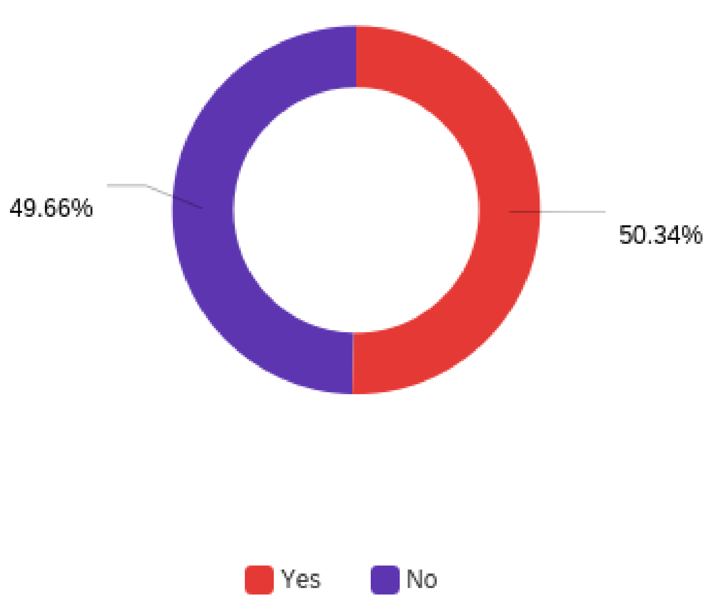


FIGURE 17. Demographics – Car Owning (Qualtrics, Own edit, 2021)

Regarding the current profession 64.43% (292 people) are students and 35.33% (160 people) are employees. The remaining participants, 0.24% (1 person) are unemployed. This is really encouraging because the possibility of students knowing a lot of things about autonomous vehicles is quite big and that means that we will have very good results later in the survey because of the more informed responders.

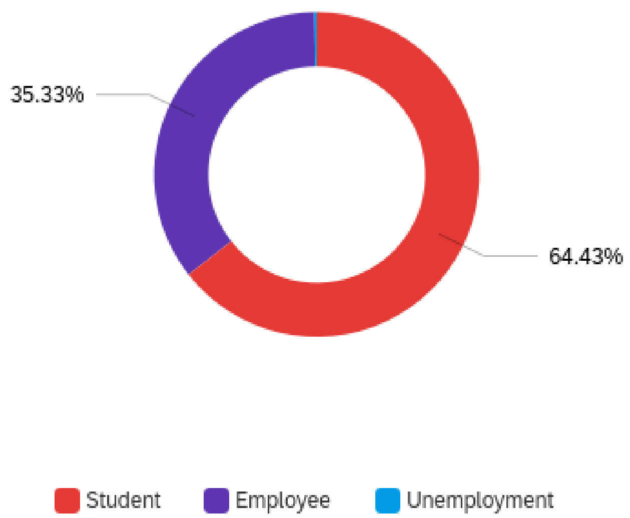


FIGURE 18. Demographics – Current Profession (Qualtrics, Own edit, 2021)

The last demographic question has to do with the means of transport participants use to go to the university or at the office etc. Most of the participants 42.26% (191 people) use the car for their daily movement. Public transport is used by circa 27.56% (123 people), 26.56% (121 people) use other means of transport, for example bicycle or taxi etc. Finally, only 3.93% (18 people) of the participants prefer to walk to their job or to the university. It is remarkable here and looking at the car owning figure, we see that almost all individuals who own a car use it every day for their daily movements and they do not prefer to use any other means of transport. Why is this happening? Poor public transport connection, lack of bicycle or bicycle routes, laziness etc.

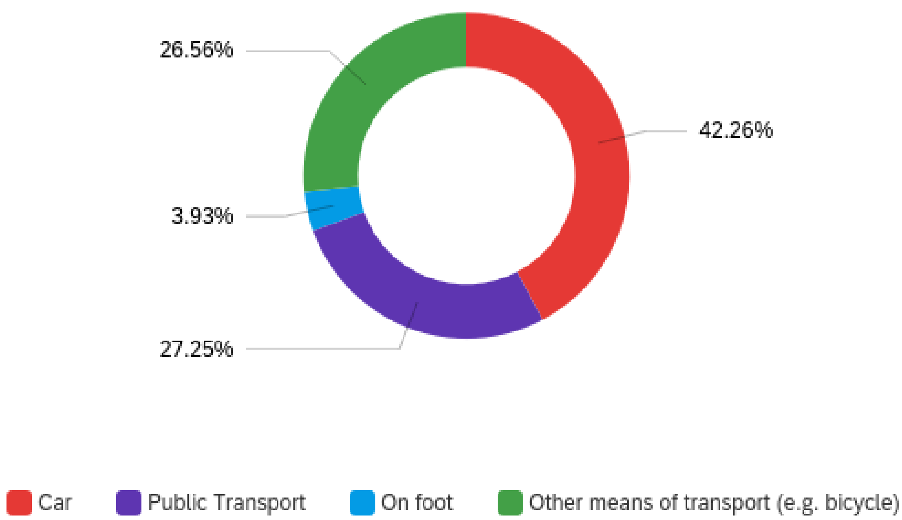


FIGURE 19. Demographics – Means of Transport (Qualtrics, Own edit, 2021)

To summarize the demographics results, all numbers, answers and percentages depicted in the table 2 below.

Age Category	**16-24**	**25-34**	**35-44**	**45-65**	**65+**	**Total**
Answers	259	110	69	15	-	453
Percentage	56.82%	24.16%	15.44%	3.58%	-	100%
Living Area	**Urban**	**Suburban**	**Rural**			
Answers	174	192	87			453
Percentage	38.58%	42.47%	18.95%			100%
Driving License	**Yes**	**No**				
Answers	331	122				453
Percentage	73.68%	26.32%				100%
Car Owning	**Yes**	**No**				
Answers	228	225				453
Percentage	50.34%	49.66%				100%
Employment Status	**Student**	**Employee**	**Unemployment**			
Answers	292	160	1			453
Percentage	64.43%	35.33%	0.24%			100%
Means of Transport	**Car**	**Public Transport**	**On Foot**	**Other**		
Answers	191	123	18	121		453
Percentage	42.26%	27.25%	3.93%	26.56%		100%

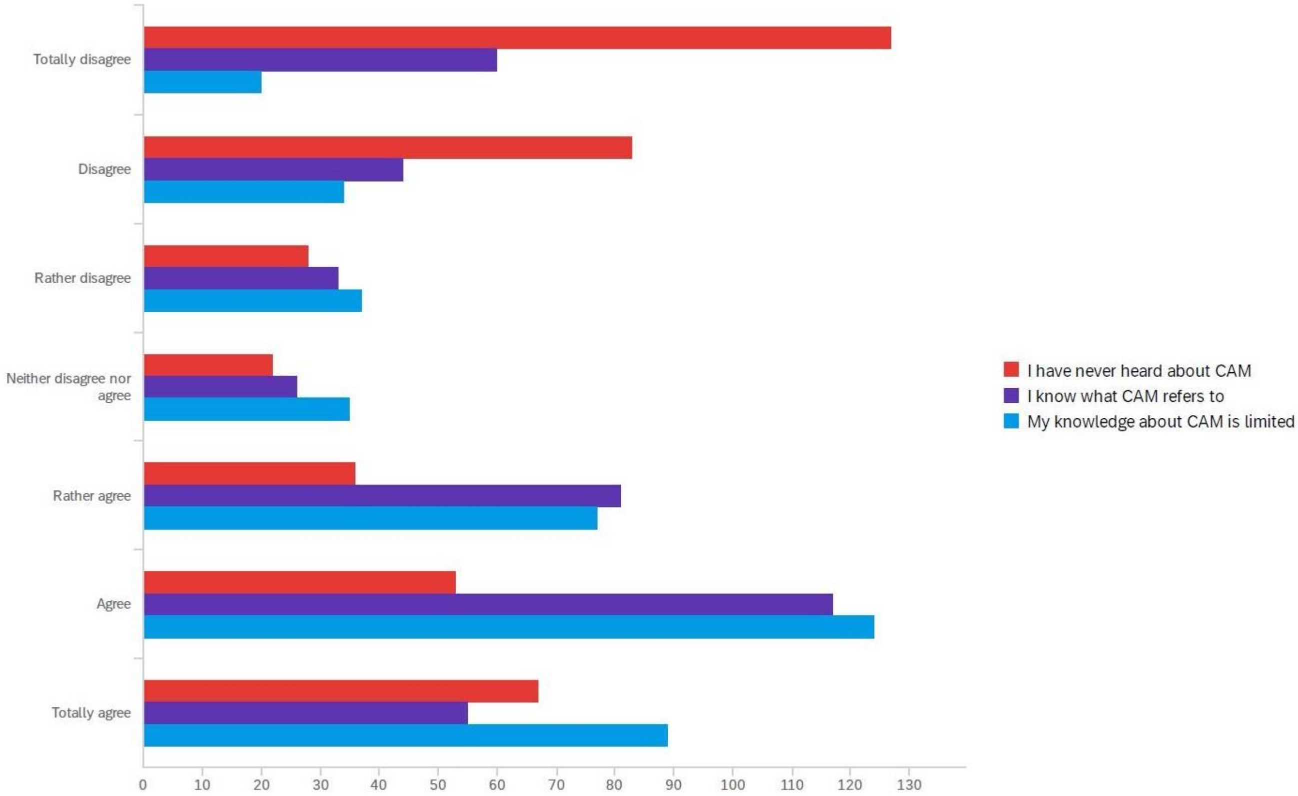
TABLE 2. Demographics Results (Qualtrics, Own edit, 2021)

4.2. Knowledge, Perception and Safety Questions Interpretation about Autonomous Vehicles and Connected Mobility

The second part of the question is important in order to understand what responders know, perceive and think about traffic safety regarding autonomous vehicles and connected mobility. In this chapter I will interpret all the questions and answers given by the responders.

4.2.1. Connected and Autonomous Mobility

This question, after explaining to responders the definition of connected and autonomous mobility, tries to extract information related to their knowledge. What they know about the specific topic. Have they ever heard about CAM? The full question is *"Connected and Autonomous mobility (CAM) refers to autonomous/ connected vehicles or self-driving cars (vehicles that can guide themselves without human intervention). To what extent do you agree with the following statement?".*



PICTURE 4. Connected and Autonomous Mobility Knowledge Question (Qualtrics, Own edit, 2021)

52.53% of the participants have heard about CAM and the specific term it's not unknown to them. Also, 55.84% of the participants stated they know what CAM refers to. Finally, 64.01% of the responders stated that their knowledge about CAM is limited. What we can conclude from the specific questions is that, even though they know what CAM means, their knowledge of the specific topic is limited. It is important here to say that 34.43 of the participants stated that they have never heard about CAM and this is a quite big number that will definitely affect the survey.

4.2.2. Mixed Traffic

The specific question tries to describe what mixed traffic refers to and asks the responder to answer if he/she has ever been involved in a mixed traffic situation. The full question is *"Mixed traffic is the situation where autonomous and conventional vehicles share the same infrastructure. To what extent do you agree with the following statements?"* Around 48.56% of the participants stated categorically that they have never been involved in a mixed traffic situation as a driver but there is also a 15.45% of the participants who are not sure. On the other hand, 22.29% of the participants are sure that they have been involved in a mixed traffic environment. Also, we have almost the same percentages on the answer *"I have been involved in mixed traffic as a passenger"*.

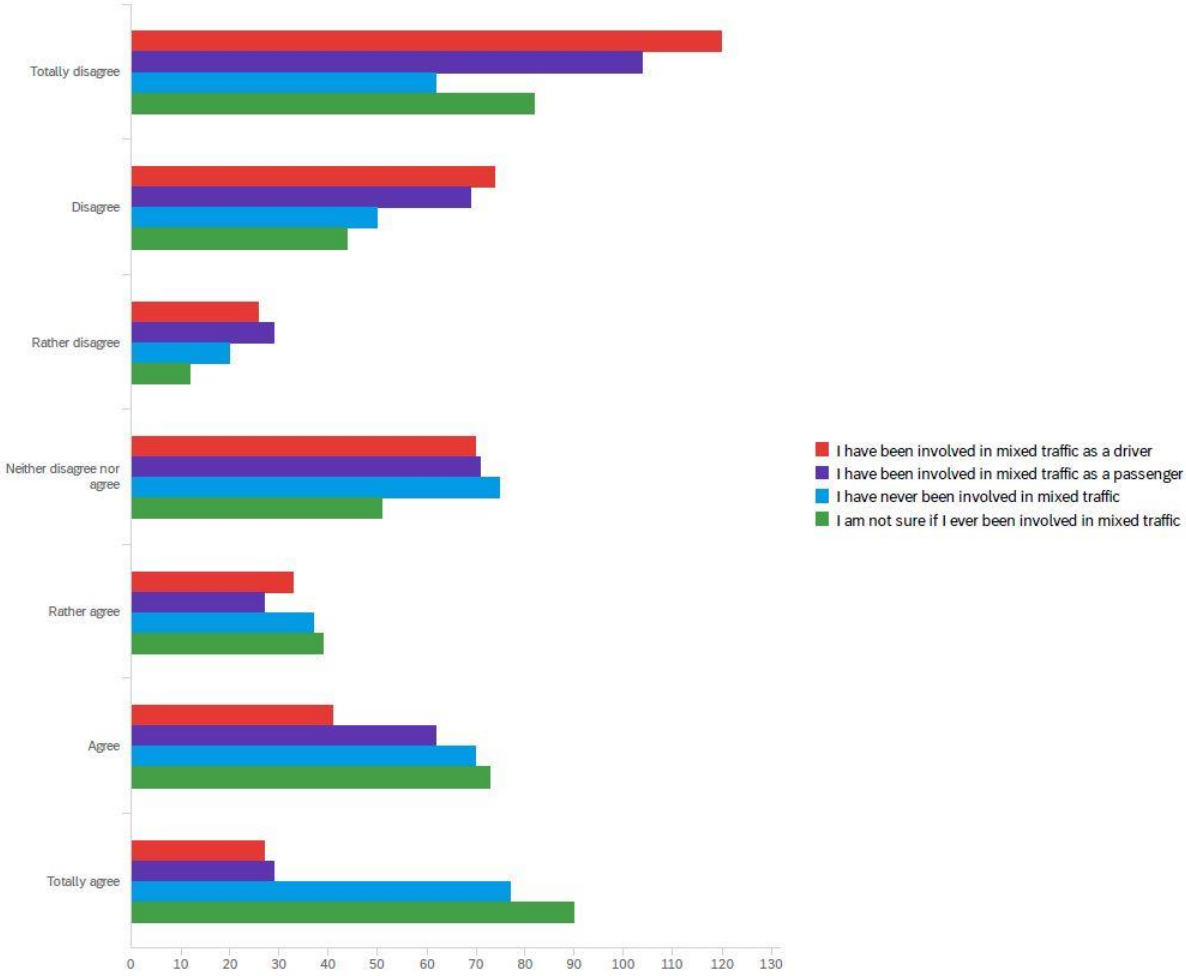


FIGURE 20. Mixed Traffic Situation Question (Qualtrics, Own edit, 2021)

Around 44.59% of the participants stated that they have never been involved in a mixed traffic environment as a passenger, but also here 15.67% of the participants are not sure. On the other hand, 20.08% of the participants are sure that they have been involved in mixed traffic scenario as a passenger. Finally, around 42.61% of the participants stated for sure that they have never been involved in a mixed traffic environment. Also, 17.55% of the participants are not sure if they have been involved or not. In this question the uncertainty of responders is the number one factor. Around 57.84% (the specific percentage, includes Neither disagree nor agree answers) of responders are not sure if they ever have been involved in a mixed traffic environment and this is absolutely logical. For example, in Greece we are still years away from CAM and a mixed traffic environment. Also, in other European countries, great efforts have been made in the field of CAM, but even greater efforts are needed in order to talk about a mixed mobility scenario. That is why the uncertainty of the responders is absolutely justified.

4.2.3. Autonomous Vehicles and Reduced Crash Rates

The specific question refers to the perception of the participants about the safety of autonomous vehicles, if they believe autonomous vehicles are safe to drive or not. The full question is *"Optimists claim that, because human error contributes to 90% of crashes, autonomous vehicles will reduce crash* *rates and insurance costs by 90%. To what extent do you agree with the following statements?"*. Three different answers are available for the participants. Around 53.21% of the participants disagreed with the statement *"I don't believe that autonomous vehicles are safe to drive"* and 54.75% are sure that autonomous vehicles are safe to drive. We see a clear balance here. More than 50% of the participants agreed that autonomous vehicles are safe to drive. 22.29% of the responders are not sure if the autonomous vehicles will reduce any safety problems because the *"Neither disagree nor agree"* answer has been chosen. Uncertainty here also represents a large percentage circa 49.66% and we can conclude this by adding all *"Neither disagree nor agree"* answers. The main reason for that is because autonomous vehicles are not so common, and people do not know many things about them.

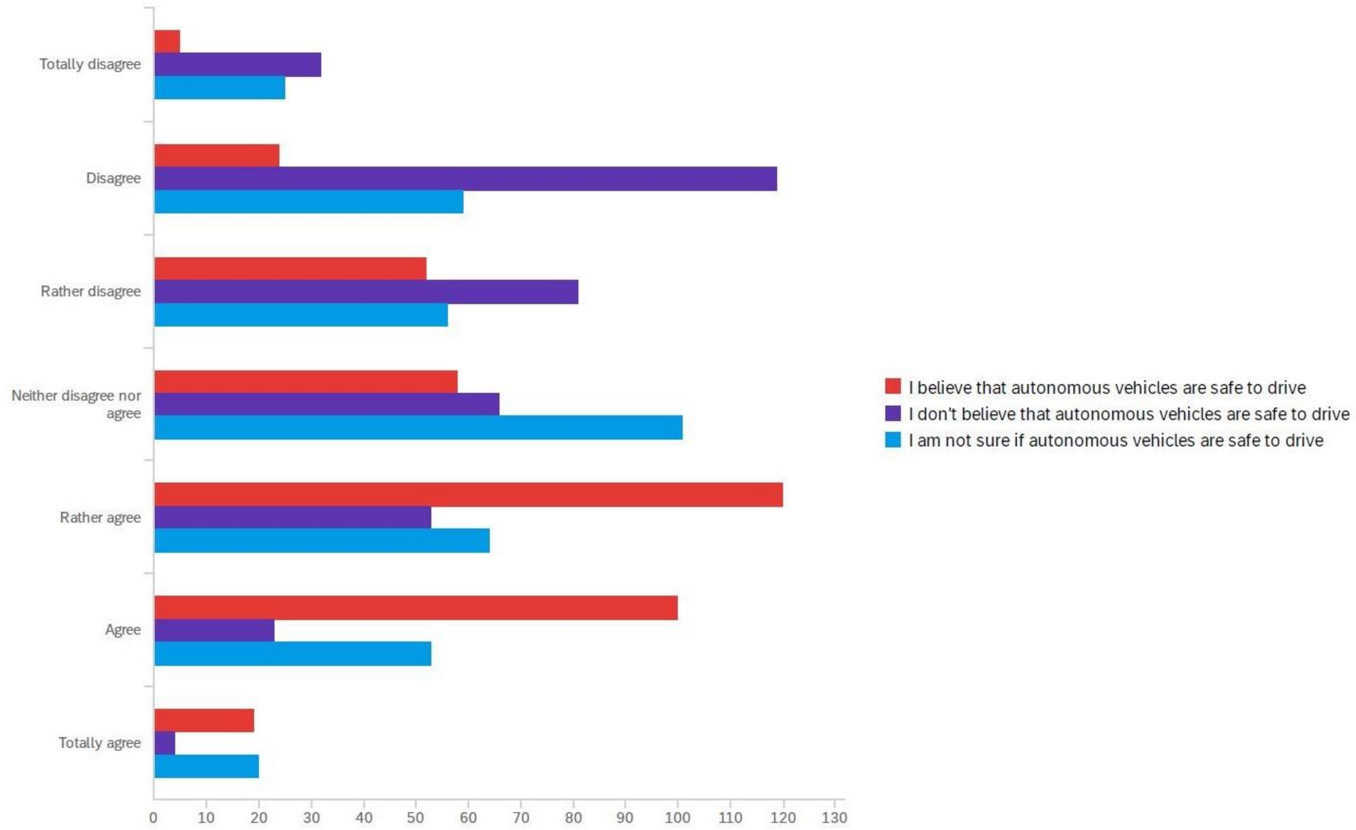


FIGURE 21. Autonomous Vehicles and Reduced Crash Rates (Qualtrics, Own edit, 2021)

4.2.4. Tailgating Issues

The specific questions focus on autonomous vehicles safety and especially on tailgating issues. Tailgating is a dangerous driving behavior and a leading cause of most rear-end crashes, so the specific question is mandatory. The full question is *"Tailgating is a dangerous driving behavior and a leading cause of most rear-end crashes. To what extent do you agree with the following statements?"*. Here also the responses are very interesting. Although the knowledge of people in the field of autonomous vehicles is limited, 64.91% of the responders are totally convinced that autonomous vehicles will reduce tailgating problems. The uncertainty here is smaller, since only 33.33% of the participants answered *"Neither disagree nor agree"*. Also, around 62.92% disagreed with the statement *"I don't believe that autonomous vehicles will reduce tailgating problems"*. It is important to mention here that from the responders disagreed with the statement above, 82.05% own a driving license and are drivers. Finally, only 5.29% agreed with the statement *"I believe that autonomous vehicles will not reduce any safety problems at all"*, a number which is very low. Spoken with real numbers, only 24 people believe that autonomous vehicles will not reduce any safety issues. This is really encouraging, that people recognize the safety that autonomous vehicles offer. Looking at the edges we see that just one person agreed with the statement "*I believe that autonomous vehicles will not reduce any safety problems at all*" and two people disagreed with the statement *"I believe that autonomous vehicles will reduce tailgating problems"*.

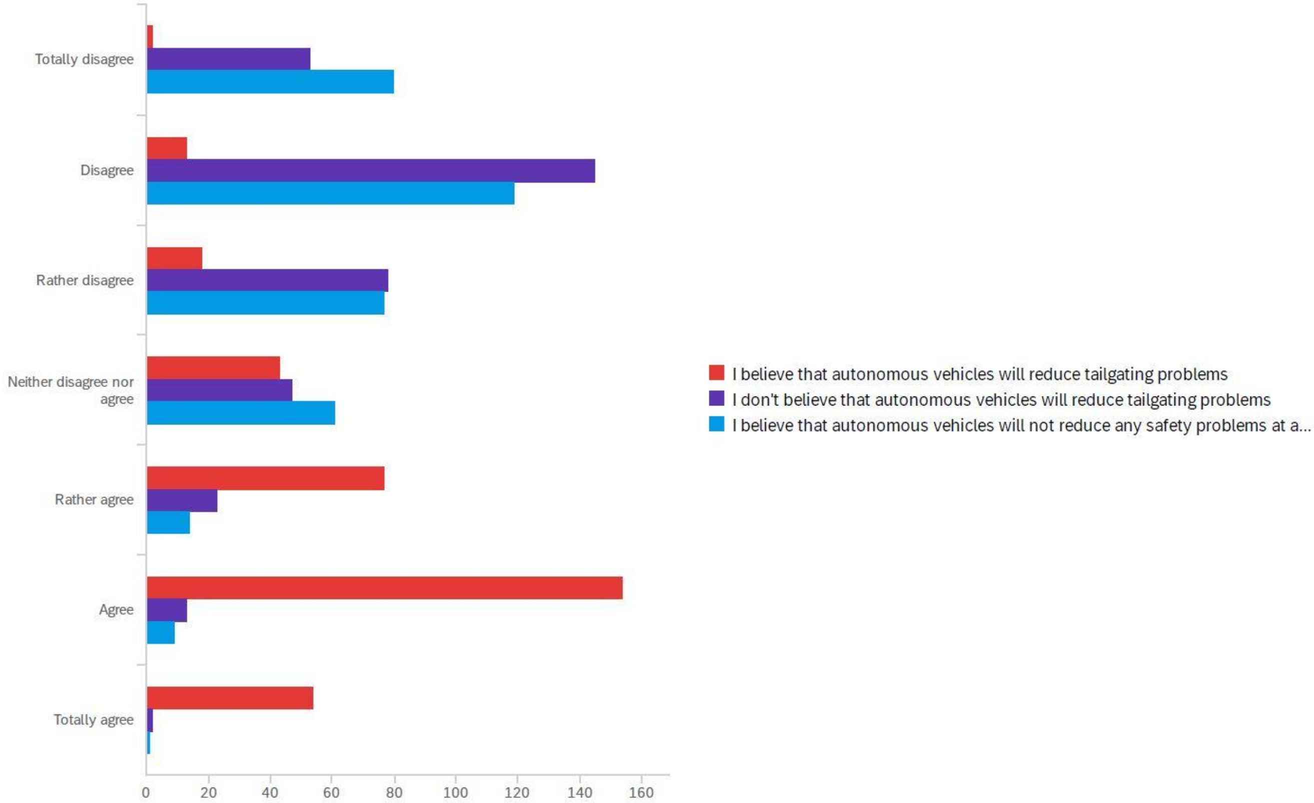


FIGURE 22. Tailgating Issues Question (Qualtrics, Own edit, 2021)

4.2.5. Autonomous Vehicles and Transportation infrastructure

The specific question focuses on transportation infrastructure and especially on the readiness of the infrastructure to support autonomous and connected mobility. What do people believe about transport infrastructure? Is it ready to support something new and revolutionary as it is autonomous mobility? The full question is *"Transportation infrastructure is the most crucial element of mixed traffic. To what extent do you agree with the following statements?"*. Here, 4 answers are available and we will analyze the results. Looking at the graphs we see that answers about infrastructure are more balanced. Around 58.65% of the participants disagreed with the statement *"I believe that transportation infrastructure is ready to support mixed traffic"* which is quite logical and only 26.60% agreed with the statement. The opposite statement, which is *"I don't believe that transportation infrastructure is ready to support mixed traffic"* has almost the same percentages, which means that there is a balance between answers. The statement that I believe has the greatest weight, is the one that refers to whether the infrastructure will be ready to support mixed traffic or not. The statement is the following, *"I believe that transportation infrastructure will never be ready to support mixed traffic"*. The majority of participants, almost 74.26% disagrees with the specific statement and that means that people are sure that infrastructure will be ready to support mixed traffic. 14.91% are not sure and 10.83% have agreed with the statement. The last statement is also important and has to do with the time that the infrastructure will be ready to support mixed traffic. The statement is the following, *"I believe that transportation infrastructure will be ready in 20-30 years to support mixed* *traffic"*. Also, here the answers are interesting. 20.17% of the participants disagree with the statement and 21.92% are not sure about it. Rest of the participants 57.91% agreed with the statement. Closing this question, we keep that most of responders see that transportation infrastructure will be ready in 20-30 years to support mixed traffic.

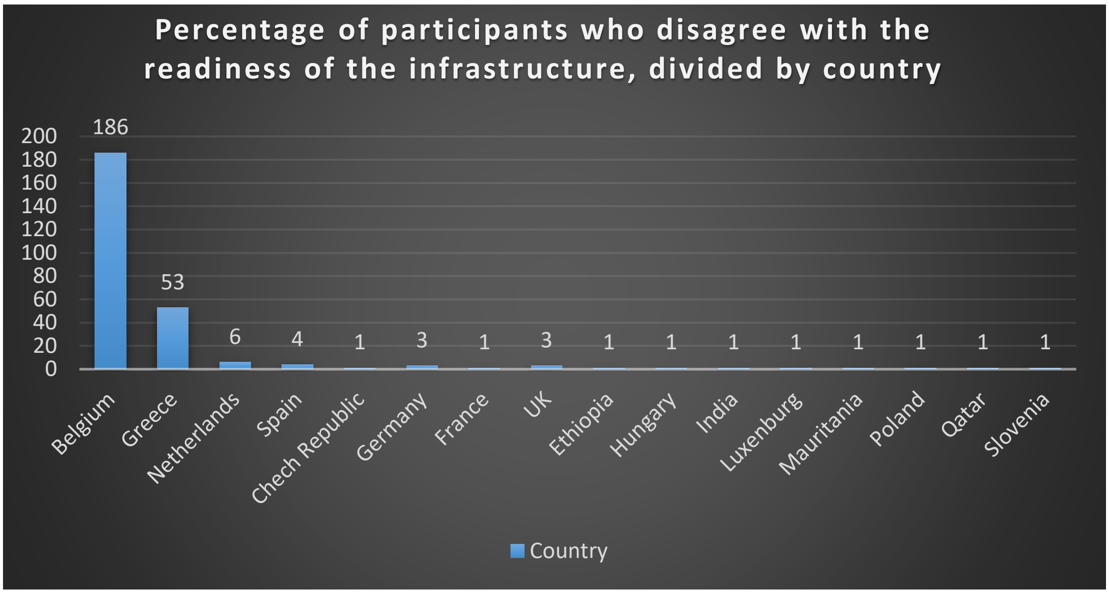


FIGURE 23. Percentage of participants who disagree with the readiness of the infrastructure - Divided by Country (Qualtrics, Own edit, 2021)

It is really important here to analyze the 58.65% of the participants disagreed with the statement *"I believe that transportation infrastructure is ready to support mixed traffic",* according their living country. Most of the responders is from Belgium and Greece and up to a point it makes perfect sense since most of the responders live in these two countries. It is also quite logical because neither in Greece nor in Belgium transportation infrastructure is not ready to support mixed traffic. It is logical also from countries like India or Mauritania people respond negatively to this question. What is not logical is that people from countries like Ghana, Turkey, Uganda, Vietnam, Palestine etc. didn't not disagree with the specific statement. I don't know what the is the level of transportation infrastructure in those countries but for sure it's not ready to support mixed traffic.

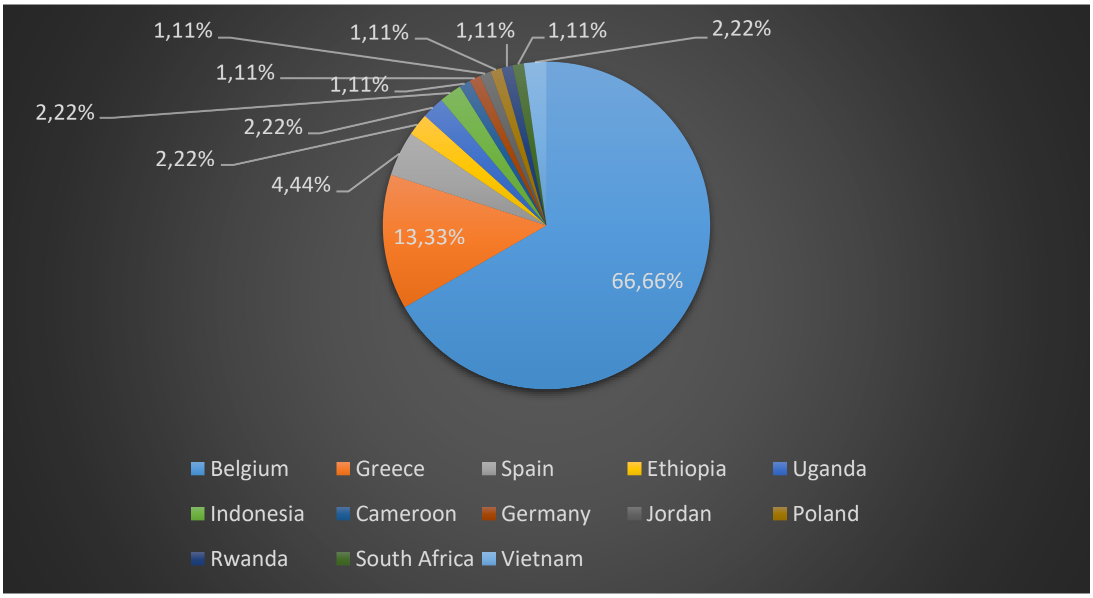


FIGURE 24. Percentage of Participants who agree with the readiness of infrastructure – Divided by Country (Qualtrics, own edit, 2021)

What we see on the figure 24 is also important. 26.6% of the responders agree with the statement *"I believe that transportation infrastructure is ready to support mixed traffic"*. The important here is to see the country of origin of the responders. Most of them can be characterized developing countries, so there is a contradiction in relation to the answer they gave.

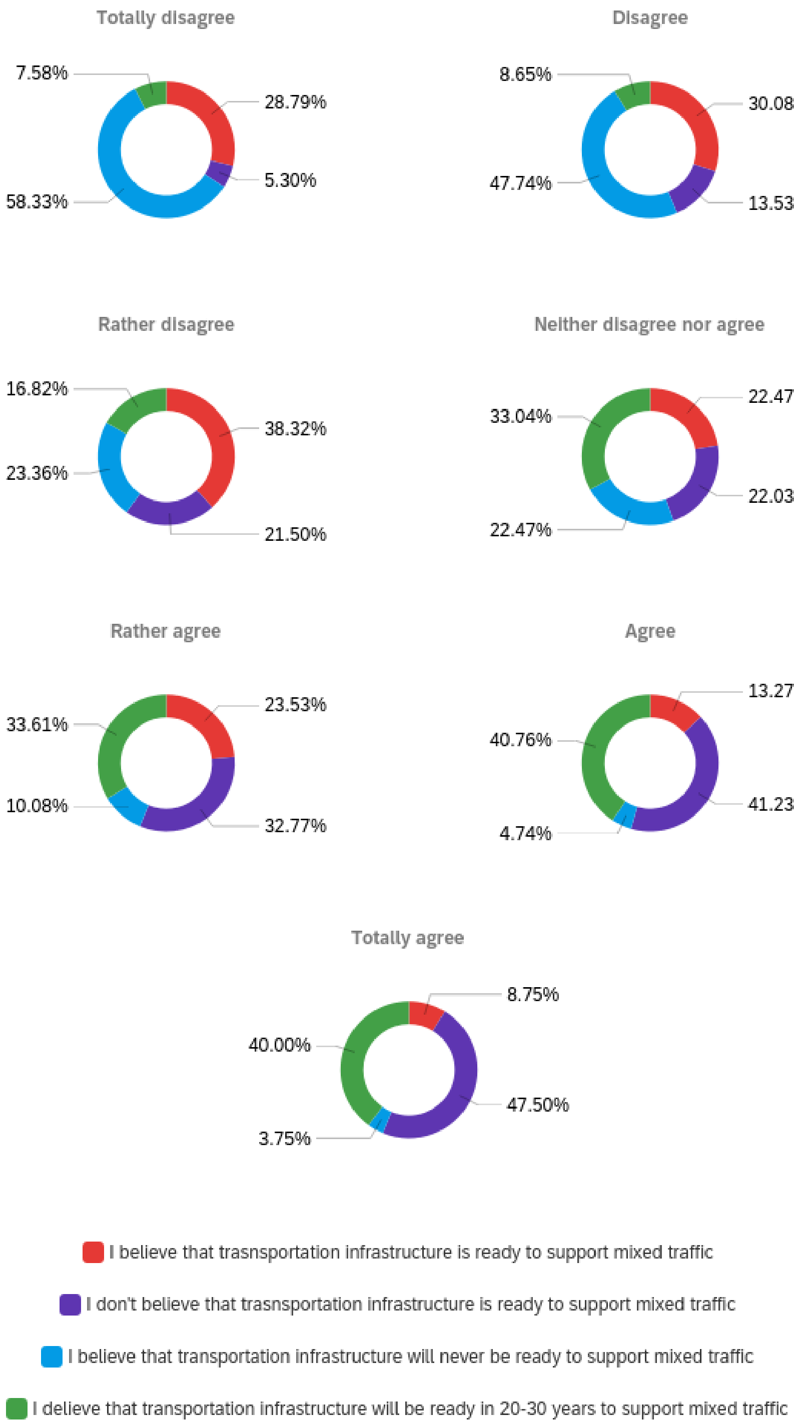


FIGURE 25. Transportation Infrastructure Question (Qualtrics, own edit, 2021)

4.2.6. Autonomous Vehicles and Additional Risks

The specific question tries to analyze all the additional risks that autonomous vehicles can introduce in order to inform participants about them. After that, participants are asked to express their opinion about 4 statements. The full question is *"Although autonomous vehicles are the future of mobility, there are some additional risks these technologies can introduce. Those kinds of risks are hardware and software failures, malicious hacking, platooning risks, increased total vehicle travel etc. To what extent do you agree with the following statements?"*. The 4 statements concern the willingness of the participant to buy an autonomous vehicle and their perspective about the safety of autonomous vehicles and mixed traffic also. Here we have some contradictions regarding the answers. 59.70% of the participants disagree with the statement "I would never buy an autonomous vehicle" and only 20.29% agrees with the statement. The rest of the participants, 20.01%, are not sure if they would ever buy an autonomous vehicle. About the safety of autonomous vehicles, 60.89% of the participants disagreed with the statement *"I would never feel safe inside an autonomous vehicle"* which means that most of them trust autonomous vehicles. Regarding autonomous vehicles safety, almost 64.17% agreed believe that technology can solve the kind of issues that autonomous vehicles can introduce and that is also relevant with the 60.89% of the participants that feel safe inside an autonomous vehicle. The problem here is the mixed traffic. Participants will never feel 100% safe in a mixed traffic environment. So, the problem is not autonomous vehicles but the human factor, because in mixed traffic scenarios will coexist AVs and CAVs. 70.44% of the participants agreed with the statement *"I believe that mixed traffic will never be 100% safe"* since human factor is involved in mixed traffic. From all the above we can conclude that participants are not afraid of autonomous vehicles but humans in case of mixed traffic.

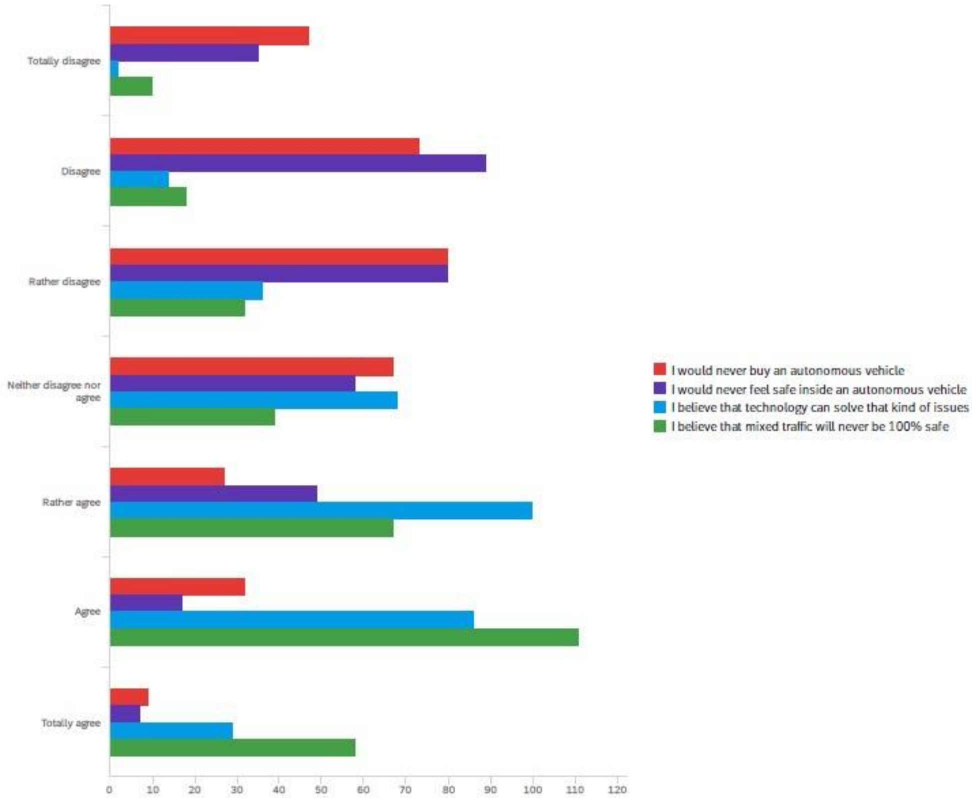


FIGURE 26. Autonomous Vehicles and Additional Risks (Qualtrics, own edit, 2021)

4.2.7. Autonomous Vehicles and Human Drivers

The specific question has to do with the interaction between autonomous and human drivers. For this part, participants must answer between 8 different statements. The full question is *"Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved. Such challenges include the impact of automated systems on drivers' mental* *workload and situation awareness, as well as the human driver's level of acceptance, trust and reliance on the automated systems. To what extent do you agree with the following statements?"*. All statements are irrelevant between them and the perception of responders about human driver and autonomous vehicles interaction is what we are looking for. Almost 89.48% of the participants agreed with the statement *"Automated vehicles have the potential to reduce crashes"* and only 3.00% disagreed. Rest of the participants, 7.52%, are not sure about the above-mentioned statement. Next statement has to do with autonomous vehicle supervision. 88.88% of the participants agreed that human drivers should be allowed to supervise their vehicle. The need of the drivers to supervise their autonomous vehicle indicates a lack of confidence in the vehicle, or even that the driver wants to have the control of their autonomous vehicle. People are still not ready to trust technology. 79.87% of the participants believe that a steering wheel in an autonomous vehicle is necessary. The need for control of the autonomous vehicle is obvious. 63.33% of the participants disagreed with the statement *"In fully automated vehicles drivers can sleep"* and only 24.02% feel safe while sleep and drive. Next statement is also clear according to participants answers. Regarding drunk driving 75.97% of the participants stated that *"In fully automated vehicles drivers can't be drunk or unconscious"*. Since drivers want to have control of the vehicle, they couldn't be unconscious in the car. The remarkable thing here is that 15.01% of the participants, don't mind to being drunk and unconscious in an autonomous vehicle. The need for control of the car is shown also in the next statement, *"In case of a vehicle failure, drivers should be able to take control"*. 88.88% of the participants agreed with the specific statement and only 3.30% believed that this is not necessary and autonomous vehicles can handle the situation. "In case of vehicle failure, the car should directly stop" is the next statement and 57.65% of the participants agreed with that but 27.62% disagreed and have a different opinion. The final statement is the trickiest one. The statement is the following, *"I would send my fully automated vehicle to pick up my kids from school"*. The specific response will test participants' trust in autonomous vehicles. 56.15% of the participants disagreed with the specific statement but the percentage is not as much as expected. On the other hand, 24.92% of the participants would send their autonomous vehicle to pick up their kids from school. 18.93% of the participants are not sure about the specific action.

Regarding all the above answers we can conclude that people trust autonomous vehicles but at the same time they want to have the control in case of an emergency or a malfunction. Also, they definitely believe that autonomous vehicles can reduce crashes.

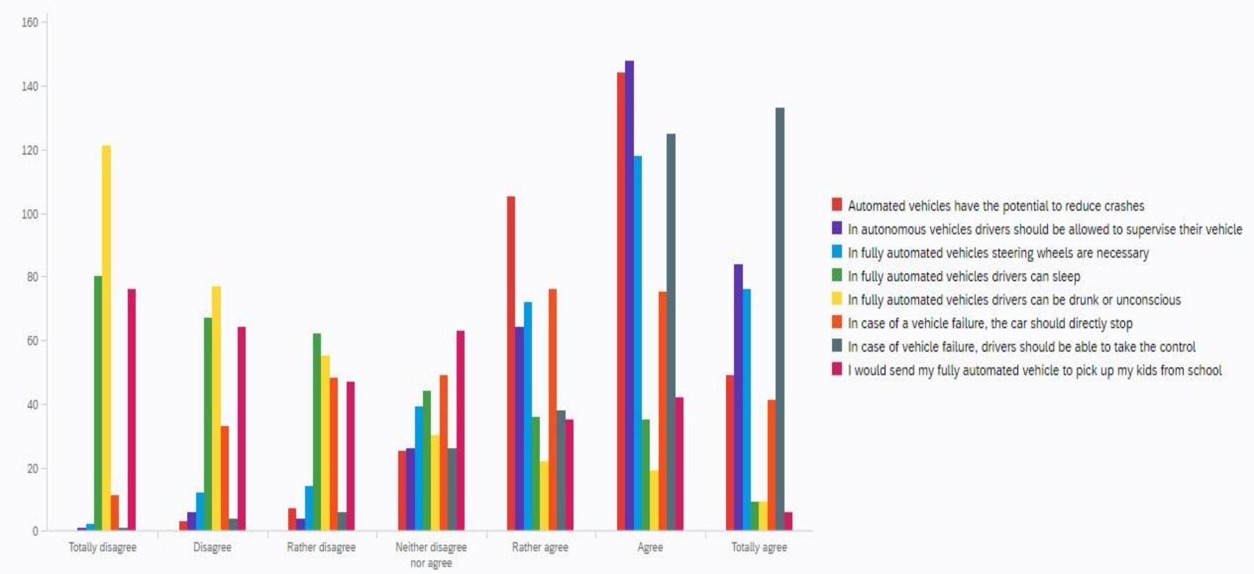


FIGURE 27. Autonomous Vehicles and Human Drivers (Qualtrics, Own edit, 2021)

4.2.8. Levels of Autonomous Driving

The specific question is important and it has to do with the levels of autonomy that participants prefer. It is important to understand the level of autonomy which is more acceptable and at which drivers feel safer. The full question is *"There are five levels of autonomous driving shown below:0: Zero Autonomy - The driver performs all driving tasks 1: Driver Assistance - Vehicle is controlled by the drive r2: Partial Automation - Vehicle has combined automated functions 3: Conditional Automation - Driver is a necessary, but is not required to monitor the environment 4: High Automation - The vehicle is capable of performing all driving functions under certain conditions 5: Full Automation - The vehicle is capable of performing all driving functions According the above, what is the degree of automation you prefer for your private car?".*

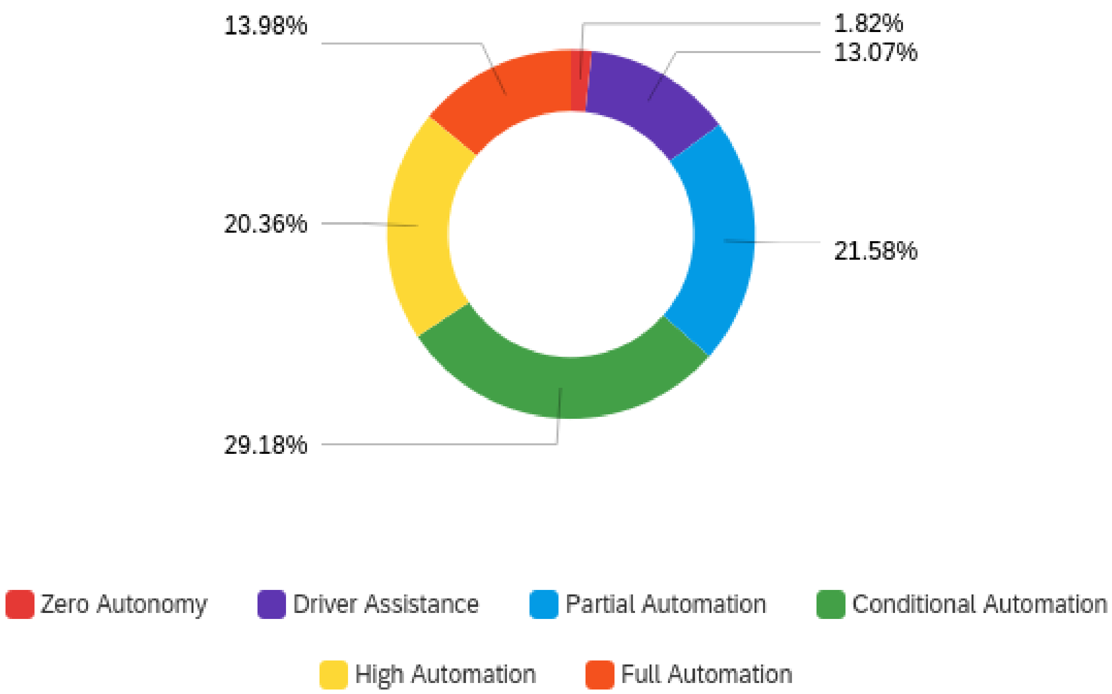


FIGURE 28. Levels of Autonomy Question (Qualtrics, Own edit, 2021)

As we can see in the figure 26 above, only 1.82% prefer a zero-autonomy vehicle, where the driver performs all driving tasks. There is a balance between partial automation 21.58% and high automation 20.36% and between full automation 13.98% and driver assistance 13.07%. Most of the participants, 29.18%, prefer conditional automation for their vehicles. Conditional automation means that a driver is necessary but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice. Most of the participants still don't prefer fully automation for their vehicle (only 13.98% prefer full automation). On the other hand, almost all participants, 98.02% prefer some degree of autonomy for their vehicles since only 1.98% prefer zero autonomy vehicles.

4.2.9. Autonomous Vehicles and Law Enforcement

The specific question has to do with the autonomous vehicles and how they will comply with traffic laws in real traffic situations. The full question is *"Because vehicles with growing degrees of autonomous function are already used on the roads or are promised to arrive soon, law enforcement (LE) needs to consider how to prepare for issues such vehicles will cause or how to contend with actual* *autonomous vehicles (AVs) in traffic. To what extent do you agree with the following statements?"* and also here the responses were interesting. First, almost 75.15% of the participants agreed with the statement *"AVs will comply with all traffic laws"*, which means that participants are convinced about AVs ability to follow the traffic rules. The percentage is even bigger regarding the speed limits. Almost 82.91% agreed with the statement "AVs will strictly comply with speed limits". Probably this is because we are already using that kind of systems now in our vehicles and people trust what is working properly. The same exists for the stop sign part. 83.85% of the participants agreed with the statement *"AVs will come to a complete stop at a stop sign".* Finally, 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. Also, 52.48% of the participants disagreed with the statement *"The law enforcement of automated vehicles will never be completed"*. Whereas, 26.08%, are not sure about law enforcement completion.

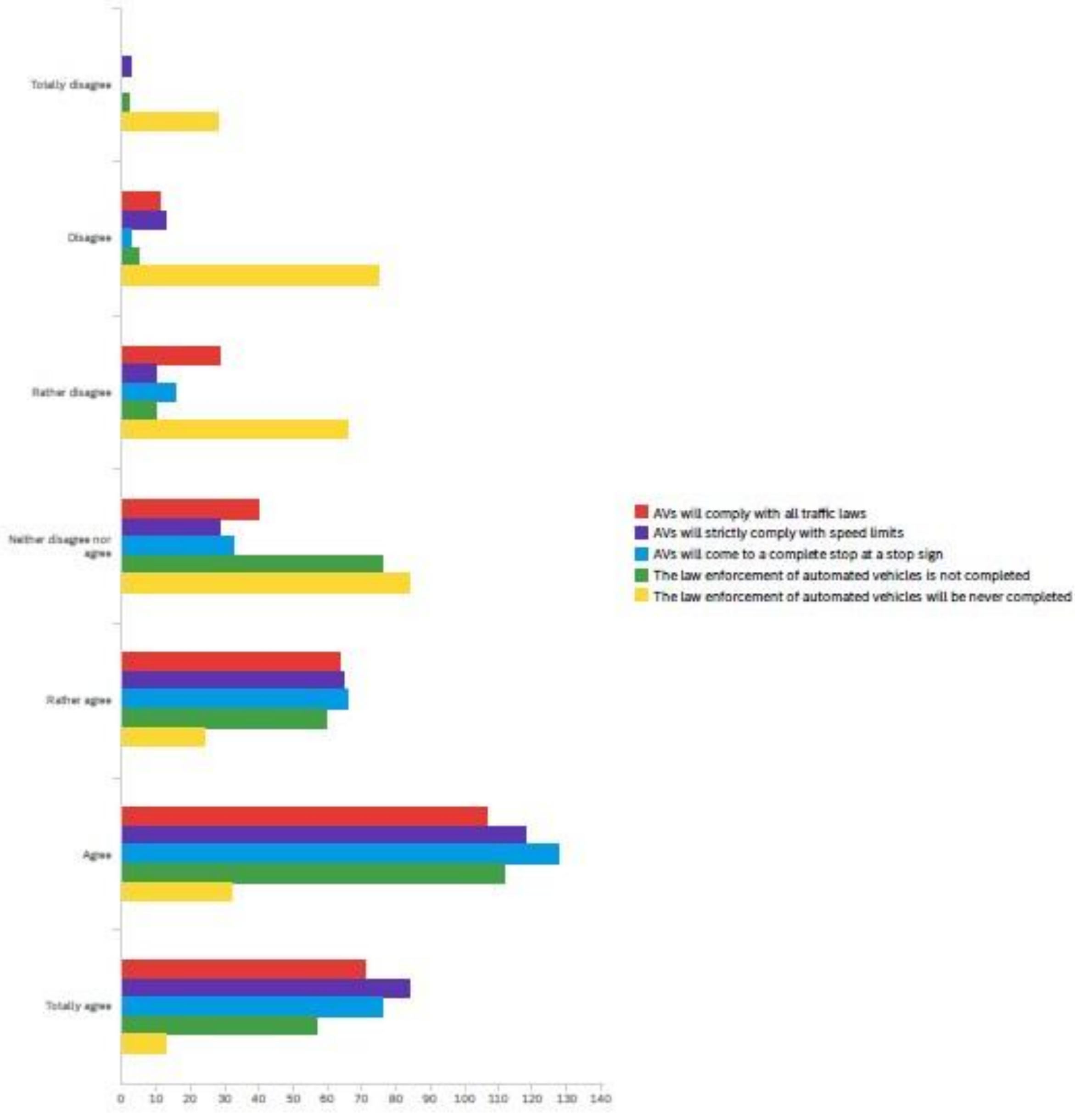


FIGURE 29. Autonomous Vehicles and Law enforcement (Qualtrics, Own edit, 2021)

4.2.10. Autonomous Vehicles and Monitoring

The last question concerns autonomous vehicles monitoring systems and we want to find the point of view of participants about monitoring systems. The full question is *"In future years, drivers are not expected to be responsible for driving and monitoring the surrounding environment in autonomous driving. The AVs will be able to maintain road variables stable (speed limit, safe distances etc.) in terms of traffic safety. But we also need an integrated system that monitors AVs in real time. Traffic centers can undertake the specific job, the monitoring of AVs. To what extent do you agree with the following statements?"*

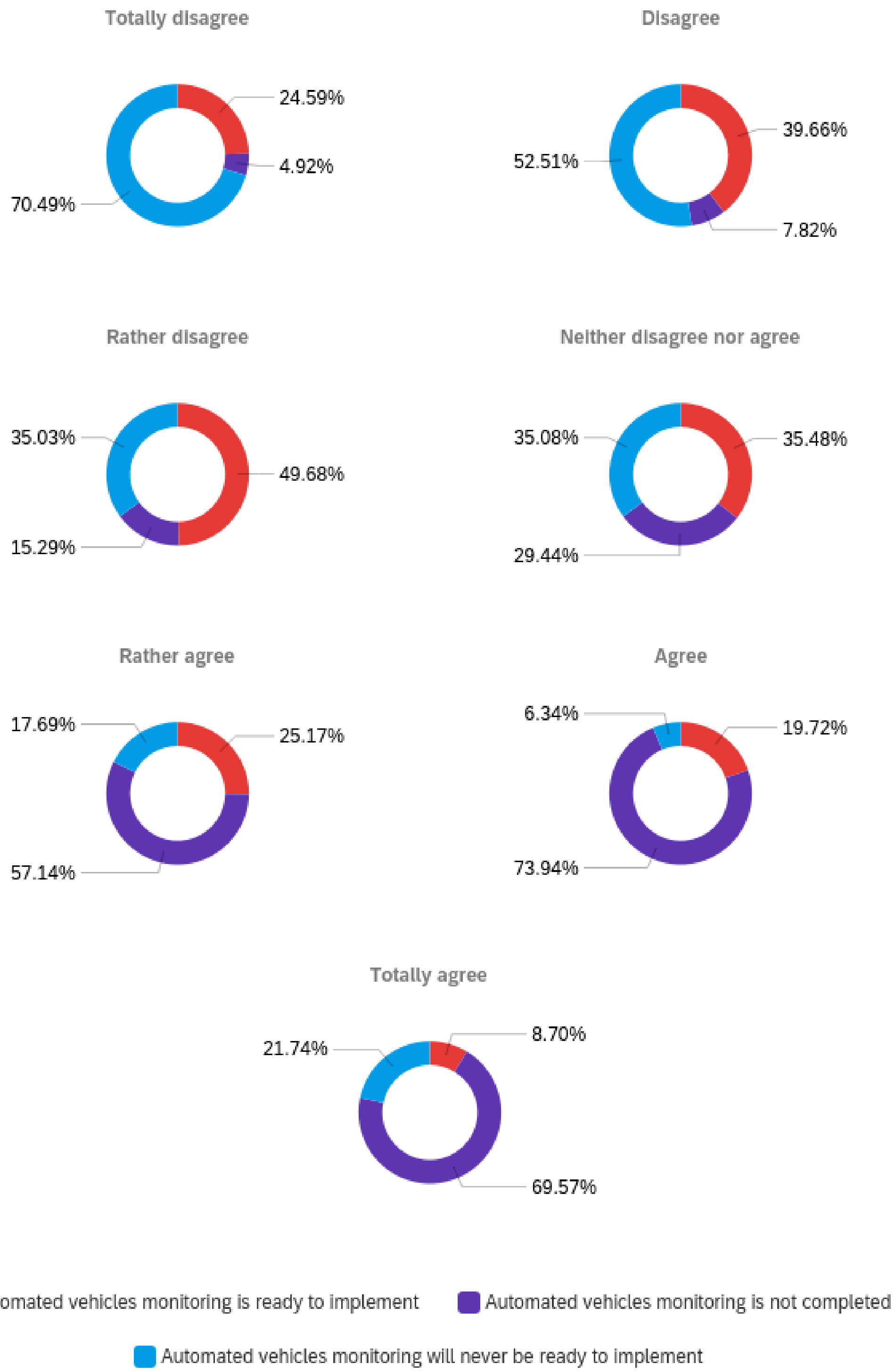


FIGURE 30. Autonomous Vehicles and Monitoring Systems (Qualtrics, Own edit, 2021)

Three available statements for the responders in this part, and useful conclusion have been drawn based on the answers. 51.41% disagreed with the statement *"Automated vehicles monitoring is ready to implement"*. The remarkable thing here is the quite big percentage of uncertainty, which is almost 27.58%. I guess people who are not involved in the autonomous vehicles sector, they don't know how this sector is proceeding. On the other hand, 62.26% of the participants agreed that automated vehicles monitoring is not completed and more steps need to be done on this part. Finally, regarding the statement *"Automated vehicles monitoring will never be ready to implement",* 60.18% disagreed and they believe that at a certain time the monitoring system will be ready and fully functional. The remarkable thing here also is the percentage of uncertainty, which is almost 27.27%. Concluding, we can say that people know that many steps need to be taken in the autonomous vehicle monitoring systems, but are convinced that it will be ready to be applied on the traffic.

5. TAILGATING DATA ANALYSIS AND INTERPRETATION OF THE RESULTS

In order to investigate how big is the tailgating problem and if there is room for improving the specific traffic behavior, a tailgating data analysis should be 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" (between two vehicles moving on the same lane)
- 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 in order to succeed, we have to measure first the velocity at which the first and the second 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:

$$V1 \times T1 - V2 \times T2$$

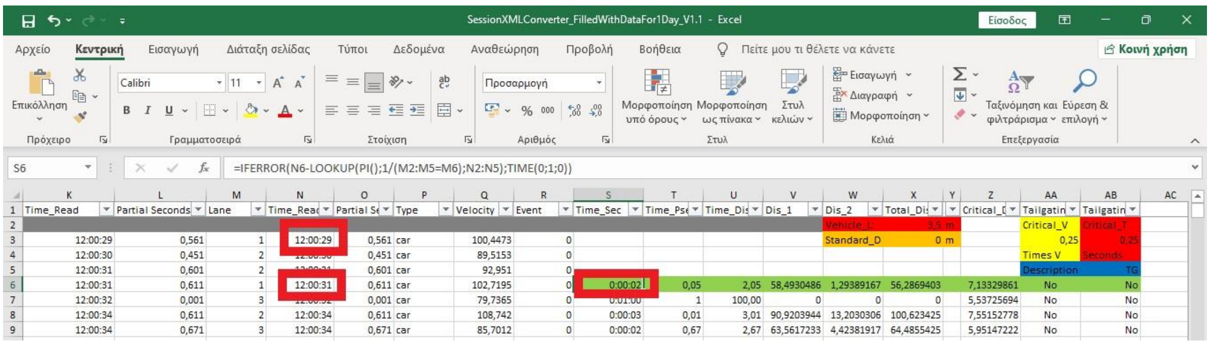
- V1: The velocity of the first vehicle at which it passes through a reference point
- T1: The time that the first vehicle passes through the reference point
- V2: The velocity of the second vehicle at which it passes through a reference point
- T2: The time of the second vehicle passes through the reference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

I will explain all the variables on the excel sheet and then analyze all the outcomes of this sheet. The excel sheet can be found in annex 12.2.

First of all, I have to mention that data includes two types of vehicles: cars and trucks and they have been taken from a road consisted of six lanes.

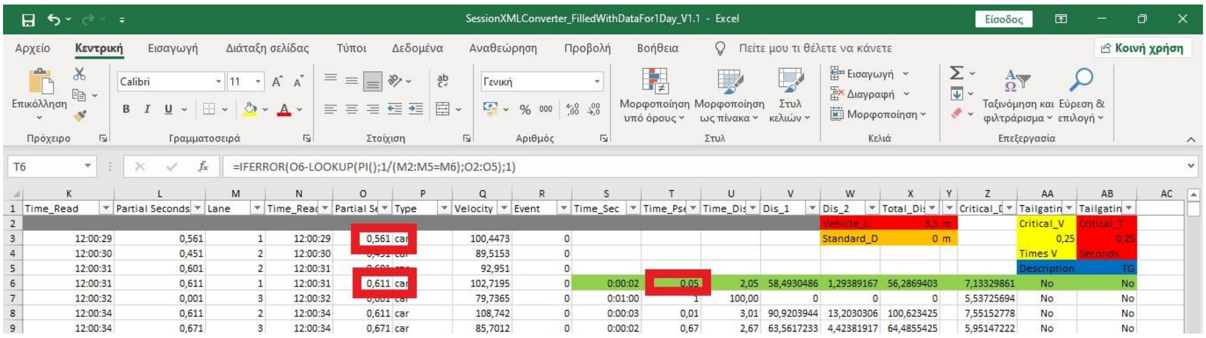
The first important value of the sheet is the velocity of each vehicle, which is measured in km/h. Also, we can see the lane where each vehicle is moving. As I mentioned before, the specific segment of the road consisted of six lanes. After that, we can see the time read value and the partial second, where is the value of time each vehicle passes the reference point. After all these values are declared on the sheet, all calculations are done in order to see what is the critical distance between the vehicles.

Time_Sec: Is the time difference between two cars that move on the same lane. As we can see in the picture below, the first vehicles pass the reference point at 12:00:29 and the second one 12:00:31, so the time difference between the two vehicles is two seconds.



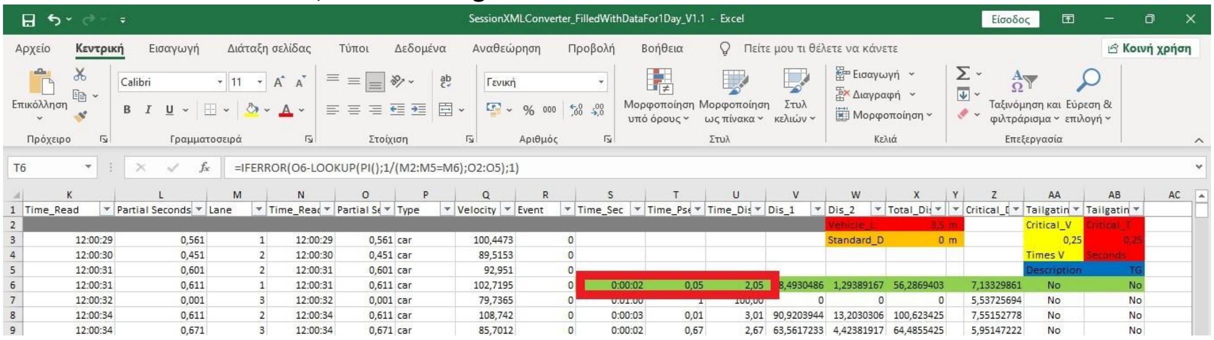
PICTURE 5. Time_Sec Explanation. Source: Excel, Own edit (2021)

Time_Psec: Is the partial second difference between the above-mentioned cars. As we can see below, we need to abstract 0,561 from 0,611 and we get 0,05 seconds.



PICTURE 6. Time_Psec Explanation. Source: Excel, Own edit (2021)

Time_Dis: Is the sum of both time values found above and shows us the total time distance between the above-mentioned cars, were moving at the same lane.

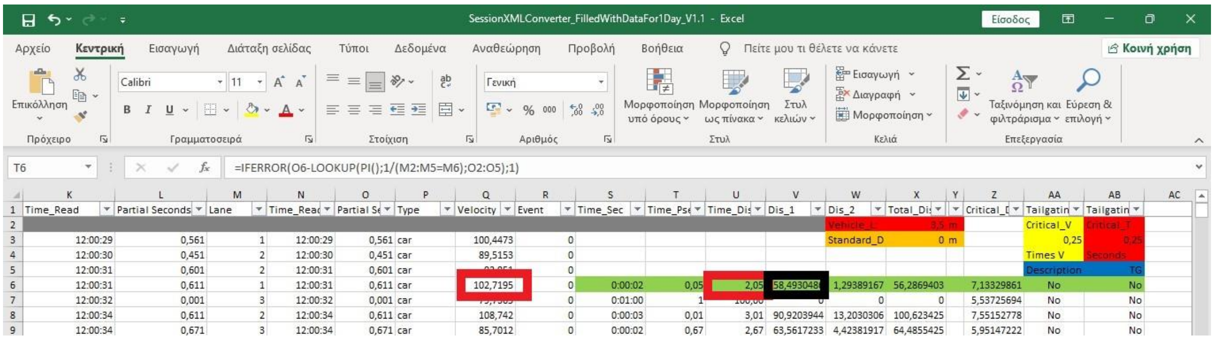


PICTURE 7. Time_Dis Explanation. Source: Excel, Own edit (2021)

Distance_1: In order to calculate the dis_1 value, we have to implement the following formula:

$$Distance\ (m) = \frac{\text{Velocity}\ \left(\frac{\text{km}}{\text{h}}\right) \times \text{Time Distance}\ (sec)}{3{,}6}$$

In our example, the velocity of the second car is 102,7195km/h multiplied by the time distance which is 2,05sec, divided by 3,6. The division by 3,6 is made for the conversion of kilometers per hour into meters.

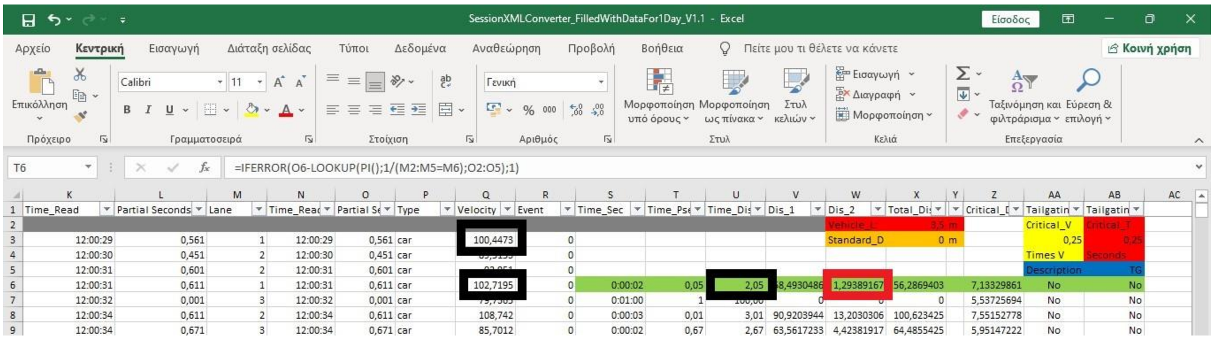


PICTURE 8. Distance_1 Explanation. Source: Excel, Own edit (2021)

Distance_2: To calculate the dis_2 value, we need to implement the following formula:

$$Distance\ (m) = \frac{\text{Velocity2}\ \left(\frac{\text{km}}{\text{h}}\right) - \text{Velocity1}\ \left(\frac{\text{km}}{\text{h}}\right)}{3{,}6} \times Time\ Distance(\text{sec})$$

In our example, we subtract the velocity of the first car which is 100,4473km/h from the velocity of the second car which is 102,7195, divided by 3,6 and multiplied by the time distance.

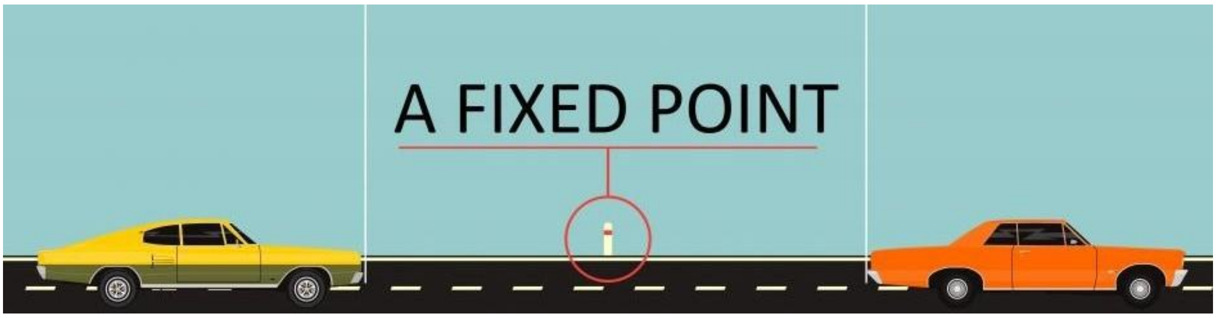


PICTURE 9. Distance_2 Explanation. Source: Excel, Own edit (2021)

Total_Distance: In order to calculate the total_dis value, we have to implement the following formula:

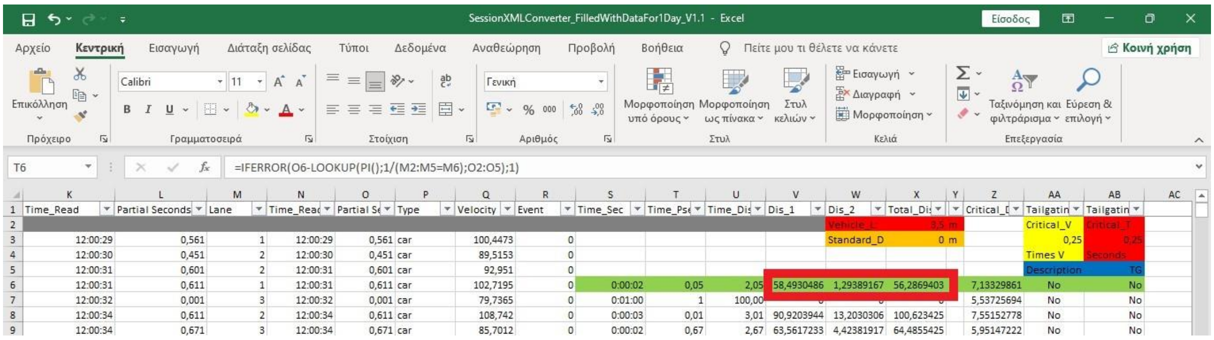
$$Total\ Distance\ (m) = \ Distance1(m) + Distance2(m) - 3{,}5m$$

In the picture below we see a simple explanation of what is the distance 1 and 2. As we see the first car passes the reference point and after a while the second car passes the same reference point. While the second car passes the reference point, we are able to calculate the distance between the two vehicles.



Picture 10. Total distance between two vehicles

In our example, the distance 1 equals 58,49 meters and distance 2 equals 1,29 meters. Subtraction of 3.5 is the length of the vehicle as I mentioned above.

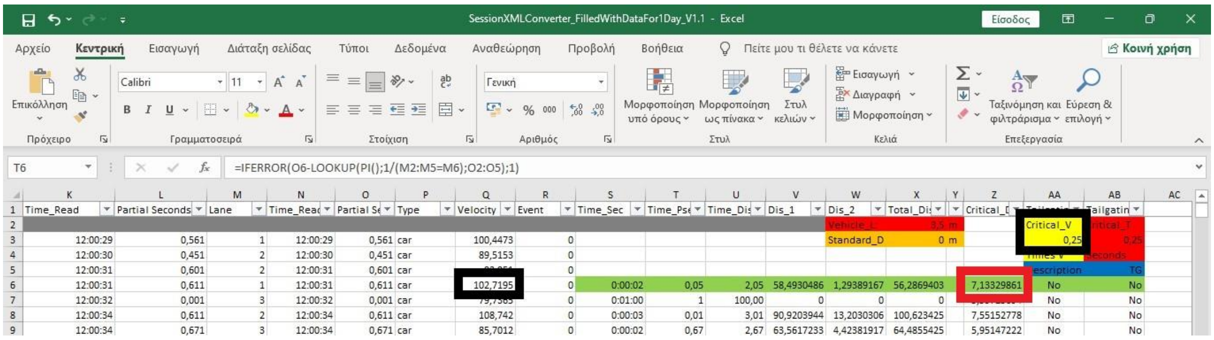


PICTURE 11. Total_Distance Explanation. Source: Excel, Own edit (2021)

Critical_Distance: In order to calculate the critical_dis value, we have to implement the following formula:

$$Critical\ Distance\ (m) = \frac{\mathrm{Velocity2}\ (\frac{\mathrm{km}}{\mathrm{h}})}{3{,}6} \times Critical\ V$$

In our example, the velocity of the second car equals to 102,7195 divided by 3,6 and multiplied with the Critical V (critical velocity) which is a standard value and equals to 0,25.



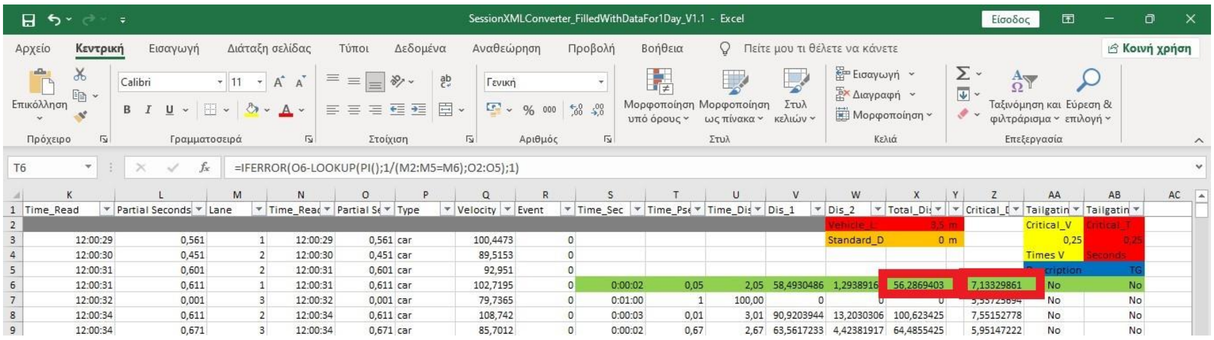
PICTURE 12. Critical_Distance Explanation. Source: Excel, Own edit (2021)

The next step is to check if a tailgating issue is existing regarding all the above findings. In order to see that, we need to make the below checks.

Tailgating Check (A): The first check is done between total and critical distance. Excel checks if the critical distance value is lower than total distance value. In case the below formula exists:

$$Critical\ Distance < \text{Total Distance}$$

Then we have a tailgating issue.

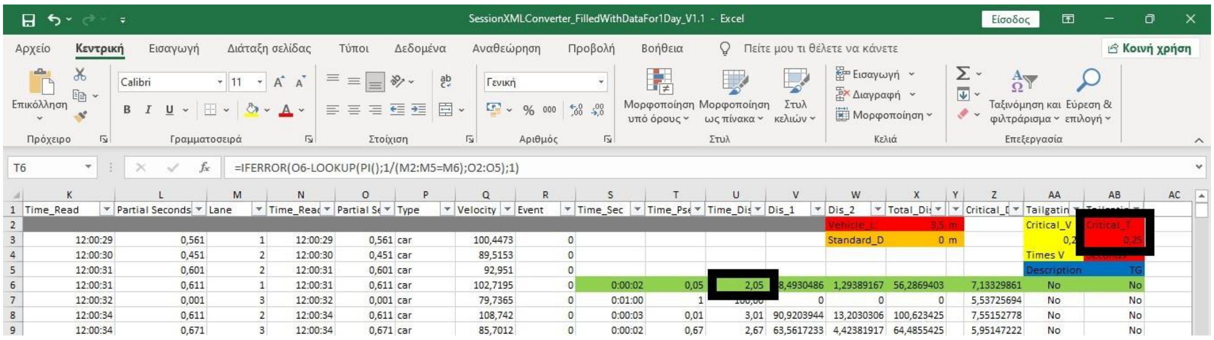


PICTURE 13. Tailgating Checking (A) Explanation. Source: Excel, Own edit (2021)

Tailgating Check (B): The second check has to do with the Critical Value of time. Excel compares the Critical value of time, which in our case equals to 0.25 sec, with the time distance value. In case the below formula exists:

$$Time\ Distance < Critical\ Value\ of\ Time$$

Then we also have a tailgating issue.



PICTURE 14. Tailgating Checking (B) Explanation. Source: Excel, Own edit (2021)

I have to mention here that the critical value can take values from 2 seconds to 0,1 seconds, but in our analysis the value equals 0,25 seconds.

According to Krizek C.G., et al, (2019) research, a table has been created that shows the safe distance between vehicles related to time in seconds and the speed of the vehicles.

speed [km/h]	[m/s]	2.0s	1.5s	1.0s	0.9s	0.8s	0.7s	0.6s	0.5s	0.4s	0.3s	0.2s	0.1s
30	8.33	16.67m	12.50m	8.33m	7.50m	6.67m	5.83m	5.00m	4.17m	3.33m	2.50m	1.67m	0.83m
40	11.11	22.22m	16.67m	11.11m	10.00m	8.89m	7.78m	6.67m	5.56m	4.44m	3.33m	2.22m	1.11m
50	13.89	27.78m	20.83m	13.89m	12.50m	11.11m	9.72m	8.33m	6.94m	5.56m	4.17m	2.78m	1.39m
60	16.67	33.33m	25.00m	16.67m	15.00m	13.33m	11.67m	10.00m	8.33m	6.67m	5.00m	3.33m	1.67m
70	19.44	38.89m	29.17m	19.44m	17.50m	15.56m	13.61m	11.67m	9.72m	7.78m	5.83m	3.89m	1.94m
80	22.22	44.44m	33.33m	22.22m	20.00m	17.78m	15.56m	13.33m	11.11m	8.89m	6.67m	4.44m	2.22m
90	25.00	50.00m	37.50m	25.00m	22.50m	20.00m	17.50m	15.00m	12.05m	10.00m	7.50m	5.00m	2.50m
100	27.78	55.56m	41.67m	27.78m	25.00m	22.22m	19.44m	16.67m	13.89m	11.11m	8.33m	5.56m	2.78m
110	30.56	61.11m	45.83m	30.56m	27.50m	24.44m	21.39m	18.33m	15.28m	12.22m	9.17m	6.11m	3.06m
120	33.33	66.67m	50.00m	33.33m	30.00m	26.67m	23.33m	20.00m	16.67m	13.33m	10.00m	6.67m	3.33m
130	36.11	72.22m	54.17m	36.11m	32.50m	28.89m	25.28m	21.67m	18.06m	14.44m	10.83m	7.22m	3.61m

recommended safety distance	Traffic ticket	working area Tailigator
acceptable safety distance	Minor traffic violation with penalty	
critical safety distance	Revocation of a driver's license	

TABLE 3. Distance (meters) related to time (seconds) and speed (kilometers per hours). Source: (Krizek C.G., et al, 2019)

For example, a vehicle that moves at 100 km/h, in case that the critical value of time is 0,25 seconds, as it is in our research data, then the critical distance is between 8,33m and 5,56 meters. According to the specific table we can calculate the critical distance between two cars, since we know their speed and since the critical value of time is known.

5.1. Data analysis

Although in our data, there is no evidence for tailgating issues, what has impressed me is the time distance between some of the vehicles. Let's analyze all the available data. First of all, the number of vehicles that have passed the specific reference point is 88.662 divided into six lanes. Observing the speed of vehicles, we can definitely assume that lane one (1) is the fastest lane and lane (6) six is the slowest one. Concerning the type of the vehicles, in a total of 88.662 vehicles, 87.223 are cars and 1.439 are trucks. In the figure 29 below, we can see the separation of the vehicles.

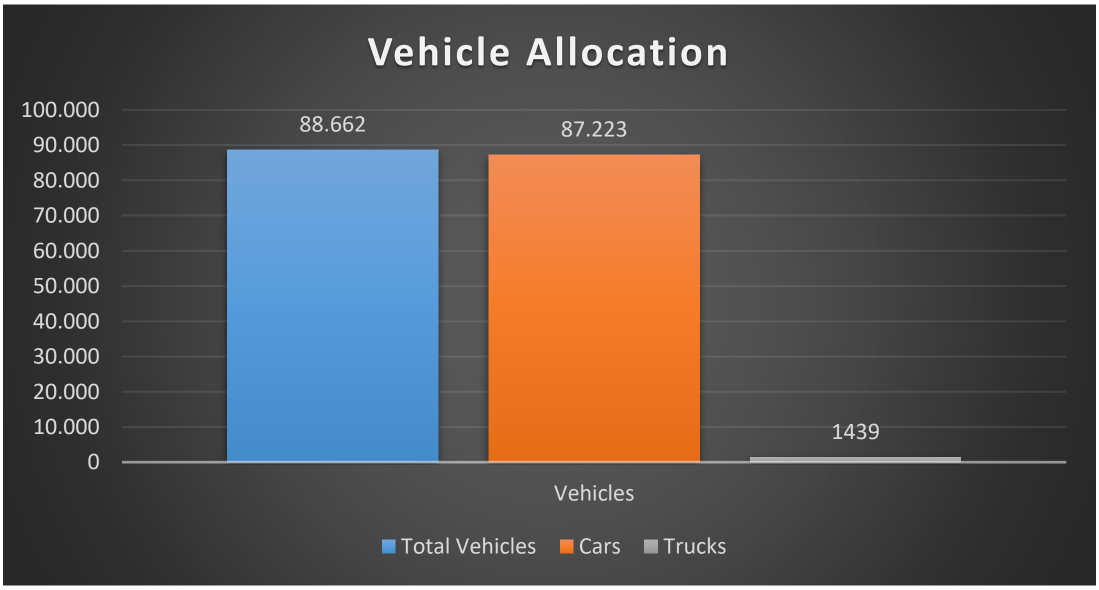


FIGURE 31. Vehicles Allocation

As I mentioned above, I will focus on time distance between vehicles and especially where this distance is quite low (until one second), even if this time is quite bigger than the critical value, which is 0,25 seconds. The number of vehicles moving at a distance of up to one second from each other is 13.586. 15,3% of the total vehicles move very close to each other. I have to mention here that the range of velocity of the above-mentioned vehicles are between 38 to 120 km/h.

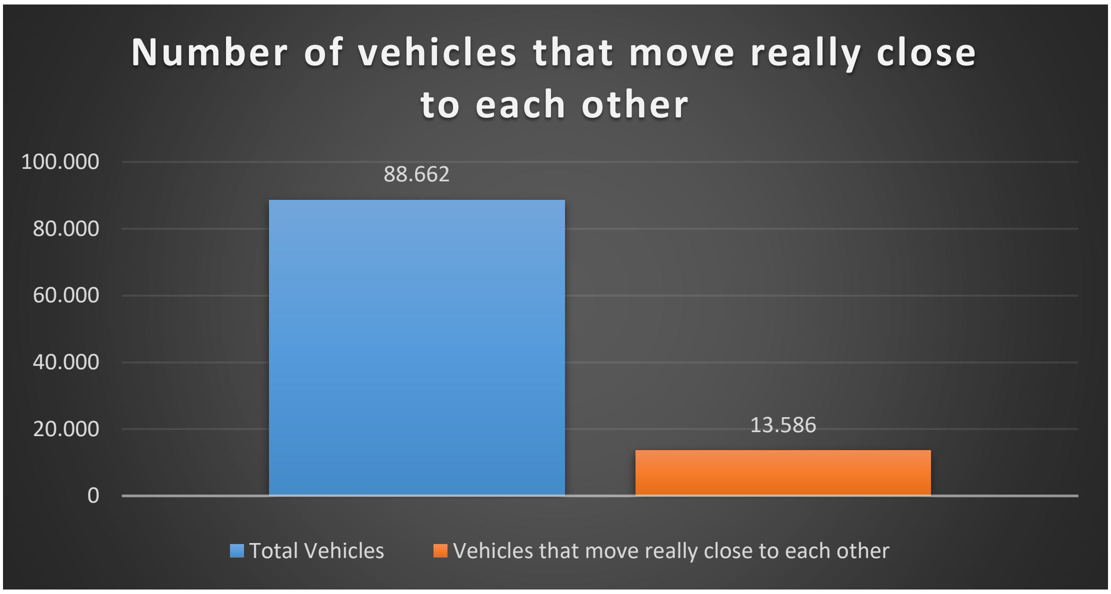


FIGURE 32. Number of Vehicles that Move Really close to Each Other

Concerning the type of the vehicles, in a total of 13.586 vehicles that move really close to each other, 13.568 are cars and only 18 trucks are trucks. What does that mean? This means that truck drivers drive more carefully than car drivers and keep safe distances between predecessor vehicles. In the figure 31 below, we see how the velocity varies between vehicles.

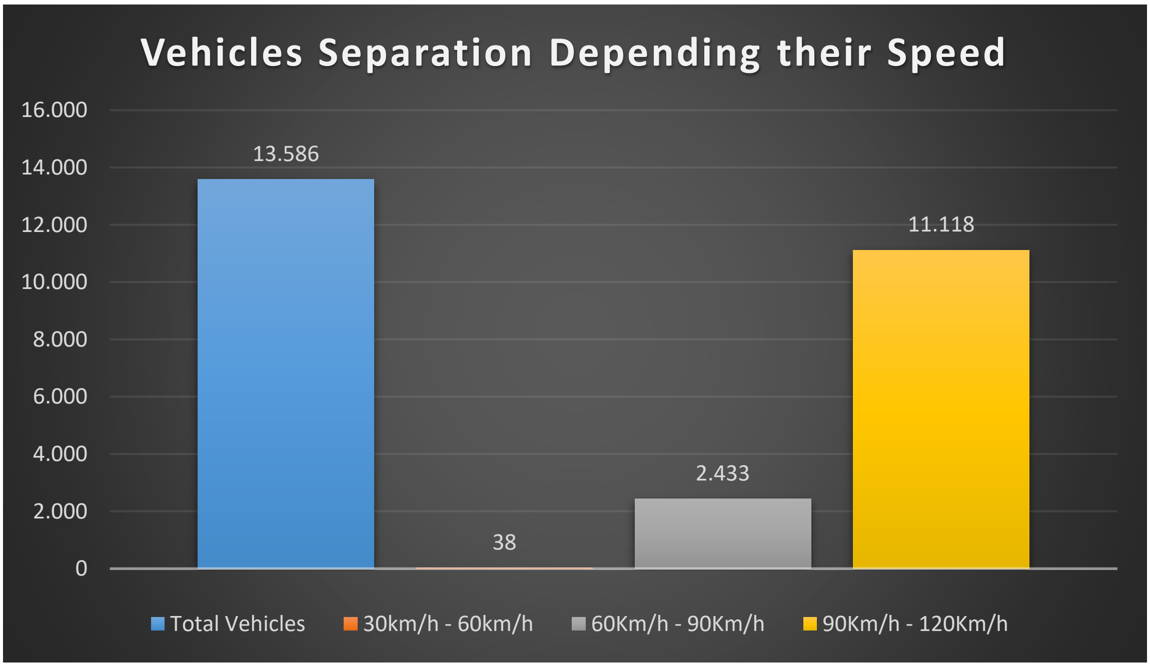


FIGURE 33. Vehicle Separation Depending Its Speed

From the specific figure a lot of useful conclusions can be drawn. From a total of 13.586 vehicles only 0,2% (38 vehicles) move at a speed between 30 to 60km/h. 2.433 vehicles, which means 17,9% moves at a speed between 60 to 90km/h and the majority of the vehicles, 11.118 (81,8%) move at a speed between 90 to 120km/h. The most frightening thing is the time distance of all the above-mentioned vehicles is less or equal to just one second. It is almost impossible for a driver that moves at a speed of 120km/h to reduce the speed of its car in order to avoid any upcoming crash.

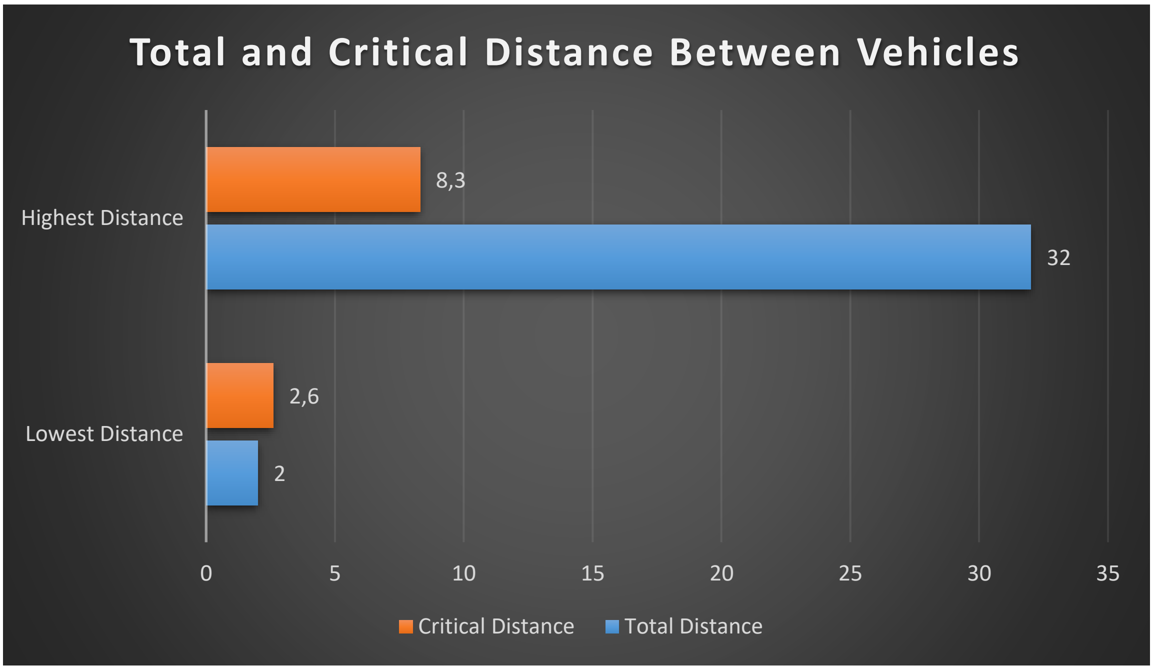


FIGURE 34. Difference between Total and Critical Distance

Figure 32 is also important to understand the quite small distances between the vehicles. Looking at the figure above we can compare the differences between total and critical distances at the lowest and the highest values. The difference between the lowest values is really small and tends to become zero. About the highest values, although we see there is a bigger difference between values, we can surely state that 24 meters for a car that moves at a speed of 120 km/h is not enough space for its safe immobilization. Looking at the UK Gov page, I found a very interesting page that shows the typical stopping distances at different speeds of a car.

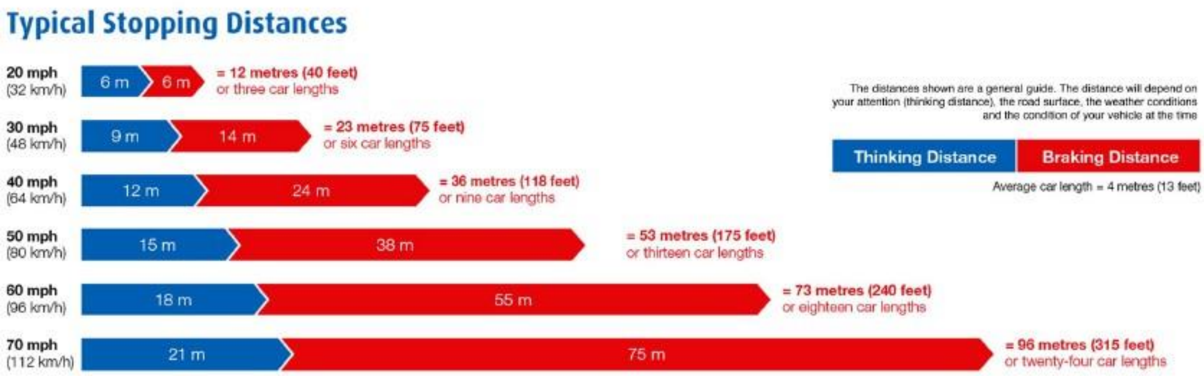


FIGURE 35. Typical Stopping Distances. Source: (Gov.UK,2020)

As we can clearly see a car that moves at a speed of 112km/h and not at a speed of 120km/h, needs 96 meters to stop. In our research, where each car equals to 3,5 meters, the specific distance equals to twenty-seven cars. Based on all the above, we can say with certainty that none of the aforementioned distances, are not safe, since the speed of the cars is quite big.

In the next figure we can see how the vehicles are distributed between the lanes.

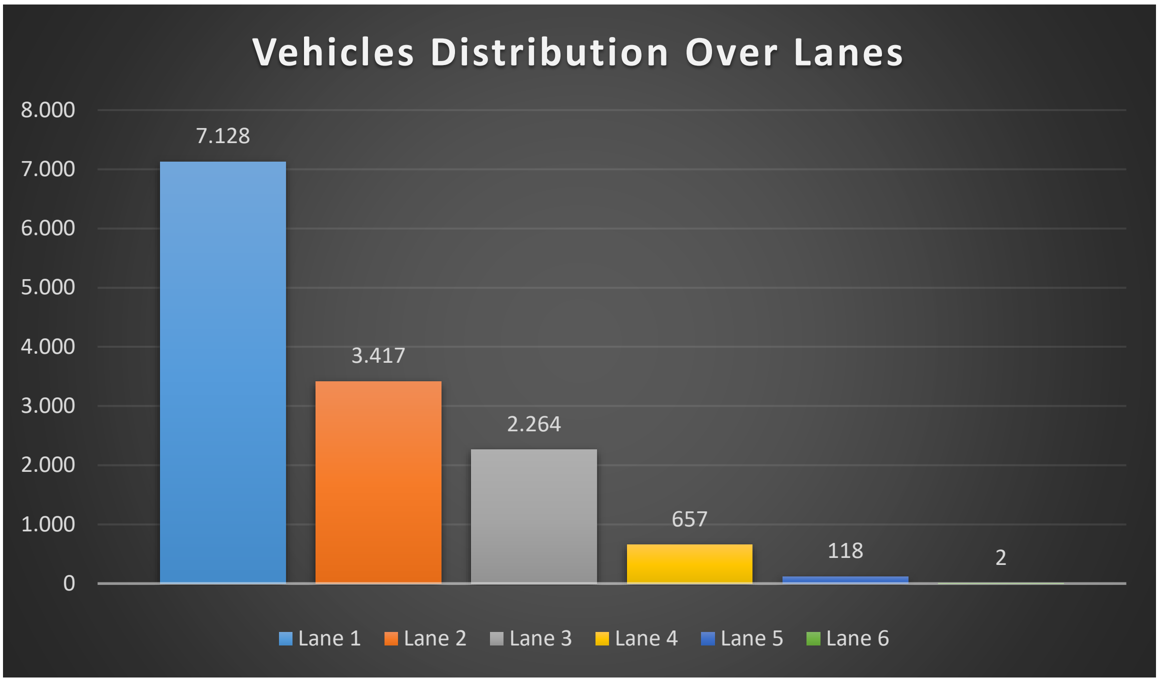


FIGURE 36. Vehicles Distribution Over Lanes

As we can see from the figure 34, 7.128 vehicles, which is equal to 52% of the total vehicles, shows this behavior in the fast lane. 3.417 vehicles which is equal to 25% of the total vehicles, move in the second lane and 2.264 vehicles, which is equal to 16% of the total vehicles, move in the third lane. The rest of the traffic, which is equal to 777 vehicles and 7% of the total vehicles, is distributed in the other three lanes. The figure above is quite logical, since the majority of the cars move at a speed 90 to 120 km/h and occupy the fast lane.

Finally, according the typical stopping distance figure I have to emphasize in the following figure 35.

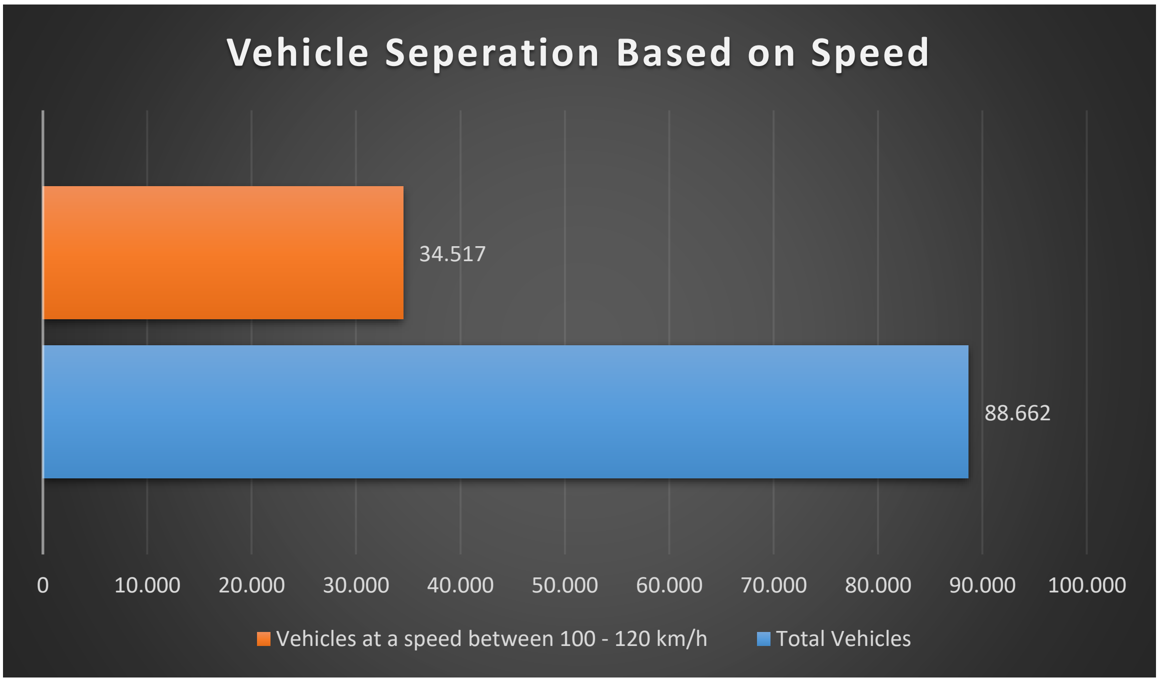


FIGURE 37. Vehicle Separation Based on speed

As we can see from the figure 35, from a total of 88.662 vehicles, 34.517 vehicles which is equal to 39%, a huge number, moves at a speed between 100 to 120 km/h. From a total of 34.517 vehicles, 17.675 vehicles which is equal to 51% keep distances between 4 to 100 meters, and that shows an unsafe driving behavior. 51% of those who move at a very big speed, don't keep safe distances and the possibility of an accident becomes even higher.

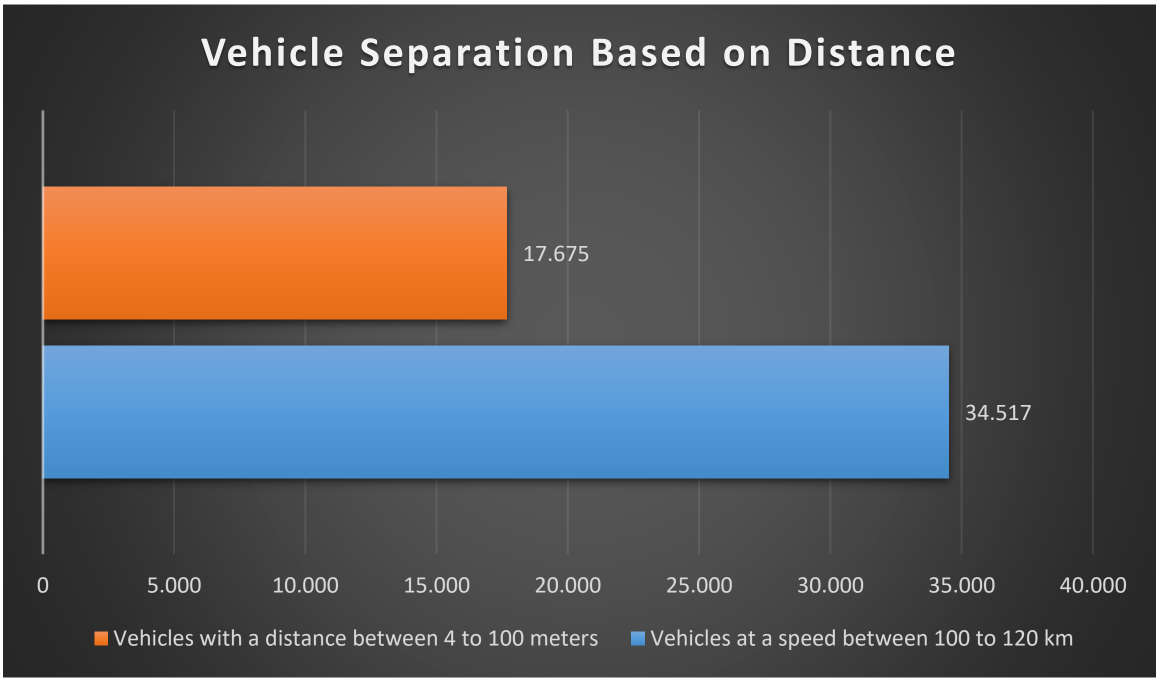


FIGURE 38. Vehicle Separation Based on Distance

5.2. Data Analysis Conclusion

This data analysis examined the tailgating behavior in Abu Dhabi and tried to identify how big the tailgating behavior is. From a total of 88.662 cars, I chose to work only with those that their time distance equals to 1 second at the most. Through the vehicle headway analysis, non-serious tailgating situations were observed, according to the data, but critical conclusions were drawn from this analysis. Tailgating behavior was classified by lane and the analysis showed that the specific behavior was worse in the lanes with high traffic volumes. Less tailgating behavior was observed in the slowest lanes where the speed is reduced. We also compared the highest and the lowest distance differences between critical and total distance between cars. In most of our cases the total distance between cars was less than 10 meters, and if a vehicle moves at a speed of 120km/h 10 meters are not enough space for a vehicle to come to a complete stop. As we saw above, when a vehicle moves at a speed of 112 km/h, the driver needs 21 meters just to think what he/ she wants to do, for example to hit the brake, and 75 meters needs to come the vehicle to a complete stop. So, the majority of the vehicles are in a real danger.

Tailgating is a very dangerous driver's behavior that affects the traffic safety and increases the probability for an accident. From all the above we can conclude that the tailgating monitoring system is not efficient and a number of countermeasures should be taken in order to mitigate the problem.

According to research from the University of Adelaide in Australia (Hutchinson TP., 2008), it is possible that advisory signs at the roadside might persuade drivers to leave longer gaps, and that markings on the road might help them judge what is an appropriate length of gap. Tailgating is largely a voluntary behavior, and it is natural to direct countermeasures at the driver rather than the vehicle or the road. Furthermore, the possibility of increased enforcement, with the aid of technology, of traffic laws requiring drivers to keep a safe distance, with a quite big gap possibly defining what is safe. Some of the countermeasures can be shown below.

Advisory Signs: Signs warning of short headways have been used for some decades. Also, the installation of automatic warning signs can be used in order to investigate their effectiveness.
Dots or chevrons on the road surface: Regularly-spaced markings (dots or chevrons have been used) can help drivers judge the distance between the vehicle ahead and themselves. Suppose the dots are 25 meters apart and a driver maintains a headway such that two dots are in sight at all times.
Enforcement: Increased police officers on the streets, enforcing traffic using high tech equipment for tailgating behaviors detection.
Stricter laws and fines: In case of a driver moving at a high speed and the gap from the headway vehicle is quite small, then a fine ticket or a revocation of a driver's license should be addressed to the driver.
Advanced warning systems on vehicles: Advanced systems implemented on cars, such as adaptive cruise control and advanced collision warning systems can help the driver to keep safe distances and drive more safely. Autonomous vehicles are able to mitigate problems such as tailgating since the human factor will be almost extinct.

6. LIMITATIONS

Regarding this study, I must highlight the two limitations of my study. The first one is the people's participation in my survey. From the beginning of my research, I knew that the survey's participants will be only students and some of my colleagues, so participation is limited. As we know in research, the greater the participation in it the better its results. The survey was mainly distributed using an email that was sent to all students at Hasselt University and to all of my colleagues. Also, the survey was distributed using social media, and especially LinkedIn, where most of my connections are relevant to the transportation sector. Although the survey was sent to a quite big number of potential responders, I am not sure if autonomous and connected mobility concept is available in the above-mentioned areas. For example, in Greece there is no experience with connected mobility and this necessarily leads you to a potentially less favorable set of participants. Also, since most of the participants are students, their experience in such systems is limited if not zero. The results could thus be different if a larger part of the respondents would have a more elaborate experience. Another important factor is the living area and the living country of the responders. 61.42% of the participants live in suburban and rural areas and that means that access to connected and autonomous mobility is limited. Also, in this survey participants are from 27 different countries where the situation in terms of connected mobility is different. But let's take as an example the city of Hasselt, since most of the participants (326 people) live in the city. As far as I know, the autonomous mobility concept is not available in the city, so knowledge on the specific topic is limited.
The second limitation is the limited available data for analysis. For my own analysis, I had at my disposal data for only one day so the analysis may not be so representative of reality. In each case, many useful conclusions can be drawn. Furthermore, the objective of this research is to highlight the smart dynamic traffic monitoring and enforcement system for connected and intelligent mobility and describe the future and the limitations of that system. It is really important here to mention that the specific data was from Abu Dhabi where drivers' behavior is totally different compared to Greek or Belgian drivers. Also, I did not know the speed limit of the specific road from which the data came, and the percentage of the AVs vehicles, if any, relative to conventional vehicles. It would be better to have data from all countries participants participated on the survey. This would help us to have a clearer image about tailgating behavior and maybe we could do a comparison between the survey results and tailgating results.

7. CONCLUSION

This research tries to find an answer to the main research question "What systems (onboard and outboard of the smart vehicle) must be used concerning monitoring and enforcement of intelligent mobility, in order to mitigate problems like traffic accidents due to tailgating?". In order to answer this main research question, a number of sub-questions need to be answered, that were formulated in the first part of the thesis. To evaluate the above-mentioned sub-questions, three strategies have been used.

The first strategy has to do with the conducting of literature review. The literature review part moved around the main axes which are, the history of autonomous vehicles, safety and security of autonomous vehicles, serious problems such as tailgating, crashes etc. of autonomous vehicles and solutions for mitigating these problems, human factor, traffic monitoring and enforcement systems and traffic centers, in order to have a clearer picture about the current situation in different aspects of autonomous and connected mobility.

The second strategy has to do with the conducting of a survey. The main axis of the survey is to investigate the human factor, since human factor is a really important factor on traffic safety chain and especially in mixed traffic environment. It is important to know how the drivers, in case of mixed traffic, can coexist safely with autonomous vehicles in order to increase traffic safety and avoid tailgating accidents. This survey targeted a variety of categories of drivers including young novice and older experienced drivers. Also, it is crucial to know what people think about security and safety of autonomous and connected mobility.

For the third strategy a tailgating analysis performed using excel, in order to figure out how big the tailgating problem is.

The first sub-question *"How can we evaluate the efficiency of existing tailgating systems, based on available data? Is there room for improvement?"* tries to investigate the efficiency of the existing tailgating system and what can be done in order to improve the existing system. According to the literature review part, serious tailgating issues have been identified and there is a need for countermeasures taken to mitigate the problem. The use of advisory signing is a must in order drivers keep safe distances to avoid rear-end crashes. Also, drivers' behavior should also be changed and aggressive driving should be avoided. Nevertheless, other measures must be taken to further reduce the above-mentioned problems such as driver training, road safety seminars, awareness of driving risks, stricter laws etc. Regarding the analysis part, we can conclude that the tailgating monitoring system is not efficient and a number of countermeasures should be taken in order to mitigate the problem.

According to research from the University of Adelaide in Australia (Hutchinson TP., 2008), it is possible that advisory signs at the roadside might persuade drivers to leave longer gaps, and that markings on the road might help them judge what is an appropriate length of gap. Tailgating is largely a voluntary behavior, and it is natural to direct countermeasures at the driver rather than the vehicle or the road. Furthermore, the possibility of increased enforcement, with the aid of technology, of traffic laws requiring drivers to keep a safe distance, with a quite big gap possibly defining what is safe. Finally, I have to mention the use of a driving simulator can reduce tailgating behavior according to Song M., Wang H. J. research. In conclusion, we can say that the existing tailgating system has several gaps and a number of countermeasures need to be implemented in order to mitigate this dangerous behavior.

The second sub-question "*How can the human factor(drivers) influence autonomous and connected mobility?* tries to investigate the human factor. Human factor plays the most crucial role on autonomous vehicles issues such as crashes etc. According to unpublished data of Aegean Motorway, 90% of accidents or more are due to the following reasons:

- Speeding
- Driving under influence of substances
- Fatigue
- Inattention (texting or speaking on phone)

All the above-mentioned reasons, makes human factor the most crucial aspect of the mobility chain. According to Cunningham M., Regan A. M., 2015 a range of human factors challenges that will need to be addressed during the transition from fully manual to fully automated driving. Autonomous vehicle technology is not yet completely safe and reliable, therefore necessitating driver input when autonomous systems fail or have limited performance capabilities. Shifting the driving mode from human's manual control to automated driving with human's primary responsibility may lead to problems of inattention, reduced situational awareness and manual skill degradation. In turn, these human factors may compromise the safety of manual control in cases where autonomous systems fail. Regarding survey results we conducted the below main conclusions:

- People have heard about CAM, but their knowledge is limited
- Most of the people are not sure if they have ever been involved in mixed traffic environment and this affects their driving behavior
- More than half of the responders believe that autonomous vehicles are safe to drive
- Most of the responders believe that autonomous vehicles will reduce tailgating and traffic issues
- Most of the responders believe that transportation infrastructure will be ready to support mixed traffic
- Most of the responders will feel safe inside an autonomous vehicle and technology can solve any risk that the specific technology can introduce
- Despite all the above positives about autonomous vehicles, only 25% will send an autonomous vehicle to pick up their kids from school
- Despite all the above positives about autonomous vehicles, most of the respondents prefer a conditional automation vehicle and not a fully automation vehicle
- Most of the respondents believe that autonomous vehicles will comply with all traffic laws
- Most of the respondents believe that autonomous vehicles monitoring is not ready to implement.

From all the above we can conclude that people are willing to follow the technological revolution but they fear the unknown, because they don't know what to expect. According to Carleton R. N., 2016, *"The oldest and strongest emotion of mankind is fear, and the oldest and strongest kind of fear is fear of the unknown".* The fear of the unknown is a negative factor that affects the willingness of people to trust autonomous vehicles.

The third sub-question "*How systems for monitoring and enforcing mixed traffic can be made more effective?*" tries to investigate the efficiency of the existing monitoring and enforcement system. What kind of systems will allow us to efficiently monitor and enforce mixed traffic? Since the human factor and autonomous vehicles are involved, the monitoring and enforcement of traffic becomes a challenge. According to the literature review part, we have to focus on two different factors, systems and human behavior.

ITS play a key role in monitoring and enforcement of mobility, and they will also play a key role in monitoring and enforcement of autonomous driving and connected mobility. There are a lot of systems such as VMS, LCS, VSLS but also some strategies like STIMF that tries to monitor autonomous mobility. Different systems are responsible to inform drivers about the road condition, weather condition, detours etc. Information is the most important thing for a driver because it keeps the motorists informed about the possible events, accidents or road conditions and identifies the shortest route for its destination. In terms of autonomous vehicles, the same principle exists. The car needs to be updated through the various systems in order to take the shortest route or to keep the appropriate speed etc. in order to keep the drive safe.
Also, according to Farrag G. S. et. al. making the right decision at the right time has been a major problem in traffic incident management because human operators need to analyze a lot of information and make critical decisions very quickly. When an incident occurs, it creates a non-recurrent congestion. Because of this, applying the wrong response strategy may have a big impact on the safety of the road users as well as the network performance. STIMF is a smart traffic incident management framework that assists operators of traffic control centers in choosing the best strategies to address traffic incidents on highways. STIMF is based on a microsimulation of the network that allows different response strategies to be evaluated according to specific criteria given a certain traffic situation.
Reading the above, we can see the efforts that have been made until now to solve the major problem called monitoring and enforcement of autonomous mobility. There is still room for improvement but so far, several steps have been taken.
The last sub-question "*Is it possible to enforce, control and monitor autonomous and connected mobility by a traffic control center?*" It has to do with traffic control centers and how they can help us to monitor and control autonomous and connected mobility. They are the most important element for monitoring traffic on motorways or on rural roads. The traffic center is the heart of the system. All information gathered from various sensors is processed from operators in order to make the right choice. For example, in case of an accident the creation of a safe detour is a must. Traffic centers will also play a crucial role for monitoring autonomous mobility. Traffic control centers is not something new, but people are not familiar with all that information. According to unpublished data of Aegean motorway, most of the people that call in case of emergency on the motorway management centre, they don't even know what control center offers to the users.
We also saw AVTCT, where one human operator can manage multiple AVs, and the specific technology can be applied on the road traffic control centers. A lot of solutions appear from time to time, and people try to find the best solution for their problem. Monitoring of autonomous vehicles is a problem that tries to find the best solution. According to the literature review, we are close to implementing the best solution but a lot of work is still needed.
The answer to the main research question of this master thesis is a cumulation of the above-mentioned answers. Reading all the above we can conclude that autonomous driving and connected mobility depends on a lot of parameters. Human behavior, infrastructure, technology, CAVs and AVs, perception of people, fears and expectations, laws etc. So, we can understand that we are speaking about multiple and demanding parameters that must cooperate efficiently to succeed in traffic safety. We mentioned all the barriers and the benefits of connected mobility which will exist forever. Problems will always be overcome but new ones will always appear. Always, our number one target is to mitigate accidents and make traffic safer. Using connected mobility can help us to achieve our target. Until now many steps have been taken, but a lot of work is still needed to achieve the best result.

8. PRACTICAL RECOMMENDATION AND FUTURE RESEARCH

Three methodologies discussed in this research, literature review, a survey and an analysis of tailgating data. All of the methodologies could be used in further research but with some changes. The changes have to do with 2 of the 3 methodologies 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 data, as I mentioned before, 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.

This master's thesis was the trigger for creating a survey and discussing a really difficult to manage problem of the near future, connected mobility. Of course changes could be made to the questions but the core of the questions was quite good and useful conclusions were drawn. We can say the same for the tailgating data. Although the data was limited, useful conclusions were drawn about the specific dangerous human behavior.

In terms of practical level, I have learned how to set up a survey and how to take the best answers from participants to have the best results. Also, the analysis of the survey data is crucial to depict the results. Also, the analysis of tailgating data needs a quite big effort to create graphs from numbers.

The specific thesis is a very good effort and the recommendations are feasible to be carried out, in order to achieve the best possible results on traffic monitoring and enforcement of autonomous and connected mobility.

9. LIST OF FIGURES

10. LIST OF PICTURES

11. LIST OF TABLES

12. ANNEXES

12.1. Annex 1: Survey

Human Factor and Autonomous Mobility

Start of Block: Default Question Block

Q1.1
My name is Dimitrios Zavantis and I am studying for master's degree in Transportation Sciences by distance learning at University of Hasselt. 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 survey will take approximately 8 minutes to complete and you can be assured that all information will be kept private in the strictest confidentiality.

Before starting the survey, please read the information below thoroughly.
I have read the above information about this study.
I understand the purpose of this study as well as what is expected of me during the study.
I understand that my participation in this study is voluntary and that I have the right to discontinue my participation at any time during the intake (by closing the browser window).
I do not have to give a reason for this and I know that no disadvantage can arise for me.
I understand that the results of this research may be used for scientific purposes and may be published. My name will not be published and the confidentiality of my data is guaranteed at every stage of the research.
I know that the results of this research will be kept for 5 months, starting 6/10/2021, and will be deleted after this period.
For questions I know I can contact after my participation: dimitrios.zavantis@student.uhasselt.be.

By submitting this survey form you are indicating that you have read the purpose of the study and that you agree to the terms.

Many thanks in advance for your participation

○ I agree and would like to fill in the survey (1)

○ I disagree and would not like to fill in the survey (2)

Skip To: End of Survey If My name is Dimitrios Zavantis and I am studying for master's degree in Transportation Sciences b... = I disagree and would not like to fill in the survey

End of Block: Default Question Block

Start of Block: Block 1

Q2.1
What is your gender?

○ Male (1)

○ Female (2)

Q2.2 What age group do you belong to?

○ 16 - 24 (1)

○ 25 - 34 (2)

○ 35 - 44 (3)

○ 45 - 65 (4)

○ 65+ (5)

End of Block: Block 1

Start of Block: Block 2

Q3.1 In which country do you live in?

____

Q3.2 In what kind of area do you live in?

○ Urban area (1)

○ Suburban area (2)

○ Rural area (3)

End of Block: Block 2

Start of Block: Block 3

Q4.1
Do you own a driving license?

○ Yes (1)

○ No (2)

Q4.2 Do you own a car?

○ Yes (1)

○ No (2)

End of Block: Block 3

Start of Block: Block 4

Q5.1 What is your current profession?

○ Student (1)

○ Employee (2)

○ Unemployment (3)

Q5.2 You go to work/ university by using....

- ◯ Car (1)
- ◯ Public Transport (2)
- ◯ On foot (3)
- ◯ Other means of transport (e.g. bicycle) (4)

End of Block: Block 4

Start of Block: Block 5

Q6.1 Connected and Autonomous Mobility (CAM) refers to autonomous/ connected vehicles or self-driving cars (vehicles that can guide themselves without human intervention).

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I have never heard about CAM (1)	◯	◯	◯	◯	◯	◯	◯
I know what CAM refers to (2)	◯	◯	◯	◯	◯	◯	◯
My knowledge about CAM is limited (3)	◯	◯	◯	◯	◯	◯	◯

End of Block: Block 5

Start of Block: Block 6

Q7.1 Mixed traffic is the situation where autonomous and conventional vehicles share the same infrastructure.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I have been involved in mixed traffic as a driver (1)	○	○	○	○	○	○	○
I have been involved in mixed traffic as a passenger (2)	○	○	○	○	○	○	○
I have never been involved in mixed traffic (3)	○	○	○	○	○	○	○
I am not sure if I ever been involved in mixed traffic (4)	○	○	○	○	○	○	○

End of Block: Block 6

Start of Block: Block 7

Q8.1 Optimists claim that, because human error contributes to 90% of crashes, autonomous vehicles will reduce crash rates and insurance costs by 90%.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that autonomous vehicles are safe to drive (1)	○	○	○	○	○	○	○
I don't believe that autonomous vehicles are safe to drive (2)	○	○	○	○	○	○	○
I am not sure if autonomous vehicles are safe to drive (3)	○	○	○	○	○	○	○

End of Block: Block 7

Start of Block: Block 8

Q9.1 Tailgating is a dangerous driving behavior and a leading cause of most rear-end crashes.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that autonomous vehicles will reduce tailgating problems (1)	○	○	○	○	○	○	○
I don't believe that autonomous vehicles will reduce tailgating problems (2)	○	○	○	○	○	○	○
I believe that autonomous vehicles will not reduce any safety problems at all (3)	○	○	○	○	○	○	○

End of Block: Block 8

Start of Block: Block 9

Q10.1 Transportation infrastructure is the most crucial element of mixed traffic.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that transportation infrastructure is ready to support mixed traffic (1)	○	○	○	○	○	○	○
I don't believe that transportation infrastructure is ready to support mixed traffic (2)	○	○	○	○	○	○	○
I believe that transportation infrastructure will never be ready to support mixed traffic (3)	○	○	○	○	○	○	○
I believe that transportation infrastructure will be ready in 20-30 years to support mixed traffic (4)	○	○	○	○	○	○	○

End of Block: Block 9

Start of Block: Block 10

Q11.1 Although autonomous vehicles are the future of mobility, there are some additional risks these technologies can introduce. Those kinds of risks are hardware and software failures, malicious hacking, platooning risks, increased total vehicle travel etc.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I would never buy an autonomous vehicle (1)	○	○	○	○	○	○	○
I would never feel safe inside an autonomous vehicle (2)	○	○	○	○	○	○	○
I believe that technology can solve that kind of issues (3)	○	○	○	○	○	○	○
I believe that mixed traffic will never be 100% safe (4)	○	○	○	○	○	○	○

End of Block: Block 10

Start of Block: Block 11

Q12.1 Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved. Such challenges include the impact of automated systems on drivers' mental workload and situation awareness, as well as the human driver's level of acceptance, trust and reliance on the automated systems.
To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
Automated vehicles have the potential to reduce crashes (1)	○	○	○	○	○	○	○
In autonomous vehicles drivers should be allowed to supervise their vehicle (2)	○	○	○	○	○	○	○
In fully automated vehicles steering wheels are necessary (3)	○	○	○	○	○	○	○
In fully automated vehicles drivers can sleep (4)	○	○	○	○	○	○	○
In fully automated vehicles drivers can be drunk or unconscious (5)	○	○	○	○	○	○	○
In case of a vehicle failure, the car should directly stop (6)	○	○	○	○	○	○	○
In case of vehicle failure, drivers should be able to take the control (8)	○	○	○	○	○	○	○

I would send my fully automated vehicle to pick up my kids from school (7)	○	○	○	○	○	○	○

End of Block: Block 11

Start of Block: Block 14

Q19 There are five levels of autonomous driving shown below:
0: Zero Autonomy - The driver performs all driving tasks
1: Driver Assistance - Vehicle is controlled by the driver
2: Partial Automation - Vehicle has combined automated functions
3: Conditional Automation - Driver is a necessary, but is not required to monitor the environment
4: High Automation - The vehicle is capable of performing all driving functions under certain conditions
5: Full Automation - The vehicle is capable of performing all driving functions

According to the above, what is the degree of automation you prefer for your private car?

○ Zero Autonomy (1)

○ Driver Assistance (2)

○ Partial Automation (3)

○ Conditional Automation (4)

○ High Automation (5)

○ Full Automation (6)

End of Block: Block 14

Start of Block: Block 12

Q13.1 Because vehicles with growing degrees of autonomous function are already used on the roads or are promised to arrive soon, law enforcement (LE) needs to consider how to prepare for issues such vehicles will cause or how to contend with actual autonomous vehicles (AVs) in traffic.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
AVs will comply with all traffic laws (1)	○	○	○	○	○	○	○
AVs will strictly comply with speed limits (2)	○	○	○	○	○	○	○
AVs will come to a complete stop at a stop sign (3)	○	○	○	○	○	○	○
The law enforcement of automated vehicles is not completed (4)	○	○	○	○	○	○	○
The law enforcement of automated vehicles will be never completed (5)	○	○	○	○	○	○	○

End of Block: Block 12

Start of Block: Block 13

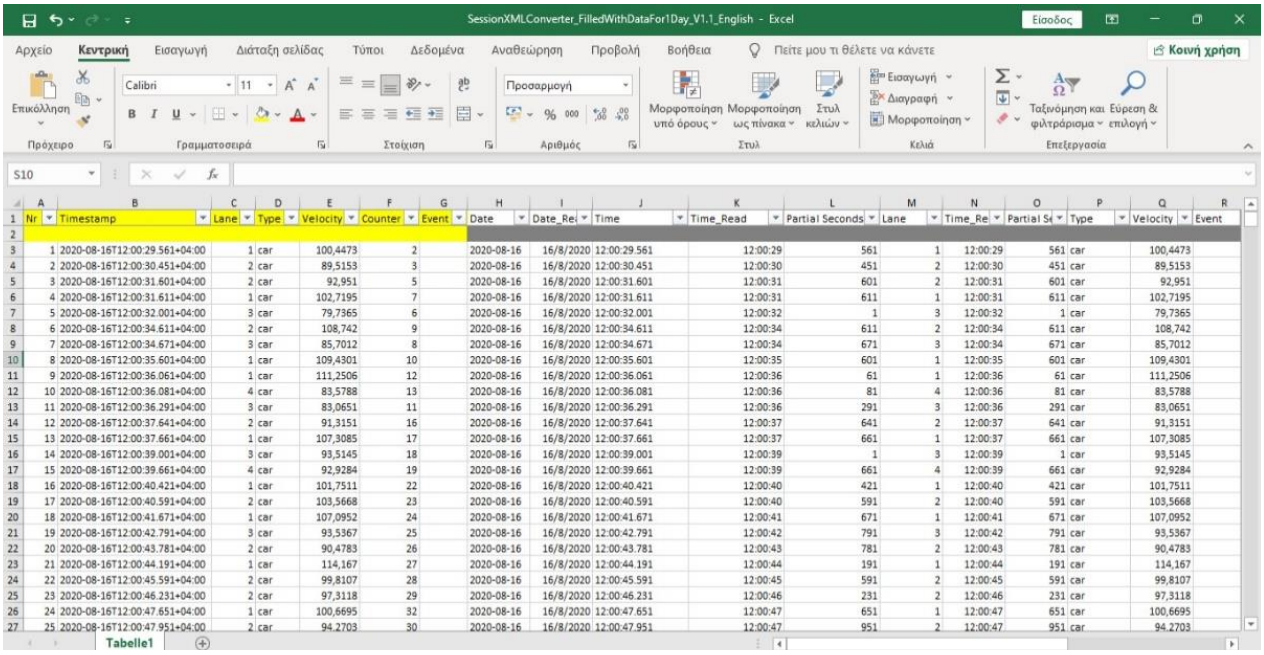
Q14.1 In future years, drivers are not expected to be responsible for driving and monitoring the surrounding environment in autonomous driving. The AVs will be able to maintain road variables stable (speed limit, safe distances etc.) in terms of traffic safety. But we also need an integrated system that monitors AVs in real time. Traffic centers can undertake the specific job, the monitoring of AVs.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
Automated vehicles monitoring is ready to implement (1)	○	○	○	○	○	○	○
Automated vehicles monitoring is not completed (2)	○	○	○	○	○	○	○
Automated vehicles monitoring will never be ready to implement (3)	○	○	○	○	○	○	○

End of Block: Block 13

12.2. Annex 2: Tailgating Data



Nr	Timestamp	Lane	Type	Velocity	Counter	Event	Date	Date_Re	Time	Time_Read	Partial Seconds	Lane	Time_Re	Partial Se	Type	Velocity	Event
1	2020-08-16T12:00:29.561+04:00	1	car	100,4473	2		2020-08-16	16/8/2020	12:00:29.561	12:00:29	561	1	12:00:29	561	car	100,4473	
2	2020-08-16T12:00:30.451+04:00	2	car	89,5153	3		2020-08-16	16/8/2020	12:00:30.451	12:00:30	451	2	12:00:30	451	car	89,5153	
3	2020-08-16T12:00:31.601+04:00	2	car	92,951	5		2020-08-16	16/8/2020	12:00:31.601	12:00:31	601	2	12:00:31	601	car	92,951	
4	2020-08-16T12:00:31.611+04:00	1	car	102,7195	7		2020-08-16	16/8/2020	12:00:31.611	12:00:31	611	1	12:00:31	611	car	102,7195	
5	2020-08-16T12:00:32.001+04:00	3	car	79,7365	6		2020-08-16	16/8/2020	12:00:32.001	12:00:32	1	3	12:00:32	1	car	79,7365	
6	2020-08-16T12:00:34.611+04:00	2	car	108,742	9		2020-08-16	16/8/2020	12:00:34.611	12:00:34	611	2	12:00:34	611	car	108,742	
7	2020-08-16T12:00:34.671+04:00	3	car	85,7012	8		2020-08-16	16/8/2020	12:00:34.671	12:00:34	671	3	12:00:34	671	car	85,7012	
8	2020-08-16T12:00:35.601+04:00	1	car	109,4301	10		2020-08-16	16/8/2020	12:00:35.601	12:00:35	601	1	12:00:35	601	car	109,4301	
9	2020-08-16T12:00:36.061+04:00	1	car	111,2506	12		2020-08-16	16/8/2020	12:00:36.061	12:00:36	61	1	12:00:36	61	car	111,2506	
10	2020-08-16T12:00:36.081+04:00	4	car	83,5788	13		2020-08-16	16/8/2020	12:00:36.081	12:00:36	81	4	12:00:36	81	car	83,5788	
11	2020-08-16T12:00:36.291+04:00	3	car	83,0651	11		2020-08-16	16/8/2020	12:00:36.291	12:00:36	291	3	12:00:36	291	car	83,0651	
12	2020-08-16T12:00:37.641+04:00	2	car	91,3151	16		2020-08-16	16/8/2020	12:00:37.641	12:00:37	641	2	12:00:37	641	car	91,3151	
13	2020-08-16T12:00:37.661+04:00	1	car	107,3085	17		2020-08-16	16/8/2020	12:00:37.661	12:00:37	661	1	12:00:37	661	car	107,3085	
14	2020-08-16T12:00:39.001+04:00	3	car	93,5145	18		2020-08-16	16/8/2020	12:00:39.001	12:00:39	1	3	12:00:39	1	car	93,5145	
15	2020-08-16T12:00:39.661+04:00	4	car	92,9284	19		2020-08-16	16/8/2020	12:00:39.661	12:00:39	661	4	12:00:39	661	car	92,9284	
16	2020-08-16T12:00:40.421+04:00	1	car	101,7511	22		2020-08-16	16/8/2020	12:00:40.421	12:00:40	421	1	12:00:40	421	car	101,7511	
17	2020-08-16T12:00:40.591+04:00	2	car	103,5668	23		2020-08-16	16/8/2020	12:00:40.591	12:00:40	591	2	12:00:40	591	car	103,5668	
18	2020-08-16T12:00:41.671+04:00	1	car	107,0952	24		2020-08-16	16/8/2020	12:00:41.671	12:00:41	671	1	12:00:41	671	car	107,0952	
19	2020-08-16T12:00:42.791+04:00	3	car	93,5367	25		2020-08-16	16/8/2020	12:00:42.791	12:00:42	791	3	12:00:42	791	car	93,5367	
20	2020-08-16T12:00:43.781+04:00	2	car	90,4783	26		2020-08-16	16/8/2020	12:00:43.781	12:00:43	781	2	12:00:43	781	car	90,4783	
21	2020-08-16T12:00:44.191+04:00	1	car	114,167	27		2020-08-16	16/8/2020	12:00:44.191	12:00:44	191	1	12:00:44	191	car	114,167	
22	2020-08-16T12:00:45.591+04:00	2	car	99,8107	28		2020-08-16	16/8/2020	12:00:45.591	12:00:45	591	2	12:00:45	591	car	99,8107	
23	2020-08-16T12:00:46.231+04:00	2	car	97,3118	29		2020-08-16	16/8/2020	12:00:46.231	12:00:46	231	2	12:00:46	231	car	97,3118	
24	2020-08-16T12:00:47.651+04:00	1	car	100,6695	32		2020-08-16	16/8/2020	12:00:47.651	12:00:47	651	1	12:00:47	651	car	100,6695	
25	2020-08-16T12:00:47.951+04:00	2	car	94.2703	30		2020-08-16	16/8/2020	12:00:47.951	12:00:47	951	2	12:00:47	951	car	94.2703	

FIGURE 39. Raw Tailgating Data in Excel. Source: Excel, Own edit (2021)

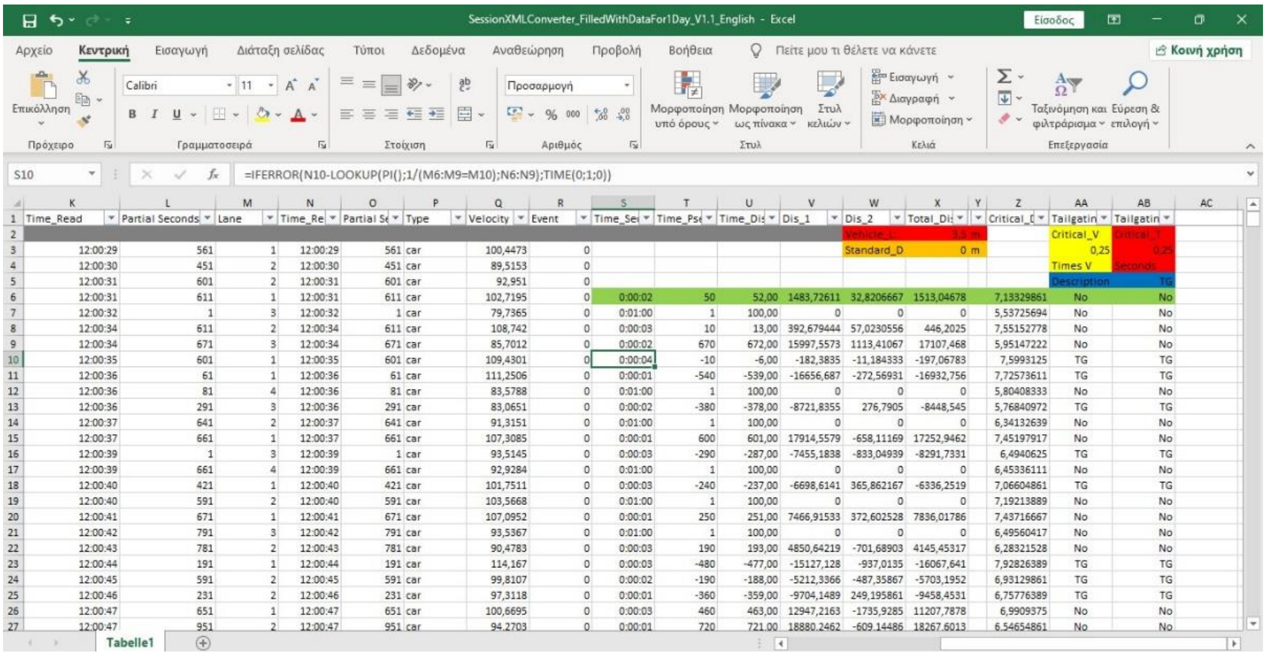


FIGURE 40. Raw Tailgating Data in Excel. Source: Excel, Own edit (2021)

12.3. Annex 3: Qualtrics Raw data

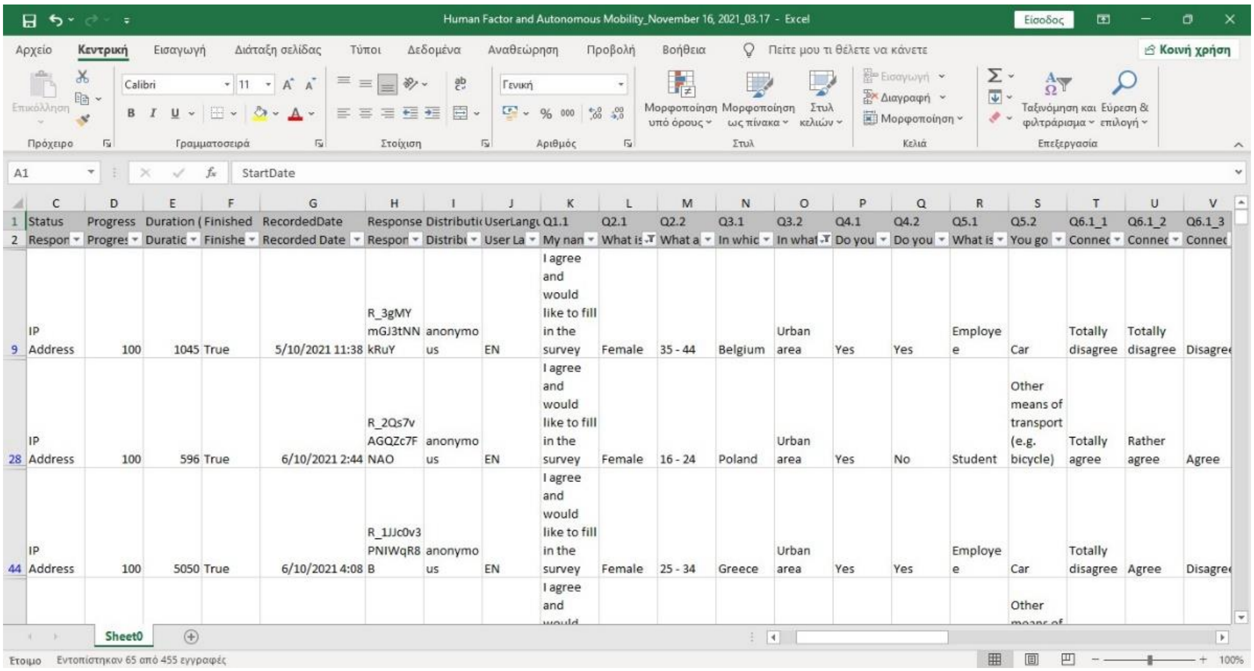
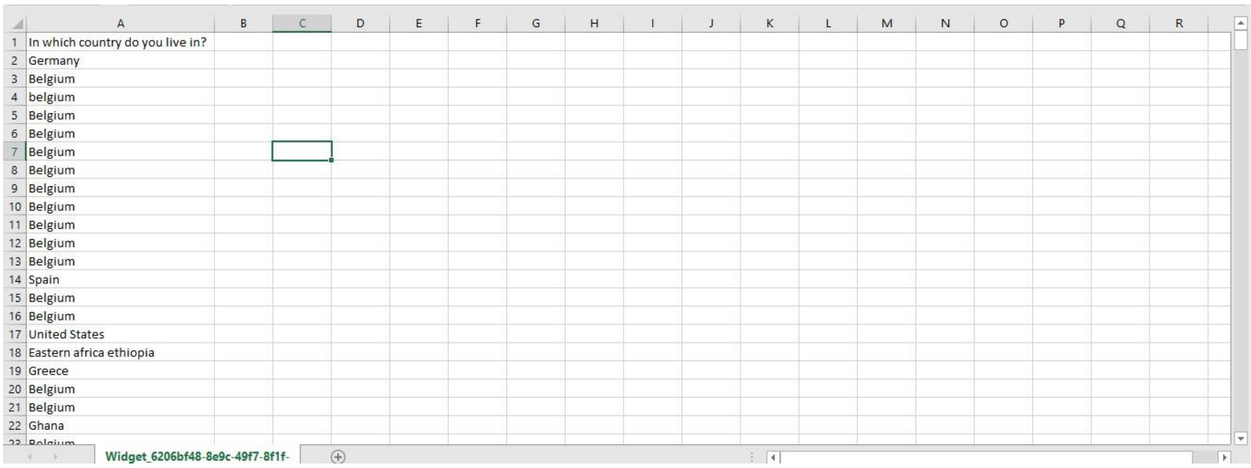


FIGURE 41. Survey Raw Data in Excel. Source: Excel, Own edit (2021)

12.4. Annex 4: Raw Data about the living Country



	A
1	In which country do you live in?
2	Germany
3	Belgium
4	belgium
5	Belgium
6	Belgium
7	Belgium
8	Belgium
9	Belgium
10	Belgium
11	Belgium
12	Belgium
13	Belgium
14	Spain
15	Belgium
16	Belgium
17	United States
18	Eastern africa ethiopia
19	Greece
20	Belgium
21	Belgium
22	Ghana
23	Belgium

Widget_6206bf48-8e9c-49f7-8f1f-

FIGURE 42. Raw Living Country Data in Excel. Source: Excel, Own edit (2021)

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