Autonomous vehicles and their impact on road transportation

Quang Pham

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Jyväskylän ammattikorkeakoulu
JAMK University of Applied Sciences

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Abstract

Transportation is a crucial element in the supply chain of any business. Within transportation, road transportation of goods plays an important role due to being popular, easily implemented and cost efficient. However, by 2018, the trucking industry is facing several challenges that cannot be tackled without implementing new technologies into the field. Autonomous driving, even though only in its early testing and implementation phase, has been regarded as a potential solution for the future of transportation.

The objectives of the thesis were to explore the technology of autonomous driving and how they could be implemented in the trucking industry, as well as what benefits it can bring to the business and what limitations and challenges it has to overcome in order to become a practical solution. To achieve the objectives, available data was collected from news articles, studies and research articles and then analysed.

According to the results of the analyses, autonomous driving, if successfully implemented, can bring several benefits to the trucking industry. The improvements relate to productivity, safety and potentially to the cost efficiency aspects. However, the technology has to overcome several challenges before being able to be commercialised.

The study can serve as a systematic literature review so that the readers can familiarise themselves with the technology, prepare for the future of autonomous driving and understand what technology can and cannot bring to the trucking industry.

Keywords/tags: transportation, autonomous trucks, safety, efficiency productivity

Miscellaneous:

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1 Introduction

1.1 Preface

By definition, “self-driving vehicles are those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode” (U.S. Department of Transportation Releases Policy on Automated Vehicle Development 2013). The technology has been advertised and experimented since the 1920s (The Milwaukee Sentinel 1926). However, it was no sooner than in the 2010s that autonomous cars were officially introduced to the market (Thrun 2010). Since then, several major automotive manufacturers have been testing driverless car systems.

In 2016, Otto, a start-up company founded by former Google employees Anthony Levandowski and Lior Ron, which soon later was acquired by Uber to form Uber Advanced Technologies Group (Uber ATG), published a video showing their truck completing the world’s first commercial shipment by a self-driving truck. It travelled a 120-mile (193 kilometres) journey on highway I-25 from Fort Collins, through Denver, to Colorado Springs without a driver during the entire highway, carrying a trailer full of Budweiser beer (Otto and Budweiser: First Shipment by Self-Driving Truck 2016).

By the start of 2018, Uber had commercialised autonomous trucks in Arizona, USA, which only run on highways and still require a safety driver in the cabin during the trip (Hawkins 2018a). This indicates that the future of the transportation market with self-driving trucks are near, even if completely autonomous driverless trucks are not a reality yet.

1.2 Purposes and goals of the thesis

The overall purpose of the thesis was to identify how autonomous vehicles technology could bring improvement to the field of logistics, specifically in transportation of goods on roads. The scope of the thesis was limited to the trucking industry in Western Europe and the United States of America, since they are the two places that have adequate infrastructure and have seen actual testing of autonomous vehicles for a few years, with related data available in multiple sources. Certain examples were taken from actual industrial zones in Australia, where autonomous vehicles are already operated.

The three main research questions that the thesis aimed to answer were:

- How are autonomous vehicles more efficient than traditional vehicles in terms of goods transported?
- How can safety aspect of drivers and vehicles be improved with the advanced technologies of autonomous vehicles?
- What are the potential changes of financial costs and benefits when applying autonomous vehicles technology to the practical work environment and their potential consequences in the transportation chain?

1.3 Research methods

The research approach in the thesis was primarily that of qualitative research. The technical aspect of autonomous vehicles was explored by studying academic documents, while theories about the benefits of autonomous vehicles were explained with in-depth analyses based on practical data. In the thesis, theoretical hypotheses as well as realistic cases were presented and analysed in order to come to conclusions and further discussions.

The data was collected mainly by means of observations, such as reading of previous publications on the topic, watching videos published by automotive companies as well as studying legal and regulatory documents. Therefore, the thesis is considered a systematic review, which is an appraisal and synthesis of primary research papers using a rigorous and clearly documented methodology in both the search strategy and the selection of studies (Higgins 2011). It also studies and analyses the available literature in order to give answers to the research questions listed in chapter 1.2.

2 Current challenges of the trucking industry

This part of the thesis covers current general laws and regulations that limit the driving and working time of drivers in the EU and in the US. Moreover, it presents several safety related statistics and reasons for why the transportation field is in a stalemate nowadays if there are no big innovations coming in the near future.

2.1 Driving and working time limits

Truck drivers are subjected to strict working and driving time limits by laws and regulations. The purpose of the rules is to avoid unfair competition, improve traffic safety and ensure the drivers' working conditions. As a result, it is important for transportation firms to plan their schedules for goods and drivers accordingly so that the drivers can be utilised to their maximum allowances. The table below provides a summary of the general working and driving time limits for truck drivers in the two concerned regions of this thesis, the EU and the United States of America. (Regulation (EC) 561/2006, 6-7; Interstate Truck Driver’s Guide to Hours of Service 2015, 3–6.)

Table 1. Driving and working/on-duty time limits

	EU	USA
Driving time limits	• Maximum 9 hours daily; twice a week can be extended to 10 hours. • Maximum 56 hours weekly. • Maximum 90 hours fortnightly.	• Maximum 11 hours driving after consecutive 10 hours off duty. • May not drive beyond the 14th consecutive hour after coming on duty after 10 consecutive hours off duty; off-duty time in between does not extend the 14-hour period (other works are allowed after the 14th hour); can only drive after another 10 consecutive hour off-duty period.
Working/On-duty time limits	• At least 11 hours of daily rest; can be reduced to 9 hours at maximum thrice per week; can be splited into one 3-hour and one 9-hour rest (total 12 hours of rest if splited). • Weekly rest of 45 continuous hours; can be reduced every second week to 24 hours. • Weekly rest after six days of working.	• May not drive after 60 hours on duty in any 7 consecutive days; or 70 hours on-duty in any 8 consecutive days (only one of the two limits has to be followed, depends on agreement; other works are allowed after the 60/70-hour limit). • 60/70-hour limit restarts after 34 consecutive hours off duty.
Break requirement	• At least 45-minute break after 4½ hours of driving; can be splited into one 15-minute and one 30-minute break.	• At least 30-minute off-duty or sleeper berth after 8 hours of consecutive driving.

From the above data, a theoretical “driving time utilisation” rate can be calculated by the ratio of maximum allowed driving time and maximum available working time during an interval. However, it should be noted that the analysis is strictly theoretical, based on assumptions that the drivers are required to work at their maximum working time allowance (e.g. at a peak time of goods deliveries such as Christmas, festival seasons, or during a shortage of drivers). In addition, the mandatory time required for other work related to truck driving such as loading, unloading, logging in pre-trip or post-trip is neglected for simplification.

For a driver in the EU, in a peak day with 9 hours of daily rest and 10 hours of driving time, his/her utilisation rate is 66,7%, calculated from 10 hours of driving in a maximum 15 hours of working time. In a two-week peak period, he/she is allowed to work for 158 hours at maximum, 90 of which can be used for driving, resulting in a utilisation rate of 57,0% (see Table 2).

Table 2. Fortnightly working time example (EU)

	Work starts	Work finishes	Working hours	Daily rest
Monday	00:00	15:00	15	9
Tuesday	00:00	15:00	15	9
Wednesday	00:00	13:00	13	11
Thursday	00:00	13:00	13	11
Friday	00:00	13:00	13	11
Saturday	00:00	15:00	15	9
Sunday	Day off (24 hours rest)			
Monday	00:00	15:00	15	9
Tuesday	00:00	15:00	15	9
Wednesday	00:00	15:00	15	9
Thursday	00:00	13:00	13	11
Friday	00:00	13:00	13	11
Saturday	00:00	03:00	3	21
Sunday	Day off (24 hours rest) *			
Total			**158**	

*: 24 hours rest on Sunday combined with 21 hours rest from Saturday will make 45 hours of consecutive rest, which is required by law every two weeks.

Similarly, based on the regulations, a driver in the US, at his/her maximum working hours allowed, might have an example weekly schedule as demonstrated in Table 3, based on the agreement that he/she cannot drive more than 60 hours in seven days. In this case, the driving time utilisation rate of a driver in the US will be 71,4% of his/her total working time.

Table 3. Weekly working hours example (US)

	Work starts	Work finishes	Driving hours	Other work	Off-duty hours
Monday	00:00	14:00	11	3	10
Tuesday	00:00	14:00	11	3	10
Wednesday	00:00	14:00	11	3	10
Thursday	00:00	14:00	11	3	10
Friday	00:00	14:00	11	3	10
Saturday	00:00	14:00	5	9	**10**
Sunday	Day off				**24**
Total			60	24	84

In both cases, it is evident that transportation firms can only use their drivers for driving between 60-70 percent of their possible working time. In peak seasons, this would become a problem since it is not always possible to deliver goods before their intended delivery date to avoid congestion due to manufacturers' and retailers' constraints. This problem should encourage the transportation firms to create a solution to improve their utilisation of drivers, as hiring extra drivers is not always easy, as is explained in chapter 2.2 below.

2.2 Lack of truck drivers

According to the International Road Transport Union (IRU), over the next 10 to 15 years, Germany will have a shortfall of around 150.000 drivers, mainly due to retirements of the current drivers. The same situation is in the UK, where it is estimated that around 50,000 more drivers are needed, with approximately another 35.000 drivers retiring in the next two years who are "extremely difficult to replace" (Driver Shortage Problem n.d.)

In a report published by the American Trucking Associations (ATA), Costello (2017, 13) stated that from 2017 through 2026, America's trucking industry will need almost 900.000 more truck drivers, or 89.750 new drivers per year on average to meet the demand of the improving economy. The industry has been struggling with the shortage of drivers for a long time, as there was a shortage of around 20.000 drivers in 2005. During the Great Recession which began in 2008, the shortage issue was improved but this was due to the decrease of transportation volume which caused the lowered need for drivers. Since 2011, the shortage has been becoming worse and worse (ibid., 2017, 3). The statement is consistent with the figures in Table 4, in which the number of large trucks registered can be seen dropping from 2009 to 2011, then rising again. (Costello 2017, 8)

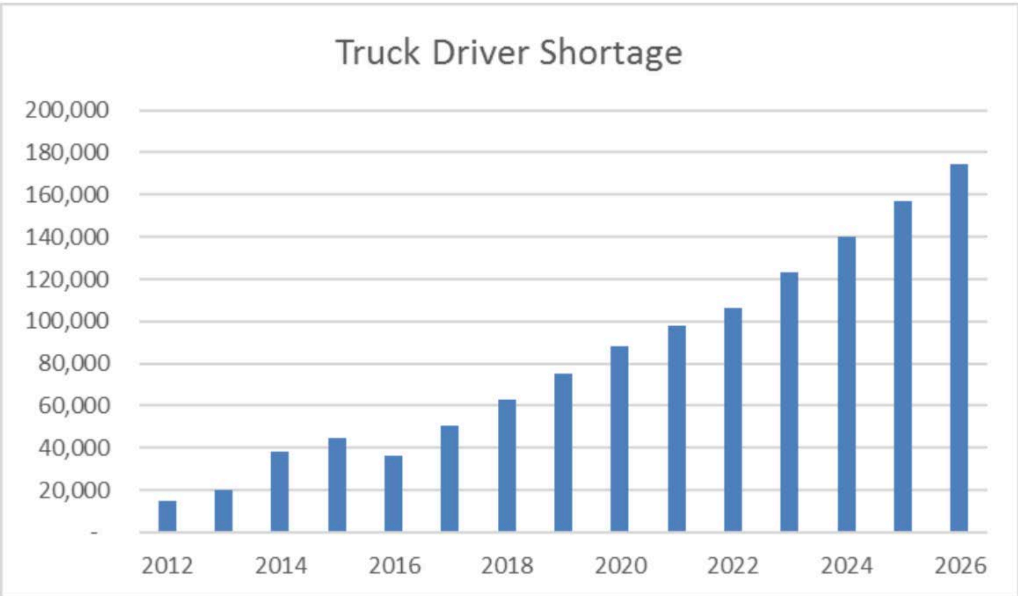

Figure 1. America's truck driver shortage until 2026

The main reason for the shortage of drivers, as stated by both ATA and IRU, is the aging demographics among the drivers. The root causes of this trend that younger people do not want to be truck drivers are mainly in the difficulties related to the job such as salaries, working conditions, social image, lifestyle (drivers have to be long times away from home and live in sub-standard conditions on the way), and many other issues. (Costello 2017, 7; America's shortage of truck drivers could affect prices and cause delivery delays 2017).

In the long term, if the situation does not improve, the consequences might include, but are not limited to, product shortages, increased delays, increased transportation costs, increased inventory carrying costs, and much more. (Costello 2017, 7; America's shortage of truck drivers could affect prices and cause delivery delays 2017).

2.3 Drivers' errors: The main reasons for road accidents

Safety has always been a primary concern in the field of transportation due to the fact that if safety requirements are not met and accidents happen, all parties involved in the supply chain will be affected (cost of delays for the receiver, vehicle repair and possible driver's medical costs for the transport acengy, cost of damaged goods for the sender, and other complications). As technologies and markets develop, traffic safety standards have become stricter over time in order to meet the requirements of the market (shorter lead time, less excess stock, more accurate tracking, among others) and trade unions (working conditions, workplace safety, among many more). However, nowadays when vehicles and road infrastructure have generally become reliable and the laws and regulations have matured to the point that all travellers should be safe on the road assuming that they follow the laws, the drivers have become the main cause of traffic accidents, according to Smith (Human error as a cause of vehicle crashes, 2013) compiling data from several relevant sources.

According to the National Highway Traffic Safety Administration (NHTSA), an agency of the Executive Branch of the U.S. Government, part of the U.S. Department of Transportation, between 2005 and 2007, 94% of the reasons for critical pre-crash events were assigned to the driver, among a sample of 5.470 crashes. The weighted sample respresented approximately 2.189.000 crashes around the country, with the other six percent of the reasons being assigned to the vehicles, the environment or other unknown factors (see Table 4).

Table 4. Critical reasons of crashes distribution (Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey 2015, 2)

Critical Reason Attributed to	**Number**	**Percentage**
Drivers	2.046.000	94%
Vehicles	44.000	2%
Environment	52.000	2%
Unknown Critical Reasons	47.000	2%
Total	2.189.000	100%

According to the same sources, critical reasons attributed to drivers can be categorised into four major categories:

- Recognition errors: Driver’s inattention, internal and external distractions and inadequate surveillance.
- Decision errors: Driving too fast under the circumstances, false assumption of others’ actions, illegal manoeuvres, misjudgements of gap or others’ speed.
- Performance errors: Overcompensation, poor directional control.
- Non-performance errors: Sleep, etc.

Those four categories, among other minor errors, have the following distribution:

Table 5. Driver-related critical reason distribution (Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey 2015, 2)

Critical Reason	**Number**	**Percentage**
Recognition Error	845.000	41%
Decision Error	684.000	33%
Performance Error	210.000	11%
Non-Performance Error	145.000	7%
Other	162.000	8%
Total	2.046.000	100%

From the two statistics, it can be concluded that recognition, decision and performance errors of the drivers account for the majority of crashes studied, with the percentage of approximately 80%, verifying Smith’s statement and being summarised in the chart below (see Figure 2).

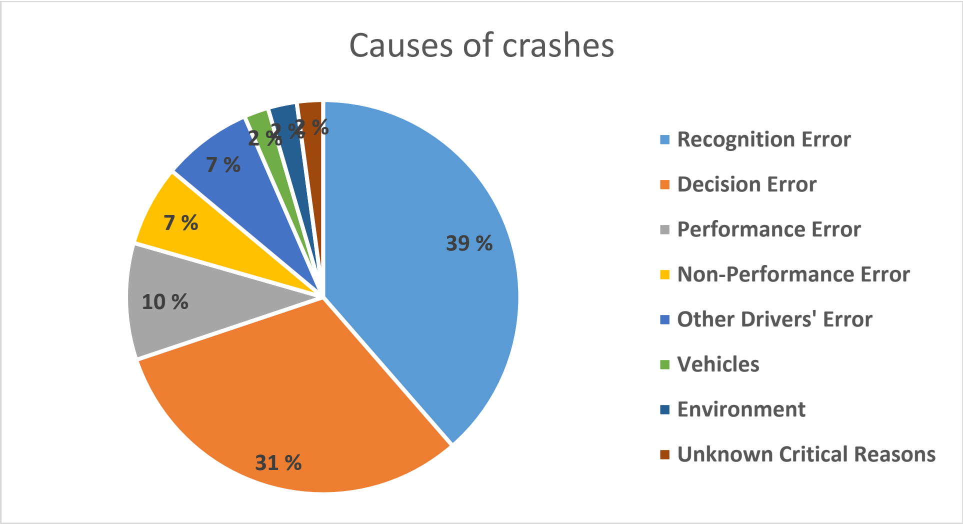

Figure 2. Causes of crashes

2.4 The need to improve accident rates

In February 2018, NHTSA published another report specialising in the involvement in crashes of large trucks, which are trucks with gross vehicle weight rating greater than 10,000 pounds (4.54 tonnes). The statistics were based on data collected from 2005 to 2016 showing, among other parameters, the level of involvement of large trucks in crashes that resulted in fatalities and injuries. This is presented in the Table 6 below.

Table 6. Large trucks' involvement in fatal and injury crashes (2016 Data: Large Trucks 2018, 3)

Year	Number of large trucks involved in fatal crashes	Number of large trucks involved in injury crashes	Number of large trucks registered	Involvement rate per 100.000 registered large trucks (fatal crashes)	Involvement rate per 100.000 registered large trucks (injury crashes)
2007	4.633	76.000	10.752.019	43,09	705
2008	4.089	66.000	10.873.275	37,61	608
2009	3.211	53.000	10.973.214	29,26	487
2010	3.494	58.000	10.770.054	32,44	541
2011	3.633	63.000	10.270.693	35,37	609
2012	3.825	77.000	10.659.380	35,88	719
2013	3.921	73.000	10.597.356	37,00	690
2014	3.749	88.000	10.905.956	34,38	811
2015	4.074	87.000	11.203.184	36,36	779
2016	4.213	N/A	11.498.561	36,64	N/A

It can be seen that during the ten years in which the data was collected, there was no clear trend of increase or decrease either in the rate of involvement in injury or fatalities of crashes by large trucks. In other words, the safety aspect of the operation of large trucks in those ten years, in which there were no breakthrough innovations for trucks, did not have any significant improvements.

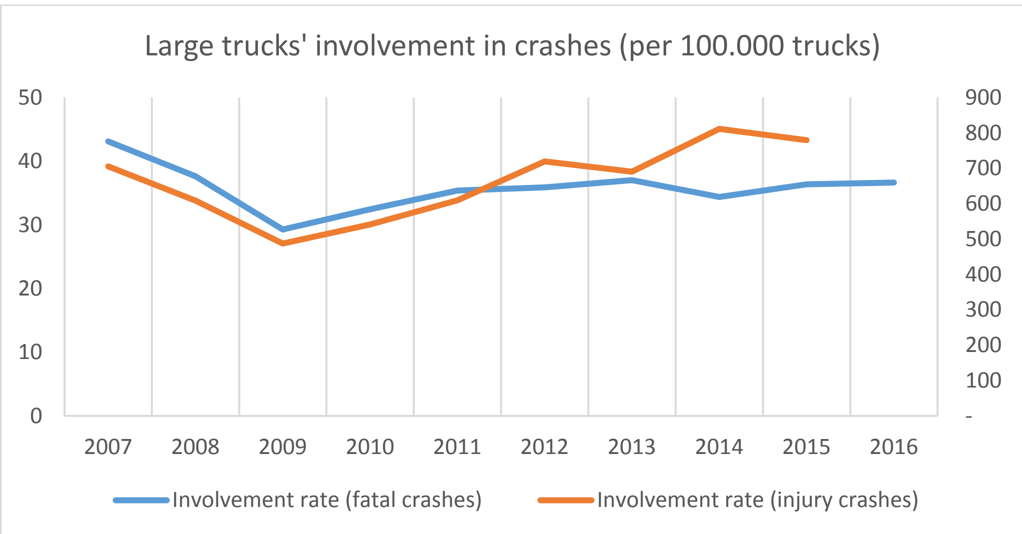

Figure 3. Large trucks' involvement in crashes rate

2.5 Summary

To summarise the chapter, it can be stated that two big problems with the trucking industry, the stall in development of efficiency and safety, are both limited by human factors, as working time limits are defined by the general level of fatigue of the drivers while accidents occur mostly due to errors of the drivers. To solve the problem, the industry has to come up with a way to either improve the quality of the drivers or substitute the drivers with other more reliable elements. The former is unlikely to happen, since humans have limited capabilities and they are already pushed to their limit because people need a certain number of resting hours every day, and tiredness and fatigue are largely unavoidable.

3 Autonomous vehicles – the solution for transportation's problems

This chapter of the thesis includes the introduction, current implementation and potential in trucking industry of autonomous vehicles technology.

3.1 Driverless vehicles - technology briefing

For a vehicle to driver itself without a driver onboard, four interdependent functions are needed: navigation, situation analysis, motion planning and trajectory control. (Heutger 2014, 5)

- Navigation: The vehicle's ability to plan its route, nowadays achieved by using satellite navigation systems, typically GPS. In addition, the vehicle has to retrieve data related to road types, settings, terrains as well as weather conditions in order to have the most suitable route. (ibid., 6)
- Situation Analysis: The vehicle's ability to keep track of its surrounding environment, including all relevant objects and their movement. This function requires the use of different types of sensors, typically visual image, radar, ultrasonic sensors LIDAR (light detection and ranging), etc. The ultimate goal is to combine the data collected to make the vehicle continuously aware of its surroundings, so that it can decide what actions to conduct. (ibid., 6-7.)

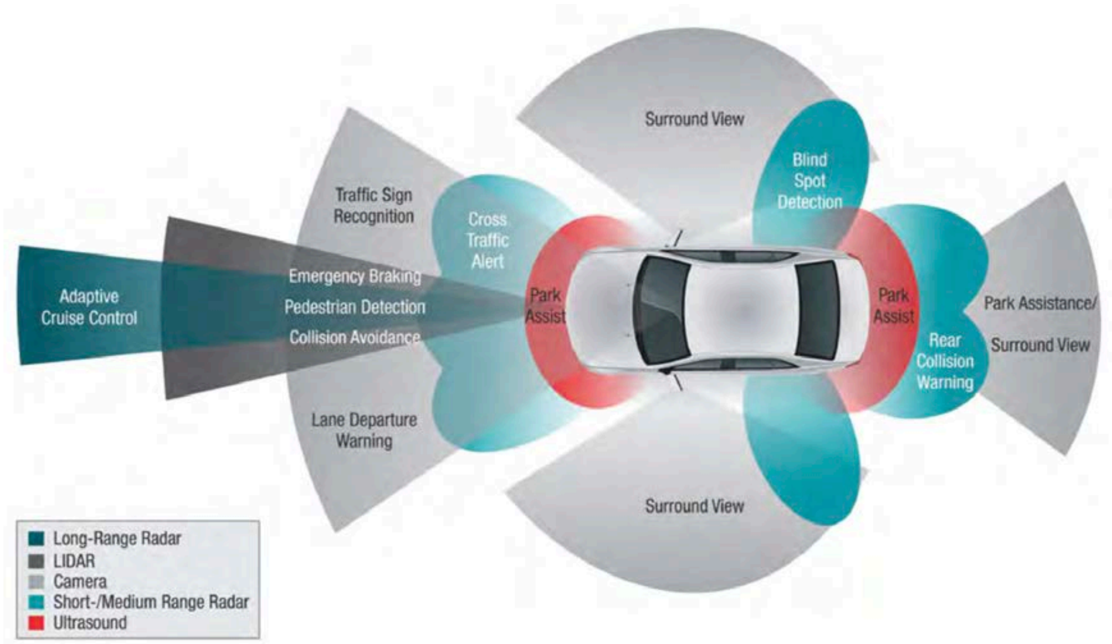

Figure 4. Sensors use for Situation Analysis (Heutger 2014, 6)

- Motion Planning: The vehicle's ability to determine the correct course of motion (speed, direction) within a certain pre-defined period of time, so that the vehicle keeps going its lane and its pre-set direction determined by navigation, without colliding with static and dynamic objects that are identified by situation analysis. (ibid., 7.). Effectively, programming an autonomous vehicle's motion planning means teaching the vehicle how to analyse the gathered data and based on that react in different situations. This function requires a lot of experiments and testing to be perfected, and errors in motion planning are the main cause of autonomous vehicles' accidents, which will be presented later in the thesis.
- Trajectory Control: The vehicle's ability to maintain driving stability in the events of changes in direction and speed planned by Motion Planning. Specifically, after a speed or direction intervention, trajectory control compares the expected changes and the actual changes and in case of high deviation, the system automatically adjusts by accelerating, braking or steering to return to stability. In other words, trajectory control manages the execution of changes in speed and/or direction. (ibid., 8.)

To summarise, in order to function, an autonomous vehicle makes use of a navigation system to determine the route, uses different types of sensors to gain awareness of its surrounding thanks to a central data processing unit, and from the data gathered and processed the control unit determines what actions to take, all in an almost instant interval. The two most important groups of components are the control unit and the sensor systems, which generally consists of the sensors below:

- Cameras: Similar to consumer camera, camera systems used in autonomous cars provide input for machine vision. Camera is the only type of sensors that can detect colours, which is crucial for vehicles to detect traffic signs and lights (Rychel 2017). Video camera systems’ disadvantages are vulnerability to different environmental conditions, difficulties detecting non-illuminating objects and in low-light conditions, inability to detect distance by themselves (Wolverton 2017).

- Radar: Short for “Radio Detecting And Ranging”, radar uses radio waves and their reflections to detect objects and determine their range, angle and velocity (Brandt 2017). Radar accuracy is mostly unaffected by environmental conditions like fog, rain, wind or lighting, but its ability to detect an object depends on the object’s reflection strength, which is influenced by several factors such as the size, distance from the radar, radio wave absorption characteristics, reflection angle and transmission power of the object. A vehicle has a large reflection which is easy to detect, but the system must also detect pedestrians, bicycles and motorbikes, which are not only smaller in size but also possibly have hard or metallic parts to reflect radar signals. In a complicated environment, the waves’ reflection from a truck might swamp those from a bike; a person standing next to a vehicle might become undetectable to a radar receiver. On the contrary, a metal object like a can may cause a reproduced radar image much out of proportion to its actual size, all of which can cause the control system to make incorrect decisions (Pickering 2017).

- Lidar: Short for “Light Detection And Ranging”, lidar functions with the same principles compared to radar, but instead of radio waves, lidar uses laser pulses. According to Waymo’s lidar fact sheet, “LiDAR bounces a laser off an object at an extremely high rate—millions of pulses every second—and measures how long the laser takes to reflect off that surface. This generates a precise, three-dimensional image of the object, whether a person, vehicle, aircraft, cloud, or mountain". Compared to radar, lidar is more advanced in creating 3D images, which helps the system detect not only the objects but also the gestures, the direction of moving of the objects. However, lidar is also more expensive, has shorter range and is more vulnerable to part failure than radar (Brandt 2017).

- Ultrasound: Also similar to radar and lidar, ultrasound sensor sends out sound waves and detect surrounding objects by the echoes from the waves in the immediate vicinity. However, ultrasound sensor has very short range and is slow, therefore only suitable for automated parking (ibid. 2017).

3.2 Current implementation of autonomous vehicles

3.2.1 Industrial applications

Autonomous technologies have been widely applied in the field of transportation for many years. A primary example is the autopilot technology which has been a standard in the aviation industry (Heutger 2014, 5). In the miliary sector, autonomous minesweeping trucks have been put into operation to keep soldiers away from improvised explosive devices (Tarantola 2014). In several other industries such as agriculture and mining, autonomous vehicles can also be operated in order to save driver costs and maximise work rate for repetive tasks such as going back and forth the same route over and over again between a mine and an extraction plant, or watering, fertilising and harvesting rows after rows of plants on a farm. (Tarantola 2013a; Tarantola 2013b)

For example, in the mining industry, Australian mining giant Rio Tinto have recently announced that the company have transported more than a billion tonnes of ore and waste material across their mining sites in Pilbara, whilst also claiming "each autonomous truck was estimated to have operated about 700 hours more than conventional haul trucks during 2017 and around 15 per cent lower load and haul unit costs.", all without any injuries to mine workers accounted to autonomous vehicles. (Rio Tinto's Autonomous Haul Trucks Achieve One Billion Tonne Milestone 2018)

Figure 5. Autonomous haul trucks in mining industry (Rio Tinto Photo Library 2017)

3.2.2 Consumers market application

According to DHL, Simple driving-assistance autonomous systems such as anti-lock braking system (ABS) and adaptive cruise control (AAC) has been implemented on most current vehicles (Heutger 2014, 5) so as to improve safety of transportation.

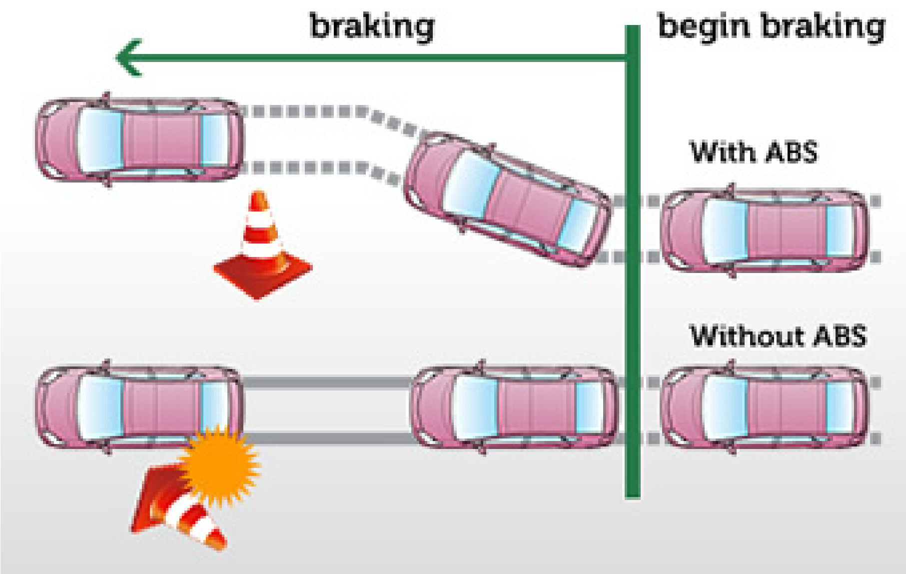

Figure 6. ABS prevent wheels from locking up and avoid skidding during braking (Toyota Malawi)

Figure 7. AAC automatically adjust speed to keep a pre-set distance to traffic ahead (Gnaticov 2016)

One prime example for fully autonomous motion of cars is the automatic parking system, by which the car comes in a tight parking spot all by itself, at a slow speed and only applicable in parking lots. A remote control parking system has been introduced by BMW, albeit with requirements including the car has to be straight and centered, facing the parking lot or garage, as the vehicle in automatic parking mode can only go forward or backward. (Nica 2016)

Figure 8. Volvo's self-parking demonstration (Self-Parking Cars: Improving Urban Mobility 2017)

However, it is important to acknowledge that all mentioned applications for autonomous vehicles are done in either a controlled environment (mines, farms, garage), or places where there are no other human-controlled vehicles around (war zones, aircraft routes). At its best, fully autonomous vehicles are able to travel in rather static environment where traffic is not busy and objects move slowly (public parking lots). At the current state of technology, programmed vehicles are certainly able travel safely and efficiently on their own where all they do is to follow the planned route. On open roads, it is a different situation since the ability to react to other humans' action of autonomous vehicles is still being extensively tested.

3.3 Potential implementation in trucking industry

3.3.1 Truck platooning

To overcome the difficulty of programming a perfect motion planning system (introduced in Chapter 3.1.3), a practical solution is truck platooning – defined as "the linking of two or three trucks in a convoy that closely follow each other at a set, close distance by using connectivity technology and automated driving support systems”. (What Is Truck Platooning? 2016).

In practice, it means a set of two or more trucks will be led by the truck in front with a driver controlling it. The following trucks will automatically follow the leading truck, keep the speed and direction so that the convoy always remain the same distance from each other. On the following trucks, there might be drivers who do not actually drive but are only present there and take the wheel in case of unexpected incidents, otherwise they can do other work and their time will not be counted as driving time, only as working time.

In the future, when the technology has matured, it is a possibility to have the following trucks operating fully driverless, which essentially means one truck driver can “drive” two or more trucks at the same time, resulting in a multiple time increase in his/her work rate in terms of transportation volume by driving time.

In January 2017, Scania, a major Swedish commercial vehicles manufacturer, announced that it “will design the world first-full scale autonomous truck platooning operations” in Singapore. Their goal is to design a convoy of four trucks, three of which autonomously follow the leading truck, to transport containers between port terminals of Singapore. The project, which is expected to last for several years, is organised and supported by the Ministry of Transport and the Port of Singapore Authority (PSA Corporation) with Toyota also participating. (Scania Takes Lead with Full-Scale Autonomous Truck Platoon 2017)

Annex B: Illustration of Autonomous Truck Platooning Technology

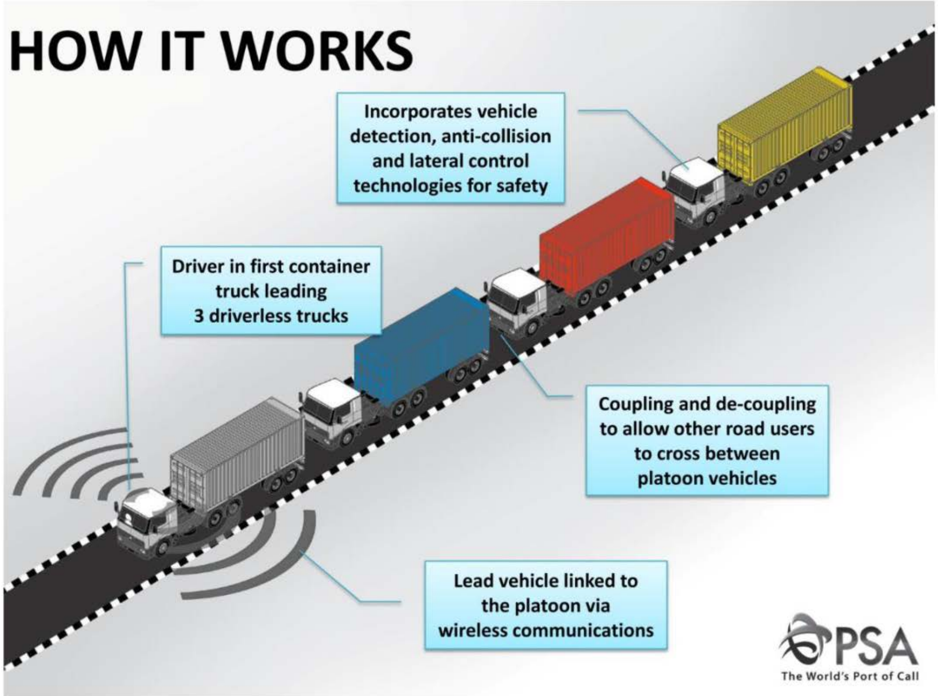

Figure 9. Illustration of Autonomous Truck Platooning Technology (Scania Takes Lead with Full-Scale Autonomous Truck Platoon 2017)

It can be expected that other automotive manufacturers will soon follow the trend in the next few years, as it is already encouraged by European Automobile Manufacturers Association (ACEA), who provides a roadmap of steps that are necessary to implement multi-brand platooning before 2025 which is shown in Figure 10 below.

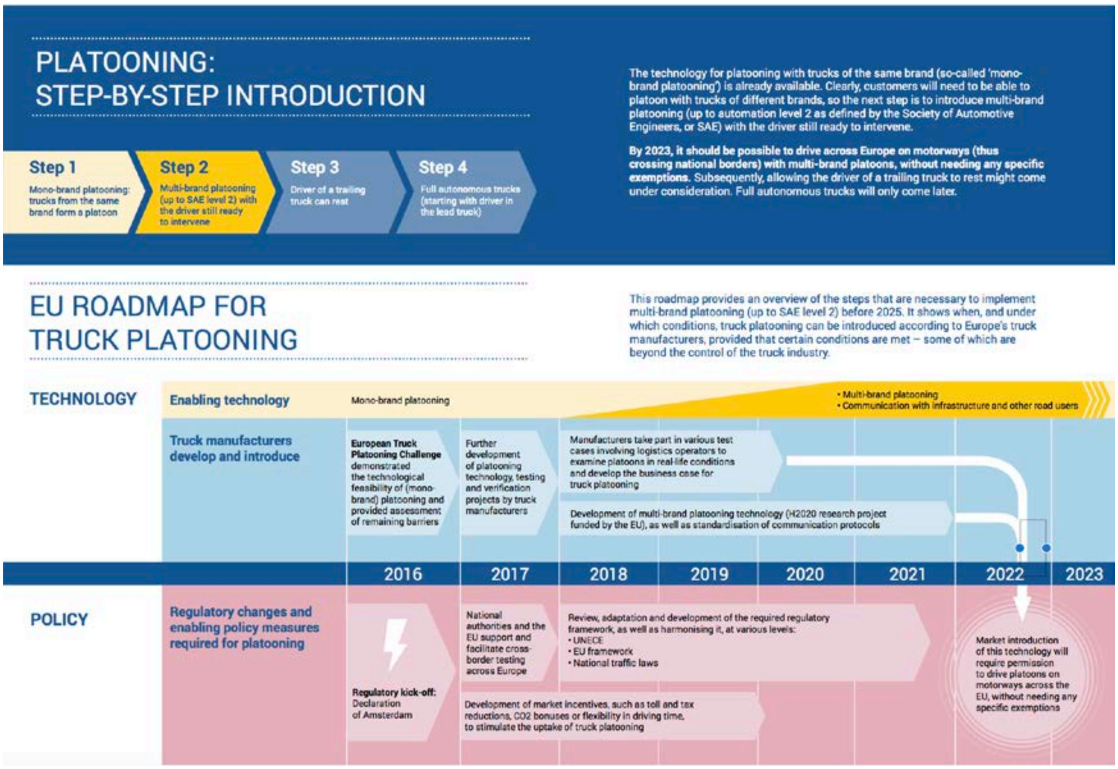

Figure 10. EU Roadmap for truck platooning (Infographic: EU Roadmap for Truck Platooning 2017)

According to ACEA, the technology for platooning with multiple trucks manufactured by the same brand (so-called 'mono-brand platooning') is already available, the next steps are multi-brand platooning (trucks from different manufacturers can form a convoy) and ultimately by 2023 there should be a possibility to drive across Europe countries on highways (thus crossing national borders) with multi-brand platoons of vehicles, without the need of any specific exemptions. (ibid., 2017).

The roadmap aims towards the implementation of SAE International's level 2 of automation, which is "Partial Automation", defined as "the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task" (AUTOMATED DRIVING LEVELS OF DRIVING AUTOMATION ARE DEFINED IN NEW SAE INTERNATIONAL STANDARD J3016, 2014) (see Appendix 1)

The benefits of platooning in terms of time efficiency, as well as other benefits such as improved safety and environmental friendliness, is studied in chapter 3.4.

3.3.2 Autonomous trucks on a fixed route

Another alternative to overcome the limitations of autonomous vehicles' motion planning system is to reduce the number and unpredictability of variables they have to deal with, so that the vehicles could more accurately plan its action. In urban areas where there are a lot of pedestrians, cyclists, motorcyclists, as well as complicated road systems and infrastructure (intersections, road signs, alleys, etc.), the vehicle needs to have the ability to predict much more signs of movement in the surrounding environment, which unavoidably results in more errors. Whereas on intercity and trans-regional highways, there are usually only cars and trucks commuting and the road are usually straight and less congested, which makes it more ideal for autonomous vehicles to operate.

As is introduced in chapter 1, the idea has already been put into practice by Otto in 2016 and other companies have also exploited the idea as well. In February 2018, Embark, a start-up company based in San Francisco, announced that their autonomous semi-truck had completed a test drive between Los Angeles and Jacksonville, Florida, over a distance of approximately 2400 miles (3862,43 kilometres) without relying on a human driver on highway (Kolodny 2018). In the test drive, the truck operated with a safety driver who, according to Embark CEO Alex Rodrigues, only had to take the wheel every few hours and only for a few seconds each time (Locklear 2018).

Also, according to Kolodny, Embark's long-term goal is to manufacture trucks that has the ability to drive autonomously on highways but would require a driver to enter and exit the highways, and to drive the vehicle in cities or small towns, which is justifiable considering the limitations of autonomous vehicles technology as of 2018.

On a general level, the idea is actually very simple and practical: trucks are driven by humans where the traffic situations are more complicated (urban areas, highway entrances and exits, road joints, among others), and drive by themselves when traffic is more predictable and consistent (typically straight highways). During the periods of autonomous driving, truck drivers can engage themselves in other work instead of driving such as making phone calls, answering e-mails or other work. This implementation not only allows the drivers to be more productive during the journey but also reduce the number of driving hours for the drivers, which would allow the drivers to cover a longer distance with the trucks, boosting the efficiency of transportation operation overall.

Looking further into the future, it is imaginable that one day drivers will only have to drive the truck from the distribution centres to the entrance of a highway, where he/she can get off the truck and let it drive along the highway all by itself, until it reaches the pre-planned exit and another driver from the destination area will pick the truck up and drive it to the final destination. If successfully implemented, this solution not only saves the time for drivers but also has the potential to attract more people to become truck drivers, as they do not have to travel far away from their home and constantly live on the go anymore. In the ideal world, that would mean drivers working only in their office's region, taking different trucks in and out of the city to and from the distribution centre in that area and go home after the shift is over. In other time, they are free to do other work such as warehousing or computer-based office work.

3.4 Benefits of autonomous vehicles

3.4.1 Efficiency improvement

By implementing autonomous vehicles into the transportation industry, the first apparent benefit is that driving hours can be reduced, since the hours which the drivers spend on a self-driving truck in its automatic mode will be counted as working time but not driving time. As mentioned in chapter 2.1, drivers, at their maximum allowed working hours, can only drive between 60 and 70 percent of their total working time. This chapter is an analysis on how much of an improvement autonomous vehicles technology can bring to the transportation field in terms of work rate, in both platooning and single truck automation.

The table belows compared the work rate of two separate trucks to a minimum convoy of two trucks with autonomous platooning, starting their working day at midnight, neglecting the time for mandatory other works such as loading, unloading and neglecting time driven in urban areas' roads. The comparison is made under assumption that the technology is applied in Finland or any other EU countries, on a day of high workload which consists of 10 hours of driving and 9 hours of daily rest for each driver. In the table, "watching" is the work when the second driver in a platooning convoy sits on his "working" means other work that is **not** driving.

Table 7. EU - Two separate trucks vs. two-truck platooning

Start	End	Time	Two separate trucks		Two-truck convoy	
			Driver 1	Driver 2	Driver 3	Driver 4
0:00	4:30	4:30	Driving	Driving	Driving	Watching
4:30	5:15	0:45	Break	Break	Break	Break
5:15	9:45	4:30	Driving	Driving	Driving	Watching
9:45	10:30	0:45	Break	Break	Break	Break
10:30	11:30	1:00	Driving	Driving	Driving	Watching
11:30	15:00	3:30	Rest/Working	Rest/Working	Working	Driving
Combined driving time			10 hours		13,5 hours	
Individual driving time			10 hours	10 hours	10 hours	3,5 hours
Total working time			11,5/15* hrs	11,5/15* hrs	15 hours	15 hours

*: In case driver 1 and 2 do other work after their driving time reaches their limit, they can work for an extra three and a half hours until their working time limit is reached, resulting in a total of 15 hours of working time on that day.

From the comparison, it can be concluded that by applying platooning technology, two drivers can drive the goods for three and a half hours more than a traditional team of two drivers. This results in an improvement of 35% in transportation hours per day. Individually, driver 3, although only drives for 10 hours, has indirectly moved the follower truck for an extra period of 3,5 hours, resulting in 13,5 hours of "transportation time" out of his 15 hours of working time – an utilisation rate of 90% on that day. In comparison, out of 15 hours of possible working hours, driver 1 and 2 can only use 10 hours of them for driving time – a 66,7% utilisation rate.

Meanwhile, driver 4, who has, directly and indirectly, driven for 13,5 hours, actually only used 3,5 hours of his driving time on that day out of his 56 hours weekly driving limit, or 90 hours of fortnightly driving limit. This means he/she has several more hours preserved for other trips compared to traditional drivers thanks to the newly adopted "watching" role, which can be later used when he/she takes the role of the leading driver, with some other driver who has used up his/her driving time quota taking the role of “watching” driver.

The difference is even more significant considering a convoy might consist of four trucks, as was mentioned in chapter 3.3.1. In that case, only one of the four drivers would have used the 10 hours of driving on the first day, the second driver would have used 3,5 hours, while the other two actually have not driven at all. Considering the limit of 56 hours of driving per week and 90 hours of driving fortnightly, it is a possible situation that the two “watching” drivers in a convoy of four have driven for 56 hours in the first week and 34 hours in the second week, which can happen in the first four days of the second week. In that case, on the fifth working day of the second week, the two of them, who would traditionally have to do other work than driving, would still be able to “indirectly” drive their trucks for another full day or two without breaking the laws, as long as their working time limits are not exceeded. For a deeper analysis, the table below shows a possible example of a driver’s schedule in two peak weeks, with platooning implemented.

Table 8. Theoretical schedule with platooning - EU

	Drive (hrs)	Break (hrs)	Watch (hrs)	Rest (hrs)	Direct driving (hrs)	Actual driving (hrs)	Working time (hrs)
Mo	9	1,5	4,5	9	56	75	84
Tu	9	1,5	4,5	9			
We	9	1,5	4,5	9			
Th	10	1,5	1,5	11			
Fr	10	1,5	1,5	11			
Sa	9	1,5	2,5	11			
Su	Day off			24			
Mo	10	1,5	3,5	9	34	68,5	76
Tu	10	1,5	3,5	9			
We	9	1,5	4,5	9			
Th	5	1,5	7,5	10			
Fr	0	1,5	12,5	10			
Sa	0	0	3	21			
Su	Day off			24			

From the schedule, it is easily seen that the actualy driving time, directly and indirectly, for a driver has increased from 90 hours to 143,5 hours, an increase of 59,4%, over a period of two weeks.

However, it should be acknowledged that the above schedule is purely theoretical and unrealistic to implement in actual working condition. The constraints include, but are not limited to:

- Over four months, average weekly working time must not exceed 48 hours (Directive 2002/15/EC of the European Parliament and of the Council of 11 March 2002 on the Organisation of the Working Time of Persons Performing Mobile Road Transport Activities, vol.OJ L 2002). This means the driver who has the schedule has to have his/her working time reduced for the periods before and after adopting the schedule so that his/her average weekly working time remains below 48 hours.
- If night work is required, the daily working time must not exceed ten hours in each 24-hour period (ibid. 2002) and most transportation operations happen in night time. The schedule may only be implemented if the majority of the working time happens in day time.

- The schedule requires a very thorough planning of working time and goods deliveries for a team of drivers, with specific driving, watching and resting schedule for every day over two weeks, and has not included obstacles that cause extra time to be spent such as maintenance, delays, traffic jams.
- Under the assumption that autonomous trucks are only allowed to operate on highways, the percentage of highways compared to total length of the route will affect the utilisation rate of autonomous driving hours.
- In the future, when the laws and regulations catch up with the development of technologies, it could be so that there would be a specific time limit for drivers who are doing the “watching” role, as they are practically on the road and that may cause for fatigue than ordinary office ground work.

The analysis should only be viewed as an example to have a broad view on the potential of platooning technology regarding increasing the actual driving time of drivers. It is a certainty that drivers’ productive hours will be improved once the technology is implemented, however, how much of an increase it brings varies from companies to companies with their own specific workload and schedules.

Looking further into the future, if a convoy may consist of from one to four driverless trucks which automatically follow the leading human-driving truck without the need of a driver in the cabin, the calculation will be vastly different and simpler. The driving time, break time and working time of a driver will stay the same, but the hours of trucks moving will be doubled, tripled or quadrupled according to the number of driverless trucks in the convoy. This means a driver could practically “drive” his trucks for a period of 180, 270 or 360 hours of moving time over two weeks. However, this report will not go deeply into that possibility as fully driverless trucks will take a much longer time to be implemented in the industry.

In case autonomous vehicles technology is implemented as in chapter 3.3.2, a single driver with his/her truck automatically driving in certain parts of the route, an analysis of reduced driving time can also be conducted. However, the benefits of this application depend on how much of the route is highway on which the truck can drive itself.

Considering a driver in the US with his/her schedule similar to that in table 3, he/she should have 84 hours of working time for a week, 60 of which are driving hours. If just 30% of a route is highway on which the trucks can be put in automatic mode, the driver can theoretically use 58,8 hours out of his 60-hour driving quota for driving, letting the truck driving itself for 25,2 hours, resulting in 84 hours of total truck moving hours, thus maximising the ratio of driving hours over working hours to 100%. In the EU where the ratio of driving hours over total working hours is even lower than that in the US, automatic driving of trucks on certain parts of the route should bring an even bigger increase in terms of productivity for the driver.

Additionally, compared to platooning, without the implementation of multi-brand platooning as mentioned in Figure 10, single autonomous truck driving is also much easier to implement, especially for smaller firms which do not usually send out more than one truck at a time. It does not require too much planning of goods loading and driver scheduling, as it can be applied at any suitable time the truck is on the road. In comparison to platooning, even though the hours benefited are lower, single autonomous truck technology with its flexibility and practicality will be a more realistic solution for the near future. In fact, all of the experiments that are already conducted by March 2018, as were mentioned in chapter 1.1 and 3.3.2, are applications of single autonomous truck driving. Platooning, though highly potential and beneficial, at the present should only be regarded as a patent, not a practical solution in the next few years.

To summarise, the implementation of autonomous trucks, in one way or another, would help reduce the number of driving hours that drivers have to do without compromising the number of actual hours that the fleets are moving on the roads, which effectively means the fleets will be used more extensively with the same amount of input hours from the drivers. Subsequently, if the volume of goods that need to be transported and the number of drivers remain the same, a firm can operate with a smaller fleet thanks to the extra hours that the technology will bring. Theoretically, the reduction in fleet could be up to 50% (MANAGING THE TRANSITION TO DRIVERLESS ROAD FREIGHT TRANSPORT 2017, 22). On the other hand, based on the same hypothesis, if the fleet remain the same size but equipped with autonomous technologies, the volume of goods transported during the same period of time would be doubled.

3.4.2 Safety improvement

As is mentioned in chapter 2, the trucking industry has not had any improvement in terms of safety in recent years, taking evidence from the fact that accident rates have not been declining for the past ten years. This chapter presents an analysis on how, theoretically and practically, autonomous driving technology brings safety improvement compared to human driving.

The majority of human errors that cause traffic accidents, analysed in chapter 2.3, are recognition errors, decision errors and performance errors. For each of those categories of errors, the technologies equipped with autonomous cars should help prevent the errors from happening, or at least reduce the impact of the happening of them.

Recognition errors, which are inattention and distractions of the drivers, will not happen to autonomous driving systems since the sensors on the vehicle are always on as long as they are powered. The combination of different kinds of sensors (radar, lidar, ultrasound, among others) will also provide a much better range and accuracy compared to the human vision and hearing – the two human senses that are used in gathering surrounding environment data for a driver. Generally, human can only pay full attention to objects within his/her field of attention of around 60 degrees (Sardegna 2002, 253), whereas the sensor systems can have a full-time 360 degrees field of view vertically, as illustrated in Figure 4. When a driver deliberately turns his/her head or eyes to one side to look at something (e.g. looking the mirrors or looking for the cause of a distracting sound), he/she immediately loses attention to the field of view ahead of them, which is very likely to cause an accident if an unexpected event happens in front of the vehicle. Meanwhile, machine visions can continously monitor everything around the moving vehicle, all at once, without any distraction, which eliminates the risk of inattention of distraction. Additionally, 360-degree vision also solves the problem with blind spots, as demonstrated below (Swapp 2017), which is a likely cause of truck-related accidents.

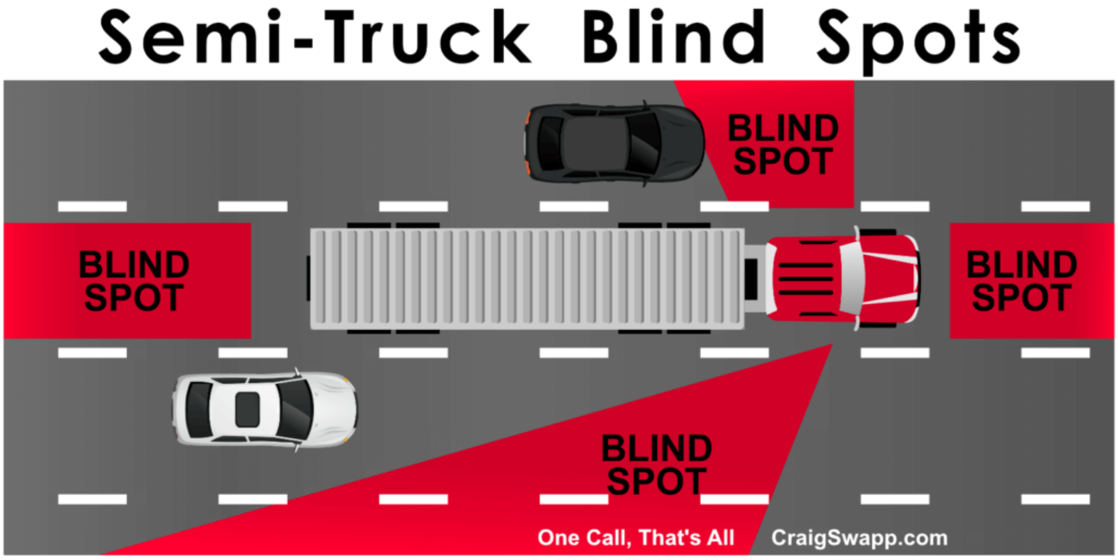

Figure 11. Truck's blind spots

Decision errors, as the name of the category suggests, are associated with the drivers' incapability to make the correct decisions under certain circumstances, may it be related to speeding or steering. In this regard, a vehicle controlled by a computer should always make the correct decision, presuming it is programmed for every possible circumstance on the road. However, preparing the autonomous vehicle to adapt to road incidents is a major challenge in the field of autonomous technologies, as computers do not have the common sense of human, thus it will not know how to react if an incident that is not pre-programmed happens on the journey. This is one of the main causes of accidents related to autonomous vehicles, which will be studied in a following chapter. Nevertheless, theoretically, with the development of machine learning and artificial intelligence, a vehicle control system would be able to learn how to react to traffic over time, and will be able to become a perfect driver with an adequate amount of programming and learning.

Performance errors are also a type of errors which autonomous technology can completely replace human input. As soon as a decision for action is made, be it accelerating or steering, it is most likely that the control unit will execute the action more smoothly than a human can, thanks to its precision in calculation, which subsequently means better decision making and timing. Additionally, thanks to its better ability to keep track of the surroundings, the autonomous vehicle is usually able to react faster than a driver can, thus lowering the risk of sudden braking or turning, which in turn decreases the probability of an accident happening.

Several studies have focused on the crash rate of autonomous cars compared to conventional drivers' cars. In a report published by Virginia Tech Transportation Insitute and commissioned by Google, Blanco et al. (2016) found that self-driving cars may have ow rates of more severe crashes when compared to national (US) rates, even though there is uncertainty to draw that conclusion with strong confidence. The results are presented by comparing the crash rates from Google's self driving cars' crashes and police-reported crashes and rates estimated from the Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS), demonstrated in the graph below (level 1 is the most severe crash category, level 3 is the less severe crash category).

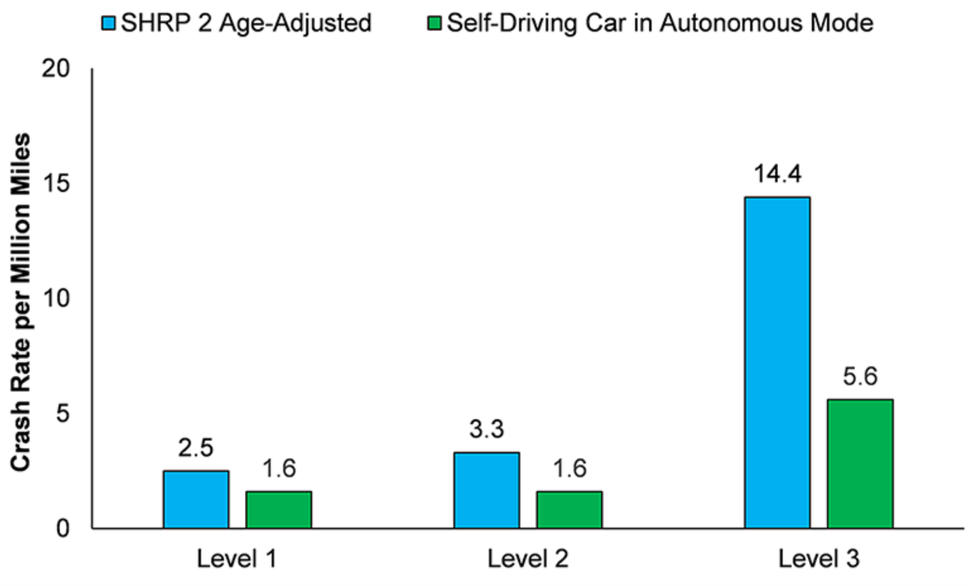

Figure 12. SHRP 2 NDS and Self-Driving Car Crash Rates per Million Miles

In early 2017, NHTSA published a report concerning Tesla's Autosteer technology, a driver assistance system that can automatically keep the cars in lane even when approaching curves, which had been implemented in several Tesla models between

2014-2016. The report shows that Tesla vehicles crash rate dropped by almost 40 percent after Autosteer installation, as illustrated in the figure below (Muoio 2017).

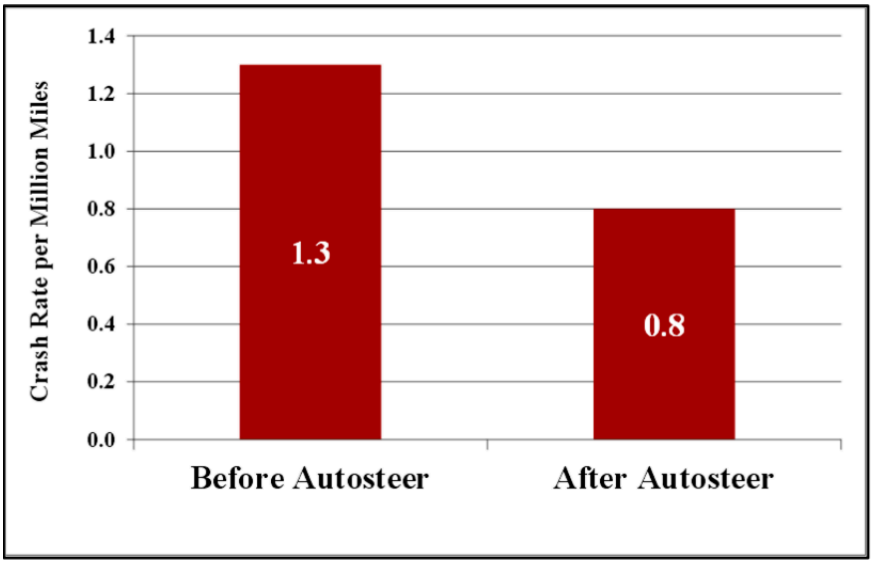

Figure 13. Crash Rates in MY 2014-16 Tesla Model S and 2016 Model X vehicles Before and After Autosteer Installation.

Additionally, with the prospect of V2V (vehicle-to-vehicle) communication, autonomous vehicles will have the ability to avoid risk before a traditional driver may even know about its existence. With this technology, vehicles can automatically communicate with each other by a common communication system such as wireless local area networks (WLANs). As a result, one vehicle can receive information about critical or dangerous situation at early stages from another vehicle ahead of it, then subsequently give warnings to the driver or control centre to adjust the vehicle's motion to better adapt to the situations (e.g. damaged roads, unexpected obstacles or accidents). In comparison to a driver who can only recognise something when he/she sees it by eyes, V2V communication would provide much more time for the vehicle controller, be it a driver or a computer, to react to the situation (Heutger 2014, 6).

3.4.3 Cost savings

According to Hooper and Murray (2017, 36), the cost structure of operating a traditional truck can be categorised as follow.

Table 9. Cost structure of truck operation

Motor Carrier Costs	**Share of Total Cost**
Fuel Cost	21%
Truck/Trailer Lease or Purchase Payments	12%
Repair & Maintenance	19%
Insurance	9%
Permits and Licences	2%
Tyres	3%
Tolls	2%
Driver Wages	23%
Driver Benefits	9%
TOTAL	**100%**

From the table, it can be stated that fuel and driver cost are two of the biggest factor when operating a truck commercially. Together, they account for roughly half of the operating costs of a truck.

As autonomous vehicles are not fully commercialised, there have been no studies with practical data concerning how much cost autonomous vehicles can save compared to human-driving vehicles. However, there are several hypotheses that autonomous vehicles would bring cost saving benefits regarding fuel consumption and labour costs of drivers. It should be acknowledged that cost savings related to fuel consumption and labour cost may not necessarily mean saving in overall transportation cost, as there could be extra costs incured when implementing autonomous driving.

Platooning of trucks has a high potential when it comes to fuel efficiency, since trucks will be able to drive close together at constant speed with less braking and accelerating (What Is Truck Platooning? 2016). An actual testing project has proved this hypothesis, estimating that a convoy of one truck and three cars travelling on road can have a saving of up to 20 percent of fuel consumption (SARTRE Road Train

Premieres on Public Roads; Focus Now Shifts to Fuel Consumption 2012). According to another study, in addition to the effect of better controlled accelerating and braking, trucks travelling in convoy also creates a better aerodynamics environment for the trailing vehicles, resulting in a reduced aerodynamic drag, which means the vehicle can use less energy to achieve the same level of movement compared to travelling individually. This effect is more pronounced when the convoy of trucks travel in close distances to each other (less than 20 metres), and overall, can achieve a fuel consumption saving of 14,2%. (McAuliffe et al. 2017, 35).

Richard Cuerden, UK's Transport Research Laboratory (TRL)'s academy director stated that platooning of trucks will make the vehicles more efficient, as drivers of the following trucks will not have to sharply apply brake and accelerate again in the event of obstacles on the way. Theoretically, this method can reduce the vehicles' carbon dioxide emissions by ten percent, which is a huge contribution to the reduction of environmental costs. (Burgess 2017).

As is shown in the analysis in chapter 3.4.1, the number of productive hours of a driver may have a huge increase thanks to autonomous driving, which consequently reduce the marginal cost of a certain load of goods. However, as pointed out in chapter 2.2, due to the lack of drivers, it might be so that in the future, companies will have to pay more for the drivers to attract people to work. Additionally, to operate a fully automated vehicle, a driver also has to have a certain level of training to get used to the technologies, as well as to dealing with technical problems that might happen along the way. In the end, labour cost is not certain to increase or decrease in the near future. However, looking further into the future, once driverless vehicles can be operated (e.g. platooning), it is a certainty that labour cost will go down because it is very unlikely that a driver's wage will be increased multiple times, even though his/her producitivy has been increased multiple times, as is explained in chapter 3.4.1.

Regarding overall financial benefits, currently there are many uncertainties about operating costs related to autonomous trucks, whose prices are not yet estimated. Compared to a normal truck, an autonomous truck would definitely cost more to purchase due to the technologies implemented. In early implementation phases, it can also be expected that the software needs to be updated on a frequent basis, and software costs cannot be determined until a final version of any software is released. Additionally, the sensors used for autonomous technologies, which is essential for driverless truck operation, also need to be carefully monitored and maintained. In short, autonomous technology should reduce the cost of driver and fuel, which are the two biggest factors in the cost structure, but at the same time will incur extra cost of capital and maintenance.

3.5 Prerequisites, limitations and challenges for autonomous vehicles

As a new technology, autonomous vehicles require several conditions to be fulfilled before they are able to operate as expected. Those conditions are related to, but not limited to, infrastructure, laws and regulations and popular opinions. Also, autonomous vehicles are not without flaws. They have to overcome several challenges in order to become the new standard of transportation. This chapter provides an overview on the prerequisites, limitations and other hindering factors when implementing autonomous vehicles technology to the real world.

Referring to chapter 3.1, to be able to perform autonomous driving, a vehicle needs four functions: navigation, situation analysis, motion planning and trajectory control. Each of them requires certain external conditions to be able to work.

- Navigation: GPS and other satellite-based navigation systems depend on signals between the receiver in the vehicle and multiple satellites in the system. Radio signals used in GPS can be interfered by unavoidable environmental factors such as dense trees, steep hillroads, high surrounding buildings or thick cloud cover (Gordon 2013). In order to maintain a stable signal connection with the satellites, it can be expected that future autonomous cars need stronger receivers as well as more suitable infrastructure for the signals to pass through. Additionally, the technology of V2V communication, explained in chapter 3.4.2, could also be used to help vehicles keep contact with other vehicles ahead of them, so that they get the exact routes and directions as expected.
- Situation analysis: In order to help a vehicle to keep track with all its surrounding, a central data processing unit must be able to perform instant

analysis and combination the data gathered by different sensors, as each type of sensor has a different hindering factor. LIDAR cannot work in foggy conditions, video cameras only work in good light, radar signals can be interfered, and other limitations. (Saripalli 2017). Additionally, road signs, traffic lights, lane dividers and other informative objects on the roads have to be in clear view for the sensors to see, while general road data such as speed limit, construction, one-way and prohibited routes, among others, have to be constantly updated in the database servers of the manufacturers.

- Motion planning: To be able to make correct decisions on the road, automatic vehicles need to be programmed for the maximum amounts of situations possible, as well as to be taught the ability to react to unexpected situations caused by other drivers.
- Trajectory control: Autonomous vehicles ideally should be able to perform better, or at least as well as a human driver, which means they need to be taught how to naturally change speed and direction like a human driver, in order not to confuse other drivers and subsequently avoid accidents.

Additionally, environmental factors need to be heavily considered when designing an autonomous driving system. In tropical areas, sudden and short-lasting heavy rains cause slippery roads and unclear view of sight, and autonomous vehicles need to know when to slow down and what to expect from other vehicles in such conditions, such as other vehicle pulling over, being more vulnerable to decision mistakes, etc. The same thing can be said about snowy conditions in regions with extreme weather. The road can be temporarily covered in snow, which makes the lane dividers invisible, at the same time worsening driving conditions. On a clear sunny day, an extremely bright sky would make it hard to the camera, which faces towards the sky, to detect and distinguish road signs and traffic lights due to high contrast. For a human driver with common sense and conditional reactions as well as memory, he/she can adjust to the condition simply by knowing what to do through experience (adjusting the speed, keeping in lane with instinct, putting on sunglasses, etc.). The computer needs to have the ability to learn and adapt before it can compares with human regarding reacting to the circumstances.

Overall, in order to implement a machine-controlled transportation vehicle system, a lot of road travelling data needs to be gathered in order to train the computers. In fact, major autonomous vehicles manufacturers like Tesla and Waymo (which belongs to Google) have been practising this action, and billions of driven miles data have been collected as of 2018. However, collecting data is only the first step of machine learning. The next step, according to Elon Musk, CEO of Tesla, is even more challenging: processing the data. In the end, it is claimed that data is the most valuable asset that an autonomous vehicle manufacturer may have (O'Kane 2018). Consequently, it can be expected that in the next years or decades, these companies would rack up a huge amount of data which needs to be collected, simulated processed and stored. In order to achieve that, the role of technology firms (Tesla, Google, Uber and others) should be as important as automobile manufacturers (Audi, GM, and others) in the development of the technology. Thus, it is safe to assume that in the near future, collaborations between those two types of companies would be a more common practice, since a company specialised in technology would not have the resources to develop and test the hardwares and vice versa.

Current laws and regulations need to be updated before autonomous vehicles are allowed to drive on the roads. According to the Vienna Convention of Road Traffic, which is ratified by more than 70 countries as the foundation for domestic and international road traffic regulations, a driver has to be present controlling a vehicle on the move at all times. Even though there has been an additional rule to the convention, stating that if the autonomous steering system can be stopped by a driver at any time, it is permissible, it will be a long way to achieve the optimal set of laws and regulations to allocate autonomous vehicles in public traffic (Heutger 2014, 8).

In case of accidents, liability issues also need to be clarified. There has to be a clear boundary between the responsibility of the car owner and the manufacturer in the event of an accident, since the actual "driver" might not be necessarily the car owner anymore. In one of the case that will be studied below, there have been controversies regarding who takes the responsibility in an accident related to autonomous vehicles. As we can expect similar incidents to happen in the future, a clear and standardised set of laws and regulations will be needed so that the authorities can consistently identify which side is responsible for an accident that does not have “driver liability” anymore. In general, it can be expected that liabilities will be shifted from drivers to manufacturers. However, there are different levels of automation, with varied level of driver’s interaction with the motion of the vehicles, which in turn means there could be cases that the driver does not intervene when he/she needs to, either because of his/her mistakes or because of the manufacturer’s misinformation. Either way, there needs to be some level of alternation to the current laws and regulations which splits clearly between driver/owner liability (damage to person to property) and manufacturer liability (defects and faulty instructions) (Heutger 2014, 8).

Another hindering factor that may slow down the implementation process of autonomous vehicles is public opinion. According to the American Automobile Association (AAA), 78% of Americans are afraid to ride in a self-driving vehicle (Americans Feel Unsafe Sharing the Road with Fully Self-Driving Cars 2017). Based on that statistics, it is assumable that the majority of people would also feel unsafe when travelling on the same roads with self-driving vehicles, especially large and powerful vehicles such as trucks. So as to commercialise autonomous vehicles, there has to be acceptance from the public so that the technology can be seamlessly implemented.

Cybersecurity can also be expected to be a concern for automotive manufacturers. As vehicles are controlled by computers, it is a possibility that computers are hacked and controlled from unauthorised users, which inevitably will cause catastrophic incidents if the hacker with bad intention controls the vehicles. Manipulated information collection could also be a problem, for example someone may intentionally send false data about road blockages or constructions in order to congest a certain route, or false weather-related information to slow down the vehicles.

4 Case studies – autonomous cars in the real world

In this part, two cases of autonomous car systems accidents are presented, in order to give practical view on the challenges and limitations of the technology. There has not been a significant incident involving autonomous commercial trucks yet, but the incidients that will be presented will mostly concern the technical aspect of autonomous driving in general. As a result, they may still bring insights to the readers about the current state of autonomous driving in general.

4.1 Tesla driver killed in car crash with Autopilot mode activated (2016)

4.1.1 Background

According to Tesla, Tesla Autopilot, first introduced in 2014 (Dual Motor Model S and Autopilot 2014), later marketed as Enhanced Autopilot, is a driver assistance system offered by automotive company Tesla, which, once activated, has the ability to automatically steer to stay in its lane, change lanes when turn signal is on and change the speed accordingly by reading road signs and using cruise control, all without the driver making inputs to the driving system.

4.1.2 The incident

According to Reuters, on May 7th 2016, in Williston, Florida, a Tesla Model S car in autopilot mode crashed into a truck-trailer vehicle combination, killing the Tesla's driver after the car's windshield hit the the trailer's bottom as the Tesla passed underneath the trailer and kept moving, left the road and hit several obstacles before stopping 100 feet (30.5 metres) away from the road (Shepardson, Sage and Woodall 2016).

According to The New York Times, "the crash occurred when a tractor-trailer made a left turn in front of the Tesla, and the car failed to apply the brakes." (Vlasic and Boudette 2016)

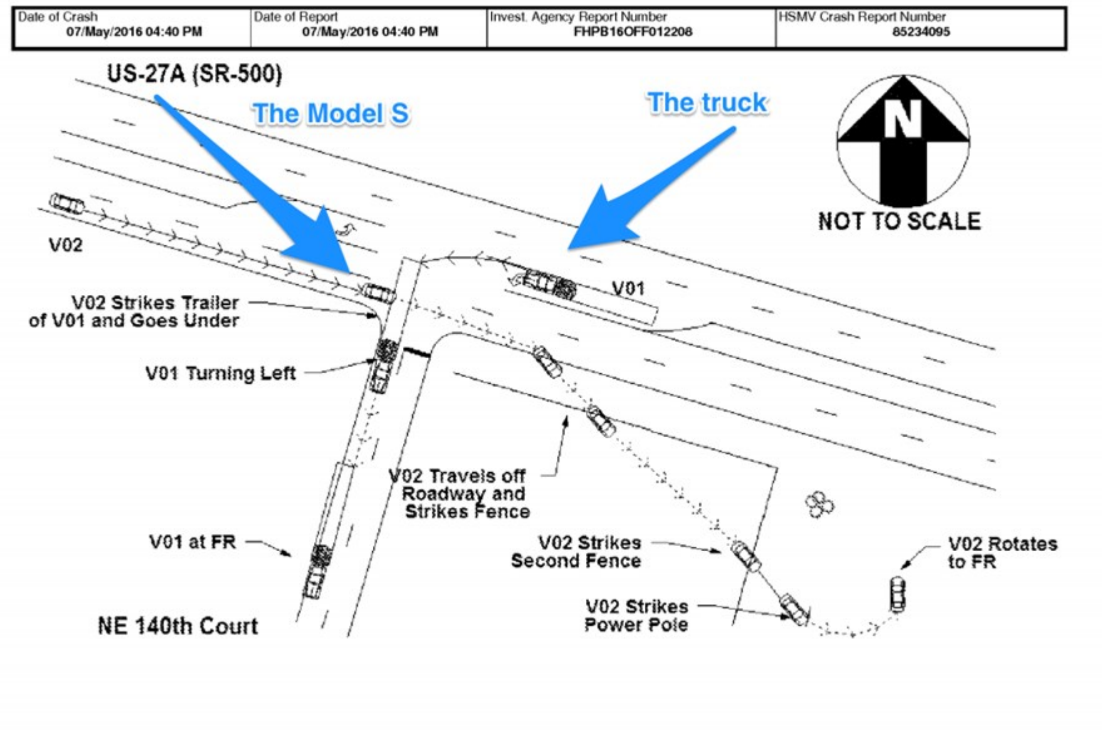

Figure 14. Diagram of the Tesla crash (Thompson 2017).

The Tesla was going straight and not slowing down as it had the right of way against the truck which was about to turn left. Therefore, it can be said that the Tesla was going by the rules, while the truck driver was at fault for turning without his right of way. However, in a normal situation when seeing a vehicle combination coming the other way signalling to turn left, most likely the car would slow down and giving the truck enough time and space to make the turn. This was a case where the machine-controlled system could not cope with variables that are not rigidly dealt with by the system of laws, but by human's common sense.

Tesla's official statement on the incident quoted:

> *What we know is that the vehicle was on a divided highway with Autopilot engaged when a tractor trailer drove across the highway perpendicular to the Model S. Neither Autopilot nor the driver noticed the white side of the tractor trailer against a brightly lit sky, so the brake was not applied. The high ride height of the trailer combined with its positioning across the road and the extremely rare circumstances of the impact caused the Model S to pass under the trailer, with the bottom of the trailer impacting the windshield of the Model S.*

And

> *Autopilot "is an assist feature that requires you to keep your hands on the steering wheel at all times," and that "you need to maintain control and responsibility for your vehicle" while using it. Additionally, every time that Autopilot is engaged, the car reminds the driver to "Always keep your hands on the wheel. Be prepared to take over at any time." The system also makes frequent checks to ensure that the driver's hands remain on the wheel and provides visual and audible alerts if hands-on is not detected. It then gradually slows down the car until hands-on is detected again.*

(A Tragic Loss 2016)

Meanwhile, Business Insider Nordic, based on a report published by The National Transportation Safety Board, stated that the Tesla driver had in hands off the wheel for the majority of the time that the car was in Autopilot mode (Thompson 2017). This clearly indicates that the driver was using the driving assistance system in a way it was not designed to be used.

On the same day that the statement was published, Elon Musk, CEO of Tesla, claimed on his social media channel (Twitter) that the radar system mistook the white trailer with a large gap from the trailer's bottom to the ground for an overhead road traffic sign, and thus, the system did not apply the brake (Hawkins 2017).

On January 19th, 2017, The National Highway Traffic Safety Administration released a report after six months of investigation into the accident concluding that Tesla's Autopilot system was largely not at fault for the accident, and that it was mostly the driver's misuse of the Autopilot system that resulted in the accident (ibid. 2017).

4.2 Pedestrian killed in a crash involving Uber's self driving car (2018)

4.2.1 Background

According to AP, Uber had been testing their self-driving cars in Tempe, Arizona since February 2017, with all of their self-driving cars having a safety driver behind the wheel to monitor and possibly intervene if required. Uber, being well-known for their peer-to peer ride-sharing service, had offered their customer in Tempe, Arizona the option to take the ride in a self-driving car. The program was welcomed by Gov. Doug Docey who took a ride in one of those cars on February 21st, 2017 (Uber Begins Testing Self-Driving Cars in Tempe Area 2017). Tempe was considered an ideal place to test autonomous vehicles thanks to its dry weather and wide road. In 2015, Arizona officials declared the state a regulation-free zone in order to attract testing operations from autonomous cars manufacturers like Uber, Waymo and Lyft (Wakabayashi 2018).

4.2.2 The incident

According to the New York Times, on March 18th, 2018, a woman was fatally struck by an autonomous car operated by Uber in Tempe, Arizona. The car had a driver at the wheel, going at around 40 miles per hour (64,37 kilometres per hour) in autonomous driving mode when it struck the victim, Ms. Herzberg, 49, who was walking with her bicycle across the street, with diagram of the incident provided below in Figure 15 (Griggs and Wakabayashi 2018).

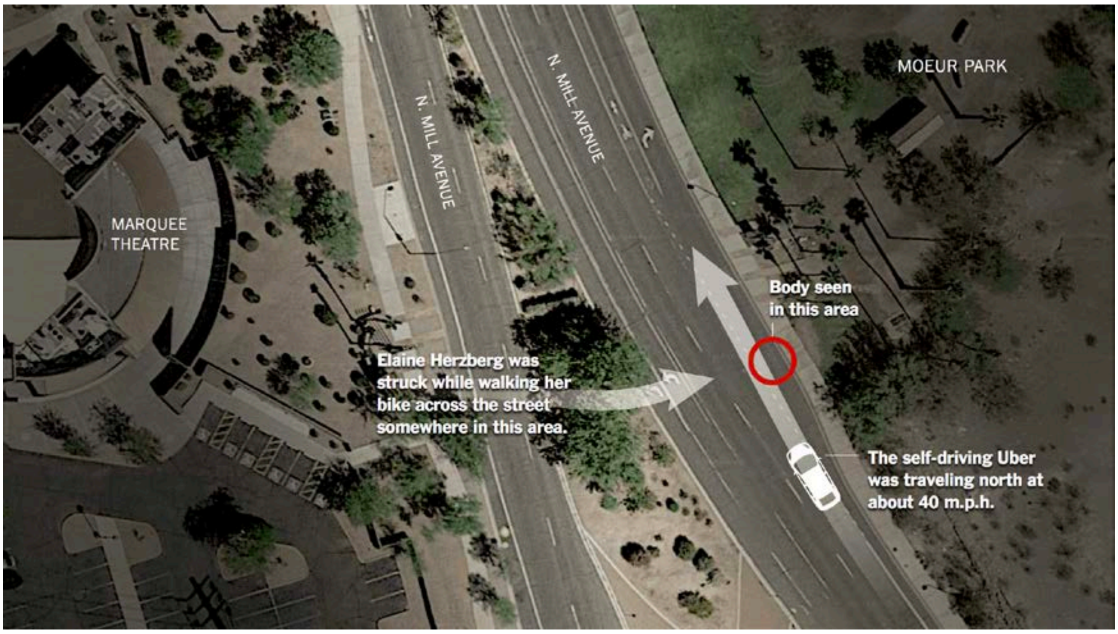

Figure 15. Tempe accident diagram

Before the fatal crash, the car showed no sign of slowing down, according to Tempe Police Department (Hawkins 2018b). On March 21st, three days after the incident, Tempe authority released footages from a dashboard camera recording from the vehicle showing the interior and exterior of the vehicle. The first footage showed that the woman was walking her bicycle across the middle of the street where there are no zebras (Griggs and Wakabayashi 2018) (see Figure 16).

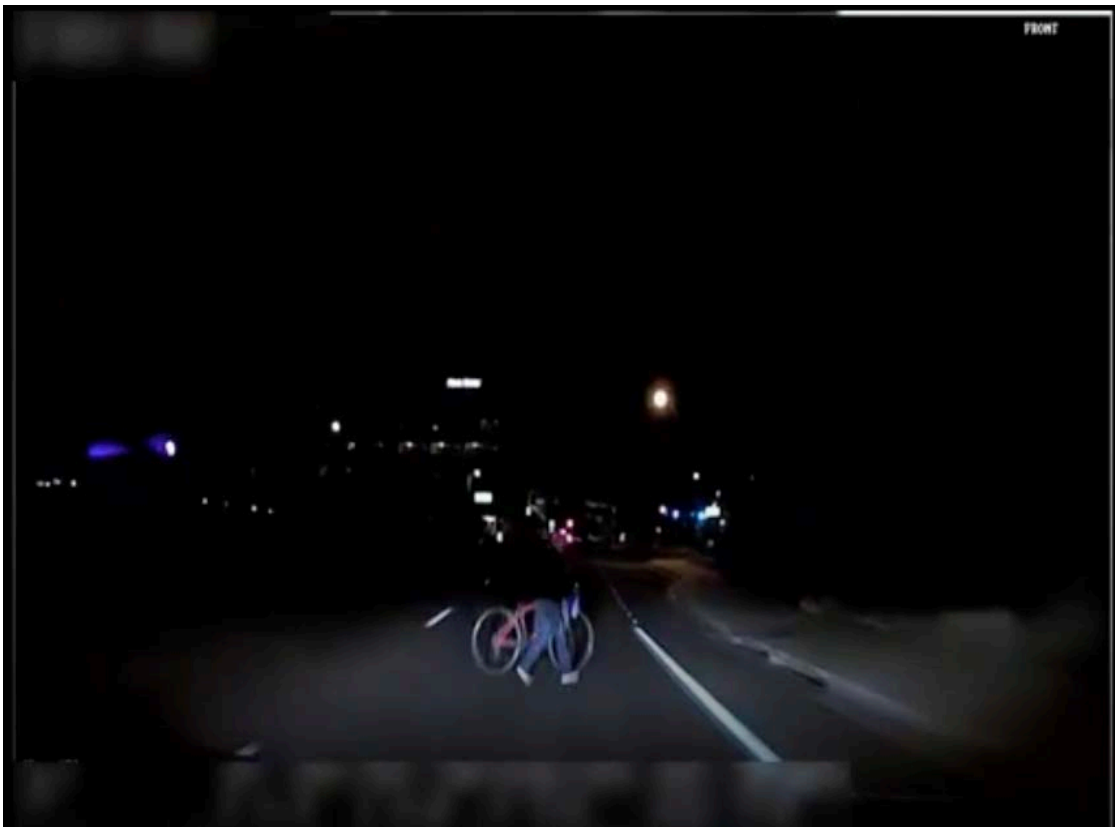

Figure 16. Tempe accident, exterior footage

Meanwhile, the second released footage showed that the driver was not paying attention to the road and her hands were not on the steering wheel. She was clearly distracted and appeared shocked when the incident happened. (ibid. 2018)

The Tempe Police Department released a full statement regarding the incident, which reads:

> *On March 18, 2018 at approximately 10pm, Tempe PD responded to a traffic collision on Curry Road and Mill Avenue in Tempe, Arizona. The vehicle involved is one of the Uber's self-driving vehicles. It was in autonomous mode at the time of the collision, with a vehicle operator behind the wheel. The vehicle was traveling northbound just south of Curry Road when a female walking outside of the crosswalk crossed the road from west to east when she was struck by the Uber vehicle. The female was identified as 49 year old Elaine Herzberg. Herzberg was transported to a local area hospital where she passed away from her injuries. Uber is assisting and this is still an active investigation.*

(Hawkins 2018c)

This was the first known incident related to autonomous cars in which a pedestrian is killed in the crash (Bergen 2018). After the incident, Uber halted autonomous vehicles testing in Arizona, as well as in other testing sites of Pittsburgh, San Francisco and Toronto (Griggs and Wakabayashi 2018).

As of April 2018, there have been no statements from Uber regarding whether the incident was caused by a software or hardware error, or if it was Uber's fault at all. However, according to The San Francisco Chronicles, Tempe police chief Sylvia Moir had stated that the collision was very difficult to avoid either with autonomous or human driving considering the woman came from the shadow straight into the highway, and that Uber was not likely to be at fault for the incident (Said 2018b). On the contrary, also speaking to The San Francisco Chronicles, Brad Templeton, a Silicon Valley entrepreneur who was an early consultant on Google's self-driving project, claimed that the technology must have seen detected the woman, and the incident must have been Uber's fault. Additionally, Brad accused the safety driver of not doing her job properly by being distracted and looking down right up until the impact (Said 2018a).

4.3 Case comments

In both cases, there are several common factors that lead to the happening of accidents:

- The autonomous vehicle drivers misused autonomous mode. In both cases the drivers were not paying attention to the traffic, and were not in a ready state to intervene.
- The autonomous vehicles' autonomous modes failed to react to unexpected events caused by other human drivers' actions in a human-like manner. In both cases, the autonomous vehicles did not slow down until the crashes happened, which indicates that the autonomous vehicles could not sense the potential of accidents.
- In both cases, even though other traffic attendants were at fault from a legality point of view, the situations could have been avoided had the safety human drivers intervened in time.

- In both cases, the lighting conditions were not ideal for the cameras onboard, which made the vehicles fail to detect the obstacles.
- Both incidents are not likely to have happened if it were a traditional vehicle driven by a driver in good state of health and paying full attention.
- Both incidents are not likely to have happened if everyone follows the laws and regulations of road travelling.

The two incidents prove that even though autonomous vehicles are promising, there's still a lot to improve before they can be officially put into operation. Specifically, autonomous vehicles should be trained to react to certain events as if a human is driving the vehicle in order to avoid confusion for the other human travelling along with them. Also, sensoring systems on current autonomous vehicles seem to be imperfect in more difficult driving conditions. Until autonomous vehicles can function safely in extreme weather conditions such as bright sunlight, fog, heavy rain, snow and in the dark, accidents due to unideal driving conditions would be a very apparent threats to the safety of the vehicles' passengers as well as other travellers on the road.

Education for autonomous vehicles operators should be treated as a priority before the implementation of the technology, especially in early implementation phase. It is proven in the two previously mentioned cases that misuses of autonomous modes in the vehicle may cause fatal consequences to both the driver of the vehicle and other road travellers.

For other road travellers, the importance of following the laws and regulations should also be re-emphasised once autonomous vehicles are allowed to operate, as computers are expected to strictly follow the laws and bypassing common sense in situations when they have the rights. For example, pedestrians should never cross the roads where the are not zebras, drivers should never take the turn without their right of ways, among other commonly ignored rules. In more complex situations such as urban areas where unexpected events are even more likely to happen, it is probable that autonomous vehicles need to be trained to predict the events based on early signs, for example they should be able to detect children in the pavements which may run into the road in any moments, or building entrances from where bicycles and motorcycles may suddenly come out, etc. In that case, the motorway should possibly treated more like railways, which should never be entered except at designated spots for entering or crossing.

5 Discussions

5.1 Research results

The research has successfully covered the proposed research questions mentioned in chapter 1.2. To recap, autonomous driving technology has the potential to significantly improve efficiency of transportation regarding transportation volume over time. With the technology implemented, a driver may theoretically increase his/her productivity by up to 50%, as analysed in chapter 3.4.1. Road safety certainly will also be improved thanks to the technology, demonstrated by the decreased accident rates of cars by up to a half after the implementation of autonomous driving assistance systems, shown in chapter 3.4.2, even though the technology is only in its early implementation phase. Backed by several studies, it is possible that road safety can be improved even more when autonomous driving can be openly applied on the roads, mainly thanks to the computers' better, faster and more reliable sensing, decision making and action executing abilities.

The improvement in cost efficiency, however, is uncertain as of May 2018, due to several undefined factors regarding the costs of operating autonomous trucks, as no autonomous trucks have been widely commercialised. There have been studies claiming that autonomous trucks, and autonomous vehicles in general, have the potential to save fuel costs and labour costs. However, the uncertainty regarding capital and maintenance costs makes it difficult to conclude whether autonomous trucks will bring an improvement to the total operating costs of the trucking industry or not; it is only certain that the cost structure of truck operation will be impacted.

Another additional finding as a result of the research is that the autonomous driving technology has to overcome several challenges before it can become a practical solution for the transportation industry. The technology has not matured enough to be reliable without human input, the public opinion on the technology also needs to be improved, while laws and regulations need to be updated to accommodate a totally new type of vehicles on the roads.

5.2 Reflections and suggestions for future further researches

The research was conducted in the early phase of implementation of autonomous driving technology, therefore the availability and variety of available data is generally limited. As of May 2018, autonomous cars have only been tested in North America, Europe and, to a limited extent, Australia. While the potential is fairly apparent in those mentioned regions, the practicality of the technology in less developed regions of the world such as South America, Africa or Asia should be put into question.

Furthermore, there have not been many academic studies on the subject due to its nature of being a newly adopted concept, which limits the number of points of view on the technology. Specifically, no autonomous trucks have been commercialised, making it impossible to accurately estimate the actual cost of operating one. The benefits and limitations analysis of autonomous driving has been conducted using available data for autonomous passenger cars instead of trucks, which is closely relevant but still might have a difference compared to autonomous trucks.

In the future, when autonomous trucks are widely commercialised, the research can be conducted again with the exact same methods and research questions. With the more relevant data collected from actual operation of autonomous trucks, the results will be more accurate and reliable, which will give a better view on the technology of autonomous trucks. At present, the research may serve as a guideline to prepare for the inevitable future of autonomous vehicles for all parties involved: manufacturers, customers and public infrastructure managers. In the meantime, it would be beneficial to educate the public about all matters related to the technology, as it is fairly new and underappreciated by the general population.

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Appendices

Appendix 1. SAE International's Level of Driving Automation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**