Autonomous vehicles and road transportation safety

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Road transportation is the final step of all transportation modes in the logistics field. With the development of technology, people are dissatisfied with traditional vehicles, especially when the annual traffic accident rates maintain a stable level. The main reasons for traffic accidents have been analyzed and published by official road safety administrations, such as the European Commission, National Highway Traffic Safety Administration, the International Road Transport Union and other organizations. However, they still do not have effective solutions for reducing the traffic accident rates. Autonomous vehicle technology combined with traditional vehicles could provide one opportunity for reducing traffic accidents.

The objective of the study was to explain how autonomous vehicles could possibly change the current road transportation safety. Moreover, it examined the public opinions on and the expected benefits of autonomous vehicles and attempted to answer the question why autonomous vehicles could be safer than traditional vehicles.

In order to achieve the objectives, this study combined the qualitative and desk research methods. All the data was collected from previous studies, journal articles, literature and specialist statements.

According to the results, autonomous vehicles are safer than traditional vehicles theoretically. However, autonomous vehicles are not widely used yet. The public have positive attitudes towards autonomous vehicle development. Safety and environment were the main expected benefits from autonomous vehicles. For now, the required technologies are still under testing. They need to be reliable before be used commercially.

Keywords/tags: transportaiton, autonomous vehicles, safety, eco-friendly, efficiency, technology.
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<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRU</td>
<td>International Road Transport Union</td>
</tr>
<tr>
<td>ATA</td>
<td>American Trucking Associations</td>
</tr>
<tr>
<td>NHTSA</td>
<td>National Highway Traffic Safety Administration</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>SARTRE</td>
<td>Safe Road Trains for the Environment</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>UCS</td>
<td>Union of Concerned Scientists</td>
</tr>
<tr>
<td>TPMS</td>
<td>Tire Pressure Monitoring Systems</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Preface

According to UCS’s definition, “Self-driving vehicles are cars or trucks in which human drivers are never required to take control to safely operate the vehicle. Also known as autonomous or ‘driverless’ cars, they combine sensors and software to control, navigate, and drive the vehicle.” (Self-Driving Cars Explained 2018).

Driverless vehicles were mentioned and tested for the first time at least in the 1920s. (‘Phantom Auto’ Will Tour City 1926). The research and development of a driverless vehicle has never stopped since. In 1969, John McCarthy published one essay with the title “Computer-Controlled Cars.” He indicated that a vehicle should have the ability to have visual input about the road situation through a camera instead of a human driver. It should possible for passengers to input the destination and the car could drive to the destination by itself immediately.

In 1995, Pomerleau and Jochem took the first self-driving system, Navlab onto the road. They installed the system into one minivan. The minivan travelled 2,797 miles from Pennsylvania to California. The journey went without human control of the steering but speeding and braking. In 2003, the Japanese car manufacturer Toyota introduced the automatic parallel parking assistant. In 2009, Ford introduced the Active Park Assist. Meanwhile, in 2009, Google started to build their own self-driving cars with the name Waymo. In 2013, the main car manufacturers including General Motors, Ford, Mercedes Benz, BMW and a few other companies were involved in autonomous vehicles technology research and development. (Dormehl & Edelstein 2018). In 2014, Tesla introduced its first version of self-driving system which installed in Model S. Moreover, Tesla’s self-driving system could receive software updates to improve the vehicle skills. (Lowensohn 2014). Autonomous vehicles received higher attention than other type of vehicles. It became the megatrends for vehicles’ future development. The following table describes the main autonomous vehicles manufacturers testing records.
Table 1. In 2016, the records of main autonomous vehicles manufacturers testing records. (Wang, 2018)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Distance between disen-gagements</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waymo</td>
<td>5,127.9 miles (8,252.6 km)</td>
<td>635,868 miles (1,023,330 km)</td>
</tr>
<tr>
<td>BMW</td>
<td>638 miles (1,027 km)</td>
<td>638 miles (1,027 km)</td>
</tr>
<tr>
<td>Nissan</td>
<td>263.3 miles (423.7 km)</td>
<td>6,056 miles (9,746 km)</td>
</tr>
<tr>
<td>Ford</td>
<td>196.6 miles (316.4 km)</td>
<td>590 miles (950 km)</td>
</tr>
<tr>
<td>General Motors</td>
<td>54.7 miles (88.0 km)</td>
<td>8,156 miles (13,126 km)</td>
</tr>
<tr>
<td>Delphi Automotive Systems</td>
<td>14.9 miles (24.0 km)</td>
<td>2,658 miles (4,278 km)</td>
</tr>
<tr>
<td>Tesla</td>
<td>2.9 miles (4.7 km)</td>
<td>550 miles (890 km)</td>
</tr>
<tr>
<td>Mercedes Benz</td>
<td>2 miles (3.2 km)</td>
<td>673 miles (1,083 km)</td>
</tr>
<tr>
<td>Bosch</td>
<td>0.68 miles (1.09 km)</td>
<td>983 miles (1,582 km)</td>
</tr>
</tbody>
</table>

1.2 Purposes of the thesis

The purpose of thesis was to illustrate the public opinions on and the expected benefits of autonomous vehicles. The aim was to compare the strengths of autonomous vehicles with traditional vehicles and give some ideas for autonomous’ vehicles future development based on the safety aspect. The main research regions were those in which the autonomous vehicles technology had already started to develop such as the European Union, USA, China and Japan. The data was collected from multiple sources. The expected result was a summary according to which the public had a
positive attitude towards autonomous vehicles. Safety and environmental awareness the expected benefits brought by autonomous vehicles. The summary is based on various sources including journal articles, literature and specialist statements. The study focused on current status of road transportation safety and it tried to forecast its future state, when autonomous vehicles and related technologies would be in wide use.

In order to reach the objective, the following two hypotheses provided the research directions.

- The public have a positive perspective on autonomous vehicles.
- Theoretically, autonomous vehicles are safer than traditional vehicles.

1.3 Research methods

The main research methods for thesis were both the qualitative research method and desk research method. The qualitative research method provided the research direction with two hypotheses. The desk research focused on the phenomenon and analyzing factors already existing in the current road transportation such as the annual traffic accident rates, the reasons of traffic accidents etc. After that, the author could gain a broad understanding of the research targets and find useful information to support the hypotheses. Moreover, a case study was conducted to present the defects of the current autonomous vehicle development. The suggestion for autonomous vehicle future development was based on those defects.

All the theory on autonomous vehicles’ technical parts and the current road transportation safety was based on the materials collected for the study. The features of autonomous were analyzed based on the collected data. The data included reading related articles and books, watching videos and reviewing previous research.
2 Current situation of road transportation

2.1 Features of road transportation

Road, maritime, air and rail are four main transportation modes of transportation chain. Comparing road transportation with other transportation models, road transportation is the final step of other transportation modes. For instance, as for maritime transportation mode. Ship only can arrive to harbor. It needs truck deliver cargo from harbor to customers. Table 2 describes the features of road freight transportation.

Table 2. Features of road freight transportation.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Safety in high priority</td>
</tr>
<tr>
<td>b.</td>
<td>Environmental awareness</td>
</tr>
<tr>
<td>c.</td>
<td>Higher labour costs and lower labour utilization</td>
</tr>
<tr>
<td>d.</td>
<td>Connectivity and information</td>
</tr>
<tr>
<td>e.</td>
<td>Flexible</td>
</tr>
</tbody>
</table>

According to Table 2, road freight transportation is best for short and medium range when flexibility and special services are needed. Even if road transportation has many advantages, there are no incredible innovations of vehicles to improve the current road transportation safety. That is a restriction on the development of road transportation safety.

2.2 US current road transportation safety situation.

According to chapter 2.1, safety occupied higher priority position for road transportation. The following tables described the number of injury and fatality accidents of US from 2008 to 2017.
Table 3. US number of annual fatality accidents of road transportation (Facts + Statistics: Highway safety n.d.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
<th>Annual percent change</th>
<th>Fatality rate per 100 million vehicle miles traveled</th>
<th>Fatality rate per 100,000 registered vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>37,423</td>
<td>-9.3%</td>
<td>1.26</td>
<td>14.43</td>
</tr>
<tr>
<td>2009</td>
<td>33,883</td>
<td>-9.5%</td>
<td>1.15</td>
<td>13.08</td>
</tr>
<tr>
<td>2010</td>
<td>32,999</td>
<td>-2.6%</td>
<td>1.11</td>
<td>12.82</td>
</tr>
<tr>
<td>2011</td>
<td>32,479</td>
<td>-1.6%</td>
<td>1.10</td>
<td>12.25</td>
</tr>
<tr>
<td>2012</td>
<td>33,782</td>
<td>+4.0%</td>
<td>1.14</td>
<td>12.72</td>
</tr>
<tr>
<td>2013</td>
<td>32,894</td>
<td>-2.6%</td>
<td>1.10</td>
<td>12.21</td>
</tr>
<tr>
<td>2014</td>
<td>32,744</td>
<td>-0.5%</td>
<td>1.08</td>
<td>11.92</td>
</tr>
<tr>
<td>2015</td>
<td>35,485</td>
<td>+8.4%</td>
<td>1.15</td>
<td>12.61</td>
</tr>
<tr>
<td>2016</td>
<td>37,806</td>
<td>+6.5%</td>
<td>1.19</td>
<td>13.01</td>
</tr>
<tr>
<td>2017</td>
<td>37,133</td>
<td>-1.8%</td>
<td>1.16</td>
<td>NA</td>
</tr>
</tbody>
</table>

According to table 4, it shows that traffic accidents is not only constraint one or two countries but also global. There did not have any hints to show that the number of accidents will decrees even safety is priority issue for road transportation. (WACO, TEXAS DRIVERS FACE HIGHER RISK OF ACCIDENTS 2017).

2.3 Driver effect road safety

What are the key elements to cause traffic accidents? According to the report published by the US National Highway Traffic Safety Administration, the elements to cause traffic accidents can be divided into four categories which are the drivers, vehicles, environment and unknown elements. In order to obtain a critical view of those four traffic accident key elements, the NHTSA took 2,189,000 crash samples from 2005 to 2007 for a deep data analysis. The results are described in the following table. (Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey 2018, 2-3).
Table 4. Share of key elements caused traffic accidents. (ibid.)

<table>
<thead>
<tr>
<th>Key elements</th>
<th>Number of accidents</th>
<th>Share of total accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver driving errors</td>
<td>2,046,000</td>
<td>94%</td>
</tr>
<tr>
<td>Vehicles</td>
<td>44,000</td>
<td>2%</td>
</tr>
<tr>
<td>Environment</td>
<td>52,000</td>
<td>2%</td>
</tr>
<tr>
<td>Unknown</td>
<td>47,000</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>2,189,000</td>
<td>2%</td>
</tr>
</tbody>
</table>

According to the table 5, drivers’ driving errors were the biggest elements in traffic accidents. Drivers and vehicles are elements that are more related to human error. This is explained in more detail in Chapter 2.3. As for the environmental element, it consists of road conditions and weather as the two biggest factors. The possible road conditions that could cause traffic accidents were improper road design, lower maintenance, lack of traffic signs or unclear signs, lack of guardrails etc. (Charles, & Gueli 2018). The possible weather conditions that could cause accidents were rain, fog, snow, sleet and other such conditions. Such weather conditions not only affect the drivers’ visual perception of the road condition, but also their driving behavior as well. For instance, pavements become wet after a rainfall or snowfall. The wet pavement’s friction is lower than that of a dry pavement. This means that a wet road is more slippery than dry road. An accident happens easily when the drivers drive on the wet pavement, but they do not notice that. This is especially true about new drivers who do not have enough driving experience. The weather conditions cannot be controlled by people, but people can use technology to improve the functions of the vehicle and make the vehicle adapt to bad weather. The number of accidents may be reduced in this way. (Bijleveld, & Churchill 2009). As for the vehicle aspect, most accidents are related to vehicle’s technical fault and the driver ‘s error. The technical faults include tyre faults, brake and steering faults etc. (Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey 2018, 2-3). The following table describes the share of different technical faults.
Table 5. Share of different technical fault. (ibid).

<table>
<thead>
<tr>
<th>Technical faults</th>
<th>Number</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyre fault</td>
<td>15,000</td>
<td>35%</td>
</tr>
<tr>
<td>Brakes fault</td>
<td>10,000</td>
<td>22%</td>
</tr>
<tr>
<td>Steering fault</td>
<td>2,000</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown</td>
<td>17,000</td>
<td>40%</td>
</tr>
<tr>
<td>Total</td>
<td>44,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Since traditional vehicles do not have different sensors to monitor the situation, those faults must be checked, and confirmed by humans. This means that the driver needs to check the vehicle situation every time before driving. However, the potential safety risk of traditional vehicles is higher than that of the autonomous vehicles in this way. For instance, tyre faults occupied around 35% of all the technical errors. The most common traffic accidents related to tyre are tyre punctures. Improper tyre pressure is the main reason punctures. The number of traffic accidents related to tyres can be reduced by 4% to 20% and the total number of traffic accidents related to tyres can reduce by 0.8% to 4% when the tyre have a proper level of pressure. (Zyl, Goethem, Kanarachos, Rexeis, Hausberger, & Smokers 2013, 6-7).

The solution to monitor tyre pressure is to install the TPMS (tire-pressure monitoring systems). However, TPMS have two different models which are indirect TPMS and direct TPMS. The main difference between the indirect TPMS and direct TPMS is that the detective accuracy of the direct TPMS is higher than with the indirect TPMS. (Matsuzaki, & Todoroki 2008). Direct TPMS requires more sensors than indirect TPMS. As for traditional vehicles, most of them do not have TPMS despite the fact the European Commission published a regulation which required that all the new cars produced from 2014 must have TPMS. (Zyl et al. 2013, 2). However, traditional vehicles do not have different functional sensors compared to autonomous vehicles. The sensors of autonomous vehicles are introduced more specifically later in the thesis.
Most vehicles are installed with an indirect TPMS. The indirect TPMS cannot detect and display the accurate tyre pressure. It will remind the driver when the tyre pressure is lower than the safety tyre pressure level. If driver did not notice the warning before drive or vehicle was running on the road, the potential possibility of accidents is very high. (Zaharia, & Clenci 2013). Which means even the vehicle installed indirect TPMS, driver still need to check the tyre pressure before they drive. As for new or less driving experiences drivers, most of them cannot easily identify the tyre need more pressure or not. In other words, drivers determine the possibility of potential accidents that are which related to tyre pressure in the traditional vehicles.

Traditional vehicles are controlled by the driver. Driver's errors affect traffic accidents to a great extent. The following picture from the report published by NHTSA describes the statistics related to different driver errors.


<table>
<thead>
<tr>
<th>Driver errors</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition Error</td>
<td>845,000</td>
<td>41%</td>
</tr>
<tr>
<td>Decision Error</td>
<td>684,000</td>
<td>33%</td>
</tr>
<tr>
<td>Performance Error</td>
<td>210,000</td>
<td>11%</td>
</tr>
<tr>
<td>Non-Performance Error (sleep, etc.)</td>
<td>145,000</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>162,000</td>
<td>8%</td>
</tr>
<tr>
<td>Total</td>
<td>2046,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

According to table 7, recognition error occupied around 41% of all driver errors. Recognition error means driver cannot absolutely focus on driving only such as driver did not see obstacle on the road. Driver may will pay attention to passenger actions such as eating, drinking, music, radio etc. Daydreaming, inadequate surveillance, internal and external distraction are categorized into recognition error. (Horrey 2016). which things are not related to driving but it will affect driving safety. Decision error related to driver driving behavior a lot such as driving too fast, unsafe driving actions, wrong estimation of another vehicles’ speed etc. performance error means driver
cannot reach to safety driving standards. For instance, driver have poor directional control. (Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey 2018, 2-3).

Driver age is another main reason to cause potential traffic accident. The average minimum legal driving age for USA is 16. (Teenagers n.d.). Are young people ready for driving at this age? Following table described the fatal crashes sort out by driver age.

Table 7. Fatal crashes sort out by driver age 2016. (Facts + Statistics: Highway safety n.d.)

<table>
<thead>
<tr>
<th>Age groups</th>
<th>Number of licensed drivers</th>
<th>Drivers in fatal crashes</th>
<th>Involvement rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 to 20</td>
<td>12,002,717</td>
<td>4,412</td>
<td>36.76</td>
</tr>
<tr>
<td>21 to 24</td>
<td>14,460,176</td>
<td>5,233</td>
<td>36.19</td>
</tr>
<tr>
<td>25 to 34</td>
<td>39,194,065</td>
<td>10,815</td>
<td>27.59</td>
</tr>
<tr>
<td>35 to 44</td>
<td>36,500,347</td>
<td>8,116</td>
<td>22.24</td>
</tr>
<tr>
<td>45 to 54</td>
<td>39,407,317</td>
<td>7,946</td>
<td>20.15</td>
</tr>
<tr>
<td>55 to 64</td>
<td>38,379,823</td>
<td>6,966</td>
<td>18.15</td>
</tr>
<tr>
<td>65 to 74</td>
<td>26,070,715</td>
<td>4,122</td>
<td>15.81</td>
</tr>
<tr>
<td>Over 74</td>
<td>15,633,421</td>
<td>2,971</td>
<td>19.00</td>
</tr>
<tr>
<td>Total</td>
<td>221,711,918</td>
<td>51,914</td>
<td>23.42</td>
</tr>
</tbody>
</table>

*: Per 100,000 licensed drivers.

According to table 8, it apparently shows that young people are not ready for driving when they are age under 25 years old. The brain is still under growing. Prefrontal cortex is very important part of brain which affect people judgment of situation and control people impulses, emotions. Prefrontal cortex will completely work when people get at least 20 years old. Dynamic hormones in teenager’s brain increase aspiration of trill-seeking activity. (Rethinking the Minimum Driving Age 2012). That is why young teenagers drive roughly on the road. That is easily to cause traffic accidents. However, most teenagers want to slip the leash from parents. They want to be independent. For instance, teenager may go to school or go to somewhere for travel with friends. At this moment, the flexibility will increase if teenager have car. Autonomous
vehicle could offer help. Teenager do not have to drive by themselves. In this way, traffic accident may will decrease.

2.4 Summary

In whole chapter 2, it introduced current road transportation safety situation of EU and USA regions. In the past years, road transportation traffic accident rates keep stable level. Driver is biggest reason to cause traffic accidents. Driving licenses only provide the permission that driver can legally drive on the road. However, Driver needs time to accumulate driving experience and acknowledge related to vehicle. After that, driver may will have ability to deal with emergency and complex road situations during the driving. Traffic accidents have high possibilities which happen during driving experience accumulation period. Autonomous vehicles can release drivers. Driver could be normal passenger. The traffic accidents may will get effective reduce.

3 Autonomous vehicles

In this chapter, it will introduce the technology, safety, public opinion and expectation of autonomous vehicles.

In order to establish global standardization of autonomous vehicle and prompt global autonomous vehicle research and development. (SAE International Publishes New Terminology Standard for Motor Vehicle Automated Driving Systems 2014). In 2014, SAE international (Society of Automotive Engineers) published information report to indicate six different levels of autonomous vehicles classifications. According to Rudolph and Voelzke, “as of today, no car manufacturer has achieved level 3 or higher in production although several have produced demonstration vehicles.” (Rudolph, & Voelzke 2017). According to currently technology development, autonomous vehicles is at 2 level or lower than 2 level. The classification details as below:
<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative definition</th>
<th>Execution of steering and acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System capability (driving modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>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 that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td></td>
<td>Partial automation</td>
<td>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</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>---</td>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Automated driving system monitors the driving environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Conditional automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td></td>
<td>High automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>---</td>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------------------</td>
</tr>
<tr>
<td>5</td>
<td>Full automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>

Figure 1. SAE international classifications. (Automated Driving, 2017).

3.1 Public opinions of autonomous vehicles

Autonomous vehicle achieved great development. It will change people lifestyle in the future. In this chapter, it will introduce the public opinion and expectations for autonomous vehicles. In USA and Australia, the autonomous vehicles have widely tested and operated on the road. Public know more information about autonomous vehicles performance. In this chapter. It will focus on USA and Australia two regions mostly.

In 2014, Schoettle and Sivak committed one survey about public opinion for autonomous vehicles and their expected benefits from autonomous vehicles. The age range of the interviewees is between 18 and 59. Most of interviewees with under bachelor education background. they may do not understand autonomous vehicle technology theory as deeper as higher-level education background interviewees, but they can
represent the common public opinion for autonomous vehicles. For instance, buyer can buy products from supplier, but buyer do not have to know the theory and production processes of the products. The only thing for buyer is good to know how to use the products. However, buyer can provide realistic feedback of products after they use it. The feedback is treasure for supplier because feedback will indicate the positive and negative things of products. It will indicate the future develop direction of products. according to the survey, around 56.3 percentages interviewees support for autonomous vehicles. 27.3 percent people have neutral attitude. 16.4 percent people disagree with autonomous vehicles in USA. As for Australia, around 61.9% people have positive opinion, 26.7% people have natural opinion and 11.3% people disagree autonomous vehicles. (Schoettle, & Sivak 2014).

Figure 2. USA and Australia public opinion for autonomous vehicles. (ibid).

According to Figure 2, more than half of interviewees support autonomous vehicles research and development for both countries. However, how many percentages of interviewees would like to try fully autonomous vehicles? Following table introduced autonomous vehicle riding acceptance sort out by interviewees attitude. Moreover, the following Figure described how many USA and Australia’s people already know autonomous vehicle technology.
According to Figure 3, USA’s people have good recognition of autonomous vehicles technology than Australia. Moreover, USA and Australia are more than half people understand autonomous vehicles technology.

Which type of vehicles are people accepted when fully self-driving vehicles operated? Vehicle types include private vehicle, commercial vehicle, public transportation.
Figure 5. US and Australia autonomous vehicle acceptance sort out by vehicle types. (Schoettle, & Sivak 2014).

According to Figure 4, it shows interviewees still worried about autonomous vehicle reliability. Only few percentages interviewees would like to try fully self-driving vehicles without any concerns. According to Figure 5, interviewees would like to make self-driving vehicle to be private car. Which proves interviewees still have positive attitude for autonomous vehicle. What are benefits which interviewees want to get from autonomous vehicles? The following table 10 picked up 7 common expected benefits which includes lower crashes, reduced technology error of crashes, shorter emergency response to crashes, less congestion, shorter travel time, less emission, better fuel economy. (Schoettle, & Sivak 2014).

Figure 6. US and Australia interviewee expected benefits. (ibid).
According to Figure 6, the benefits interviewees expected from autonomous vehicles can be divided into two biggest aspects which are safety and environmental protection. As for safety aspect, it consists of lower crashes, reduced technology error of crashes and shorter emergency response to crashes. As for environment protection aspect, it includes better fuel economy and less emissions.

Following table introduced what interviewees will do when they ride fully self-driving vehicles.

Figure 7. USA and Australia interviewees expected activities when ride self-driving vehicle. (Schoettle, & Sivak 2014).

As chapter 2.3 introduced, driver have recognition error and non-performance error. Daydreaming, inadequate surveillance, internal and external distraction are categorized into recognition error. Sleep is most representative error of non-performance errors. According to Figure 6, most people would watch the road when they ride autonomous vehicle. Which means interviewee still doubt the autonomous vehicle safety reliability. Because autonomous vehicle is new technology. The safety did not get certification by time yet. In chapter 3.2. it will deeply introduce the equipment and technology of autonomous vehicle. Providing theoretically autonomous vehicle safety illustration. Autonomous vehicles do not need driver. Driver will be passenger. They can take a wonderful journey with self-driving vehicles. In this case, driver errors are possible to avoid. Meanwhile, traffic accident rates may will reduce. Autonomous vehicle safety will be proved when autonomous vehicle widely uses.
The interview results show public have positive opinion for autonomous vehicles research and development. Safety and environment are two main benefits which interviewees expected to get from autonomous vehicles.

3.2 Autonomous vehicles technology and equipment

This part will introduce what kind of equipment and information technologies autonomous vehicles needed.

In order to make vehicle completely self-driving come true. perception, planning and control are three basic interdependent functions which autonomous vehicle required. (2018 SELF-DRIVING SAFETY REPORT n.d.)

Perception: perception includes navigation and situation analysis. perception by applying sensors to monitor autonomous vehicle surrounding environment. The sensors collecting information and send it to computer. Computer will combine information with digital map to location the vehicle. Nowadays, vehicle achieved the goal by using global positioning system (GPS). Moreover, vehicles have retrieved data. The data include information on object. The data will create and recalculates in order to find out the best route. As for situational analysis, that means vehicles have abilities to keep monitoring surrounding environment, including all relevant objects and their movements. Situational analysis needs different types of sensor, visual image recognition techniques (visual cameras), radar, LIDAR (light detection and ranging) etc. The perspective is to combine the data which collected before. According to the situation to do adaptable reactions. (2018 SELF-DRIVING SAFETY REPORT n.d.)
Planning: The main idea for planning is to choose the route which could optimize safety and efficiency from departure location to destination. There are two main factors for motion planning which are speed and direction. Direction is normally decided by the current position of the vehicle and the route of the road, avoiding any detected static objects. As for the speed, it depends on the width of the driving lane, the preferences etc. The ability and information planning required which are autonomous vehicle real time position, other vehicle action prediction and congestion control etc. planning can integrate and analysis multiple paths situation per second. According to the result, autonomous vehicle will choose the best one. Moreover, the essential function for planning is have variable back up plan. In case, some unexpected things happen. (ibid.)

Control: the main idea for control is to manage and carry out the vehicle direction and speed according to the result from planning. Control charge vehicle steering, brake, acceleration units. After a speed or direction intervention, Control will measure the actual changes and compared with expected change. If there is high difference between expected and actual changes, the autonomous system will take accelerating, breaking or steering actions to make sure vehicle’s driving on right situation. In general, Control is maintaining vehicle’s driving stability. (ibid.)
Summary, those three functions provide possibilities to make autonomous vehicle drive by itself. However, how the function could finish the mission? For example, perception is essentially part of planning. how perception collect data? It needs sensor to do it. There have two main components groups which are control units and sensor systems. As for sensor systems, it consists of the cameras, radar, lidar and ultrasound. Following picture shows the sensors autonomous vehicle required.

Figure 9. Sensors of autonomous vehicle. (2018 SELF-DRIVING SAFETY REPORT n.d.)
Cameras: Cameras will provide the video images with most of details for the human drivers meanwhile it also can put parameter for highly automated driving. Rear and 360° cameras support the best representation of the environment outside the vehicle. For now, two-dimensional cameras can display images and some additional information such as steering wheel angle. As the technology develop, cameras can with virtual three-dimensional image displays. The main function of cameras is detecting colors and fonts. They are able to read and recognises the traffic lights, traffic sings and lane markings. Through this way, cameras systems can increase vehicles’ security. However, the cameras detective distance has limitation from 100 to 275 yards (90m to 248m). As for future systems, mid and high ranges will exclusively with an optical system to improve the function of the cameras. (Rudolph., & Voelzke. 2017).
Radar: The standard name for radar is Radio Detection and Ranging which means radar detection and localization of objects by using radio waves. Nowadays, there are two frequency bands common in use which are 24-29GHz for short range and 76-77GHz for long range work. (Marshall 2018). The strengths of the 77GHz is higher accuracy for distance and speed measurements as well as in the more precise angular resolution. The strengths of the 24GHz are the smaller antenna size and lower interference problem. (Rudolph., & Voelzke 2017). The most important thing for radar is that radar detective accuracy has limited influence by environmental conditions such as fog, rain, wind or darkness. However, radar detective accuracy mostly affected by object’s reflection strength such as size, distance from radar, reflection angle, absorption characteristics and transmission of the object etc. It is easy to detect large reflection objects. As for autonomous vehicles, it has higher requirements for radar system which need to have ability to detect not only smaller reflection surface but also have few hard or metallic shapes to reflect radar signals objects such as pedestrians and motorcycles. However, radar system still needs to improve. Because the reflection comes from a truck can swamp that from a motorcycle and radar system cannot detect when people standing next to a vehicle. Additionally, radar system cannot recognize the metal object properly. Sometimes object image will bigger than object actual size. It is easily to cause control system made wrong decisions.

Lidar: Lidar is an abbreviation for Light Detection and Ranging. It is a laser-based system. The challenge for a driver assistance system is that will function under all possible environmental conditions and can recognize objects up to 300 yards (around 275
Lidar system have been using in industry and military for many years. However, because of the higher costs of complex mechanical mirror system with a 360 degrees all-round visibility. (Rudolph., & Voelzke 2017). According to Waymo’s lidar fact sheet, “LiDAR bounces a laser off an 18 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.” The biggest benefits for Lidar system are that Lidar system can create three-dimensional images. However, higher costs and shorter range may become main problems for Lidar system apply in autonomous vehicle field.

Ultrasound: Ultrasound sensor is most common applied to measure distance because of cheap price and easy to operation. Normally, the frequency of ultrasound sensor is over 20,000 Hz. Ultrasound sensor use sound waves to detect surrounding objects. (Mazzari 2017). The advantage of ultrasonic sensors is that measurements can without touch the target. The speed of sound travel in air is fast. Normally, the speed of sound could reach 6ms to travel 1m. However, environment affects ultrasound sensor measurement a lot such as weather, currents, angle and materials.

3.3 Environmental awareness

Transport occupied around quarter of total Europe’s greenhouse gas emissions. That is the main problem to cause air pollution for city area. European Union tried to control emissions of all the possible sectors which include energy industries, industries, residential and services, agriculture, transport etc. After EU administered, all the sectors get visible emission decrease expect transport. As for transport sector, it started to decrease from 2007 but it still higher than 1990. (A European Strategy for low-emission mobility N.d.) The detail as following picture shows:
Figure 11. Greenhouse gas emission from 1990 to 2014 (ibid.)

Note: * Transport includes international aviation but excludes international maritime; ** Other include fugitive emissions from fuels, waste management and indirect CO2 emissions (ibid.)

In 2014, road transportation occupied around 70% of total transport greenhouse gas emissions. The detail as following table shows:

![Pie chart showing emissions by sector]

Figure 12. Emissions of different transportation sectors. (A European Strategy for low-emission mobility N.d.)

In order to decrease the emissions, EU commission took three main areas for action:

- Increasing the efficiency of the transport system. Which means apply digital technologies and smart pricing.
• Speeding up the deployment of low-emission alternative energy for transport. Which means encourage to use advanced biofuels, electricity, hydrogen and renewable synthetic fuels.

• Moving towards zero-emission vehicles. Which means encourage to accelerate the low and zero-emission vehicles implementation. (ibid)

In 2017, European Union published legislative proposal which introduced new CO2 emission reduction standards for road transportation after 2020. Which is including passenger cars and light commercial vehicles(vans). The most important proposal is reducing fuel consumption costs and improve the competitiveness of EU automotive industry. The expected result for the proposal that is reducing 30% of emissions from both cars and vans in 2030. It will be done step by step. In 2025, the vans will reduce 15% of emissions compare to 2021.

Currently, most autonomous vehicle power by electricity. Which means fuel consumption have a great potential reduced 10-20%. Moreover, the traffic congestion will reduce when autonomous vehicle widely used. Which means around 60% traffic delay can be reduced meanwhile, fuel consumption can reduce 25%. Autonomous vehicle has ability to maintain stable speed. It could be saved around 23% fuel consumption. (Iglinski, & Babiak 2017).

4 Case studies

In this chapter, it will introduce two case studied which related to autonomous vehicles safety. Autonomous vehicle is on the start-up stage. Case studies will more concern challenges and constraints of autonomous vehicle technical aspect. The purpose of case studies is to analysis and illustrate currently technical defects of autonomous vehicle.

4.1 NAVYA shuttle involved in carsh

4.1.1 Introduction

NAVYA founded in 2014. That is a French company which focus on autonomous and electric vehicles. The representative product name is NAVYA ARMA. NAVYA ARMA is
a shuttle autonomous vehicle. It introduced to North America in 2016. (Zart 2017). The purpose for this NAVYA ARMA shuttle is to provide effective solution for the public transportation system situation which distance from departure to destination is too short to go by car, but too long by foot. Shuttle can carry Max 15 passengers. The theoretical working period of battery is 9 hours. In order to optimize the localization and detection ability, ARMA have two 360-degree lidars and six 180-degree lidars, two cameras, odometer, Global Navigation Satellite System. Those are basic equipment which makes ARMA could self-driving. (French electric autonomous vehicle maker NACYA to build 1st US assembly plant in Michigan: partnership with U Michigan 2017).

![NAVYA ARMA](image)

Figure 13. NAVYA ARMA. (THE KEOLIS AUTONOM SHUTTLES PUT INTO SERVICE WITHIN THE RENNES CAMPUS 1 ON OPEN ROAD 2018).

4.1.2 Accident review

In 2017, American Automobile Association, NCNU organized free ride shuttle activity from November 2017 to October 2018 in Las Vegas. Total operation time is 1,515 hours with 32,827 riders. That was the first-time autonomous shuttle which operate on the road and experience by public. (AAA Free Self-Driving Shuttle Pilot Program n.d.). Around 30% passenger support autonomous vehicle after ride shuttle. 98% passenger will introduce autonomous vehicle to others. (Hop on the Free AAA Self-Driving Shuttle in Las Vegas n.d.). It seems that activity achieved successful results. However, shuttle involved in car crash with delivery truck few hours after celebrating first day operation. The autonomous shuttle went to straight. Driver of delivery truck
try to back trailer into alleyway from street, but driver did not notice the shuttle coming. Shuttle detected truck and stopped immediately. However, truck did not stop. In the end, truck collided front fender of the shuttle. Luckily, no one got injury in this traffic accident. (Zurshmeide 2017). According to Las Vegas police officer, the accident happened which was truck driver’s fault. Driver was doing illegal backing. As table 4 introduced, driver driving error occupied around 94% of all possible errors which makes traffic accident. This accident could be categorized into driver error as well. (Self-operating shuttle bus crashes after Las Vegas launch 2017).

Autonomous shuttle technology defects exposed through the accident. The solution for shuttle encounter emergency situation during the operation which is to stop and stay. It cannot to do any actions to avoid accident. For instance, go forward, back up, swerve etc. How to make autonomous vehicle become intelligent that could be the new direction of future autonomous vehicle development. Moreover, truck driver has blind spot during the driving. That is not possible for driver to take care all the surrounding vision of truck. Comparing Figure 9, autonomous shuttle possible stay at truck blind spot. Following picture shows truck blind spot.
Las Vegas city government official statement on the accident quoted:

The autonomous shuttle was testing today when it was grazed by a delivery truck downtown. The shuttle did what it was supposed to do, in that it’s sensors registered the truck and the shuttle stopped to avoid the accident. Unfortunately the delivery truck did not stop and grazed the front fender of the shuttle. Had the truck had the same sensing equipment that the shuttle has the accident would have been avoided. Testing of the shuttle will continue during the 12-month pilot in the downtown Innovation District. The shuttle will remain out of service for the rest of the day. The driver of the truck was cited by Metro.

(UPDATE: Minor incident downtown Wednesday afternoon 2017).

As for truck, if truck have sensor and camera to help driver monitor surrounding blind spot that is possible to avoid accident. As for autonomous shuttle, there do not have steering wheel, braking paddle inside of the vehicle. Which means passenger cannot control vehicle to do self-rescue when accident happens, but autonomous vehicle does not have ability to dispose it. As chapter 3 introduced, autonomous vehicle technology is at second level which is partial automation right now. Vehicle have ability to assist driver such as route planning, situational analysis and navigation etc.
However, currently autonomous vehicle technology is far away from fully self-driving. That is too early to take steering wheel and braking paddle off.

4.2 Uber’s self-driving vehicle killed pedestrian

4.2.1 Introduction

Uber was not as lucky as NAVYA. Because no one got injury at NAVYA accident. However, Uber’s autonomous vehicle killed pedestrian. That is the first-time pedestrian killed by autonomous vehicle in USA. Moreover, people started to question the safety of autonomous vehicles. Public would to know does autonomous vehicle ready for the real world or not. (Higgins 2018).

4.2.2 Accident review

According to US National Transportation Safety Board (NTSB) preliminary report, on March 18, 2018, Uber’s experimental autonomous vehicle operated self-driving mode on the road. A 49 years old female walked with her bike on the street and wanted to across the avenue from east to west. Uber’s autonomous vehicle came from south to north. Driver sited inside of vehicle when accident happens. Following picture introduced the situation before accident happened. (PERLIMINARY REPORT n.d.)

![Figure 16. Uber’s autonomous vehicle accident illustration. (PERLIMINARY REPORT n.d.)](image-url)
The preliminary report indicated that Uber’s autonomous vehicle have all necessary equipment such as cameras, LIDAR, radar, navigation sensors etc. Uber’s self-driving system detected pedestrian 6 seconds before collision. At that moment, the speed of vehicle was 43 mph. The maximum speed limitation of the avenue was 45 mph. However, Uber’s self-driving system software did not define the object as a pedestrian but unknown object. Because pedestrian walked with her bike. At 1.3 seconds before collision, vehicle’s started to emergency brake. Even emergency brake was factory equipment. It disabled during self-driving mode. Anyway, that was too late to brake. The vehicle speed at collision was 39 mph. (PERLIMINARY REPORT n.d.)

![Figure 17. Uber self-driving mode accident description. (PERLIMINARY REPORT n.d.)](image)

Uber decided to freeze autonomous vehicle testing after accident happened. (Levin, & Wong 2018). The accident was still under investigation. No statement clearly defined which party should take the fault. As for Uber, that was apparently technical error. Sensors detected obstacle, but self-driving system cannot classify it. Moreover, the vehicle still moves forward during the system recognize object period. In additional, driver was inside of the vehicle. The mission for the driver was to monitor self-driving system testing and take over the vehicle at emergency situations. Self-driving system did not alert driver when it cannot identify the obstacle as well. As for pedestrian, there was no zebra crossing on the ground which means pedestrian should not across avenue from that place.
4.3 Cases comments

For both cases, the safety reliability of autonomous vehicle is not stable. Which means autonomous vehicles may not ready yet. Road transportation is essential part of people’s life. No one can take the consequence of road traffic accidents. For instance, children will support by parents to live. How should children grow up if parents occurred fatal traffic accident? People have higher safety requirement for autonomous vehicle due to traditional vehicle cannot improve road transportation safety and driver is biggest factor to occur traffic accidents. Self-driving technology will instead of human driver in the future. Which means passenger was put own’s life to driver in the past. For now, passenger need to put the own’s life to vehicle. The technology is still under testing. The safety reliability did not get prove in real life. Autonomous vehicle development should step-by-step. Autonomous vehicle manufacturer and technology company should pay more patient and cautious for self-driving technology development. NYVAY shuttle case shows the NYVAY company move too fast. shuttle still have defects of technical aspect, but company still take steering wheel, gas paddle and brake paddle away. In the end, passenger cannot do anything when accident happens. Which means accident cannot avoid if self-driving system failed to do reaction according to the emergency situations. Uber case has same problem. Uber’s autonomous vehicle did not alert to driver or deceleration when self-driving system cannot identify obstacle which stay in front of vehicle. The driver inside of Uber’s vehicle made distracted mistake. For both cases, the accident could avoid if driver take over the vehicle in time.

Moreover, autonomous vehicle should obey human ethics as well if self-driving system want to instead of human driver. Urban traffic situation is complex than highway. For instance, passenger vehicle should give way to special vehicles such as police vehicle, ambulance and fire engine etc. Autonomous vehicle should have ability to identify the special vehicle and stop let special vehicle pass first. In additional, some location infrastructure may not complete yet such as traffic signs and zebra crossing etc. Autonomous vehicle has to choose collide guardrail or human when human suddenly present in front of vehicle, but there is no time for autonomous vehicle to do emergency brake.
Autonomous vehicle provides service to human, but that is new technology. Self-driving system development process should more careful. Autonomous vehicle traffic accident will make bad influence for future. Because public will doubt the reliability of autonomous vehicle’s safety. People will lose confident of autonomous vehicle when there are too much accidents related to it. Autonomous vehicle will have no reason to survive if public not accept it.

5 Discussion

5.1 Research results

The thesis has answered the hypothesis which mentioned in chapter 1.2. The results for the thesis are public have support autonomous vehicles development and thoracically, autonomous vehicles are safer than traditional vehicles. However, as the chapter 4.3 mentioned, the safety reliability of autonomous vehicles not stable yet. Self-driving technology has a great potential ability to improve road transportation safety. It is glad to see public support autonomous vehicle development. Autonomous vehicle and self-driving technology are becoming the main battle for both car manufacturer and technology company. Moreover, in order to improve self-competitive power, most companies will exaggerate the ability of current self-driving technology even that still have technical defects. Autonomous vehicle is new technology, but it concerned about human’s life. Nothing important than life. Car manufacturer and technology companies should pay more patient. Autonomous vehicle testing should cover all the possible traffic situations in real life. Any traffic accidents related to autonomous vehicle will occur bad influences, once autonomous vehicle introduced and opened to public officially. It is easily to lose credit. However, that would be very hard to establish it again. Once again, autonomous vehicle does not have reason to survive if public question the safety reliability and do not accept it.

As chapter 3.2 introduced, self-driving technology have different sensors which makes autonomous vehicle fully self-driving. Perception, planning, controls are three main function of autonomous vehicles. Driver driving errors include recognition error, decision error, performance error and Non-performance error. Self-driving technology will replace driver. Driver driving error will not exist when fully autonomous
vehicle widely uses. Furthermore, autonomous vehicle can check self-situation by using different sensors and provide real-time feedback for the hardware and software working conditions. Autonomous vehicle safer than traditional vehicles.

5.2 Reflection

The research results have limitation because the research only pay attention to United States, European Union and Australia three regions where autonomous vehicle have widely tested. Data have limitations. It cannot represent global autonomous vehicle development. Asian countries also achieved great results for self-driving technology. However, it did not mention during research.

Moreover, fully autonomous vehicles are still under testing. Currently autonomous vehicle still need driver to monitor the operation process all the time. which means current self-driving technology stay at partial level. The safety reliability of fully autonomous vehicles did not get prove in real life yet. The data have constraints which most relate to current autonomous vehicle benefits and defects.

For future, self-driving technology companies could provide more reliable data when fully autonomous vehicle widely uses. At that moment, the research result will more reliable than now. Meanwhile, technology companies could go to university and do presentation which relate to self-driving technology. Let student deeply understand how autonomous vehicle work and involve in self-driving technology safety innovation. In that time, it will not only benefit to self-driving technology company but also education.
References


