



Cardiff University
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The Road to Driverless Vehicles

Final Report

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Abstract

Driverless vehicles could potentially change day to day travel for the better, this study investigates the benefits of such vehicles, alongside the issues that need addressing before their widespread adoption. Driverless vehicles use a collaboration of systems and algorithms to navigate the vehicle without a human operator. Many organisations and educational persons globally are continually developing and testing new systems however, fully autonomous vehicles are yet to be approved and regulated, with numerous setbacks happening in the testing phase. This said, results from the social and psychological questionnaire question whether users want driverless vehicles, as a lot of individuals still do not trust driverless vehicles. With 20.6% of participants saying they would probably wouldn't travel in a driverless vehicle, and a further 19% that would be very concerned or extremely concerned whilst travelling in one. Furthermore, this study analyses the impact driverless vehicles will have on four major stakeholders – users, technology companies, vehicle manufacturers/dealers and insurance companies. Various analysis methods have been carried out to identify how these stakeholders can thrive and adapt to this new technology. In summary, major progress needs to be done in the next five to ten years in terms of developing an effective solution that wins the trust of the users.

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List of abbreviation

DVs	Driverless Vehicles
SSM	Soft systems Methodology
SWOT	Strengths, Weaknesses, Opportunities & Threats
HAS	Human Activity System
CATWOE	Customers, Actors, Transformation Process, Worldview, Owners, Environmental Constraints
RD	Root Definition
CM	Conceptual Model
DARPA	Defence Advanced Research Projects Agency
SUV	Sport Utility Vehicle
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
RFID	Radio Frequency Identification
NHTSA	The National Highway Traffic Safety Administration
DAS	Driver Assistance Systems
VB-DAS	Vision Based Driver Assistance Systems
IoT	Internet of Things
GPS	Global Positioning System
IMU	Internal Measurement Unit
LIDAR	Light Detection and Ranging
GOV	Government
VMT	Vehicle Miles Travelled
CES	Consumer Electronics Show
TaaS	Transportation as a Service
ROI	Region of Interest
VISSIM	Microscopic Multi-Modal Traffic Flow Simulation Software

1 Introduction

1.1 Overview & Motivation

With the continuous evolution of technology, we as human beings are entering a very exciting era as regards to technology changing the way we live on a day to day basis. Driverless vehicles could potentially change the way we travel for the better, tackling issues such as safety, emissions, traffic congestion and social inclusion (Department for Transport, 2015). Furthermore, driverless vehicles could pave the way for environmental, economic and social changes. The concept of driverless vehicles has been one of the most revolutionary technology advancements in recent years with global leaders such as Ford, GM and Nissan spending millions to bring it to fruition. Experts suggest driverless vehicles could be on the road by 2021, and that the driverless vehicle industry will be worth 28bn by 2035 (gov, 2017).

Human error is the cause of most road accidents, with a staggering 1.25 million deaths worldwide due to vehicle collisions in 2014 (Mariano, 2018). Driverless vehicles use a vast combination of systems, algorithms and hardware to manoeuvre the vehicle from destination to destination without a human operator. This software is programmed to interpret road behaviour and real-life behaviour. That aside, there is an extensive list of issues surrounding driverless vehicles that need to be addressed before they roll out.

Hence, driverless vehicles will affect the way companies go about their business. It is important for these companies to plan for the introduction of DVs, with the aim to adapt and thrive. In order for the companies to thrive, an understanding of the current DV/company situation is crucial alongside identifying where they want to be in the future.

Whilst the concept sounds like science fiction, it is seemingly becoming closer to reality and is only a matter of time before we see autonomous vehicles on our roads. Elon Musk (2017) suggests, *"in probably 10 years it will be very unusual for cars to be built that are not fully autonomous."*

1.2 Aims & Objectives

Listed below are the aims and objectives the researcher wishes to achieve by the end of the project. The success of the project will be determined on whether or not these aims and objectives have been fulfilled and to what quality.

1. Gain an understanding of what driverless vehicles are and how they work.
 - a. Research and explain what driverless vehicles are.
 - b. Research and explain the technologies (and algorithms if possible) driverless vehicles use to manoeuvre and react to environmental obstructions.
2. Highlight and discuss current issues that need to be addressed to enable the distribution of driverless vehicles.
 - a. Background research and discuss current driverless vehicles their progress and issues that need to be addressed.
 - b. Recent accidents that have occurred whilst testing driverless vehicles and the reasons why the accident took place.
3. Social and psychological issues that must be addressed before the widespread adoption.
 - a. Research and discuss the current psychological and social issues that currently exist.
 - b. Create a questionnaire to gather information on the opinion of driverless vehicles from the user's perspective.
 - c. Evaluate results from the questionnaire.
4. Analyse opportunities and threats that may arise from the widespread adoption of driverless vehicles.
 - a. Research and discuss the impact driverless vehicles will have on users, technology companies, car manufacturers and global insurance companies.
 - b. Suitable methods of analysis for the impact driverless vehicles will have on users, technology companies, car manufacturers and global insurance companies.
 - c. General benefits and challenges & barriers involved with the adoption of driverless vehicles.
 - d. Additional impact driverless vehicles will have e.g. ownership of cars, jobs/companies such as taxi's, law enforcement, driving instructors, product distribution (lorries) etc.
5. Summarise whether the adoption of driverless vehicles is feasible.

1.3 Scope

This project focuses on the current issues, challenges and barriers surrounding driverless vehicles including technology, social and psychological aspects. The existing technologies that allow vehicles to manoeuvre and navigate without an operator will be discussed, including technology that already exists and technology being tested. The outcome of this discussion will highlight and explain the issues that need addressing.

The primary focus however will be on the analysis of the impact DVs will have on stakeholders, also what they want to achieve or the solution to the problem they are facing in regard to driverless vehicles. The questionnaire will help identify the areas that need to be addressed and modelled in regard to user's perspective of driverless vehicles.

1.4 Selection of Approach & Methodologies

This section will highlight and explain the approach and methodologies the researcher will be using in this project to analyse the impact driverless vehicle will have on stakeholders.

Introduction to SWOT Analysis

Tested in the 1960s and 1970s by Albert Humphrey at Stanford Research Institute, SWOT stands for Strengths, Weaknesses, Opportunities and Threats. This tool is useful for strategic planning and brainstorming by listing points in all four categories that will help come to a decision.

SWOT analysis will be used to identify the internal and external factors affecting the stakeholders of driverless vehicles, and to further help gain a suitable business strategy. Internal factors are those that you have control over, the business can address problems by affective management. Whereas, the business has little control over external factors, a good example of this would be whether and environmental conditions have reduced production or legalisation has changed working hours of staff which will affect product production, reducing sales. This business strategy is useful to businesses by helping them make important decisions on past, present or future developments that will indefinitely have an effect on the business.

To produce an effective SWOT analysis there must be a specific objective within the business e.g. responding to new trends in the market and deciding whether to implement new technology. These decisions can affect the state and growth of the business.

A SWOT analysis is an important role in the strategic planning process as it can aid businesses to decide whether to seize opportunities. If a business seizes an opportunity that was unnecessary it can have a negative impact, therefore, using this tool could help better the business.

This is useful for identifying the factors however, fails to analyse them in detail, therefore, this tool will be used in parallel with SSM which can model the individual factors and further analyse them.

Introduction to Soft Systems Methodology (SSM)

Soft Systems Methodology (SSM), developed in the mid 1960s by Peter Checkland and Brian Wilson, is a structured approach to investigating and solving real life complex organisational problems. In real life, SSM is a set of methodologies. Each methodology represents a concept, structured to be of use to the situation being analysed. All situations are different; therefore, the methodologies will be tailored to that situation.

Using SSM helps think about thinking, thus meaning we think about the thinking process beforehand. Many system development approaches do not satisfy the client or users requirements. Many organisations stumble at the first phase of defining the problem, as people within organisations have different perceptions. By using the hard systems approach to solve business problems, problem solving is structured and well defined. If the problem isn't understood the requirements won't be relevant to the situation. The user's situation must be understood in order to carry out a successful systems development. When we 'think about the real world' and the actual 'real world' we use 'Human Activity Systems'. Checkland and Wilson therefor created tools (HAS) in order to define problems and find solutions to hard and soft vague problems within business. There are seven steps to SSM:

1. Defining the situation
2. Defining the situation – Rich picture
3. Root Definitions
4. Conceptual Model & CATWOE development
5. Compare the model with the real world – gain insights
6. Develop desirable & feasible interventions
7. Action to improve the situation

SSM provides an organised defensible way to accommodate different perspectives. Also, it provides model building from a business perspective which is fitting to the situation of concern. The models are used to compare against reality in order to help organisational structure and re define roles. Also, it is used to provide information as requirements in a business situation.

The idea of systems is that many different parts interact together make a whole. When we think of a system, the whole picture is more important than one specific part. For example, a car dealer without cars cannot provide a service.

Root definition

A root definition names the system in a structured way in order to understand the systems function or purpose. It is used to find the root of the purpose, although the root definition does not exist in real life; Terms such as objectives, goals etc. are used. Knowing who is doing what activity is a key factor in organisations.

The root definition structure is essentially a representation of the transformation process and the Weltanschauung; How the T is done by the W. When writing an RD, the company must fully commit to the one Weltanschauung. The process can be repeated with another perception or W, but a new RD must be created. People have different perspectives therefor the RD can be different in terms of the aim or purpose and how to achieve that transformation process.

Transformation process:

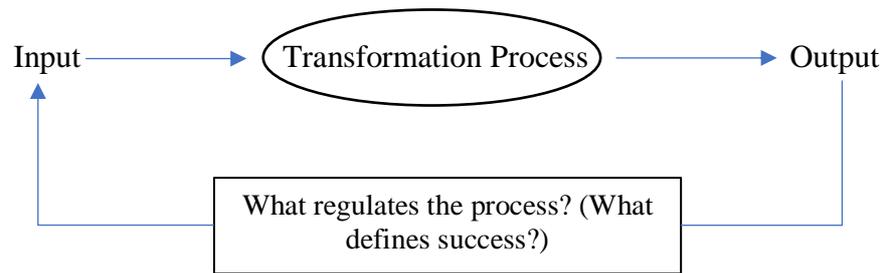


Figure 1: Transformation process.

Rules of Root Definition (RD):

1. A RD should be a sentence with a main verb to represent the transformation process. Any other sentences can be used in order to explain and elaborate this further.
2. The CATWOE must be used to test the structure of words in the RD.
3. The transformation process (T) and Weltanschauung (W) must be detectable in the RD. The C, A, O and E can be included if necessary.
4. Various words and phrases can be included as long as they are not mistaken for any CATWOE elements in order to compliment the RD.

CATWOE

In 1976, an Australian student studying at Lancaster published an article about methods to structure conceptual models and root definitions. Suggesting that there is a way to check the formulation of a RD as there is a way to check the formulation of a conceptual model by using FSM. A Device named a mnemonic would be used to question the words from a RD. The mnemonic chosen was CATWOE.

CATWOE is used in business situations frequently. Its purpose is to figure out what the business is setting out to accomplish, the key problems and how the chosen solution will affect those within the business. It is essentially a checklist for thinking to ensure all factors are considered to find the best solution. There are six elements to be considered in the CATWOE process, these elements help consider the main aspect of a business problem and finding a solution that is relevant. CATWOE stands for:

Customers – who the customers are, and how they are affected by the issue

Actors – who is involved, their activities, and will it affect their success

Transformation Process – The processes affected by the underlying issue

World View (Weltanschauung) – Processes that transform inputs into outputs

Owners – The big picture, real life problem that needs a solution

Environmental Constraints – rules and regulations that will affect how it is carried out

CATWOE must be a test of the structure and words chosen in the RD.

Many analysis methods such as tabular, enterprise and gap are then used to compare the models to the real world.

Using SSM provides me with an in-depth solution and analysis of the situation. Using only a SWOT analysis this would not provide the necessary detail. System dynamics was another option however, with limited figures this would not be accurate and therefore, prove to be a useless method. SSM allows the researcher to combine qualitative analysis with any viable quantitative sources to model the best solution.

Porter's Five Forces

The Porter's five forces is a useful tool that will be used to analyse the competition within the four key industries – vehicle manufacturers/dealers, technology companies, insurance companies and users. By understanding where the power lies the business can then go ahead and take advantage, and improve on weaknesses. Often businesses will be able to use this tool to determine if a new product (DVs) will become profitable or not. As well as identifying weaknesses this tool is used to identify areas of strength that can be used to improve on specific areas.

Porter's five competitive forces:

1. Supplier power
2. Buyer power
3. Competitive rivalry
4. Threat of substitutes
5. Threat of new entries

Google Forms

Google Forms will be used to create the questionnaire as this is a free service that allows users to create a questionnaire for free with unlimited questions. The questionnaire will be sent to the public via email, and shared via social media such as Facebook.

2 Literature Review

Driverless vehicles have been widely researched and many papers, articles or other types of literature have been published extensively in recent years. The concept of driverless vehicles has been around for many years however, only in the 20th century are we seeing a proactive attempt to make it a reality. Recently, literature has focused on when driverless vehicles will be adopted, new emerging technologies and the issues surrounding them. This literature review will focus on the existing literature surrounding the technologies used to manoeuvre the vehicle, issues that need addressing and papers that analyse the opportunities and threats of the adoption of driverless vehicles. This review will not explore all of the technology and issues but a general overview of the content available from published sources.

Technology

Literature regarding technologies used are generally vague or very complex. A DV is composed of a number of different systems/algorithms to manoeuvre it safely. Given the pivotal role of these systems/algorithms it is important to establish what the key systems are and if they need further work. One study, Rezaei & Klette (2017) has shown many different computer vision techniques are used for driver assistance systems. The paper was useful to identify the different video camera methods used to detect the surrounding environment. Häne,

Sattler, & Pollefeys (2015) also show a camera vision method using monocular fisheye cameras to detect obstacles. Furthermore, sensor fusion is necessary Silver (2017), suggesting sensors can measure distances and velocities better than standard video cameras. Rezaei & Klette (2017) also identify a range of different lasers used. One area neglected in this area is the identification and explanation of standardised DV systems and components. To appreciate the many available systems we must research, in detail the many different papers published. Traditionally, researchers in this area have focused on one component, whereas a paper for a full DV system would be beneficial. Whilst the above studies provide valuable systems and algorithms caution must be exercised when applying them to real life vehicles. The majority of sources used were published in the past decade. However, with the progressing industry these algorithms and systems could well be outdated due to the fast evolution of DV technology. The papers used in the systems and algorithms section were somewhat reliable due to the use of academic and research papers.

Issues

Literature surrounding issues on the adoption of driverless vehicles identifies an extensive range of different issues that need to be addressed. Social and psychological issues are widely discussed and many surveys have been deployed to analyse the public's opinion. Literature example regarding why we don't trust driverless vehicles can be found via scholar searches and libraries in the form of published papers. To support this, Waytz, Heafner & Epley (2014) tested a theoretical determinant of trust – anthropomorphism. The study proved anthropomorphism features would pave the way for humans to trust machines. Questionnaire results are widely published on the internet however, the reliability of the results can be questioned. After examining the results online, a first party questionnaire would give the researcher an opportunity to analyse the results first hand.

Safety being the main issue, Lari, Douma & Onyiah (2015) suggests a crash causation survey carried out by the NHTSA in 2008, found that almost 90 percent of accidents were caused by human error. One study, Kalra & Paddock (2016) conducted a statistical analysis of the number of miles DVs need to travel before they can provide accurate crash rates. This paper being useful to predict the safety of machines in comparison to humans. The research carried out on DV safety generally suggests DVs will be safer than humans however, this information must be used appropriately. Another study shows that driverless vehicles could be a privacy risk, as the vehicle will generate personal information about users including frequent tracking journeys resulting in surveillance issues. According to Collingwood (2017), if people were not involved with driverless vehicles privacy would not be an issue. To appreciate the effects of privacy in DVs, we must examine and research the different types of privacy. Glancy (2012) identified three areas of privacy concern, personal autonomy, personal information and surveillance. In the future, driverless vehicles will need to accommodate privacy concerns. One area neglected in this area is liability, as researchers focus on issues surrounding the rolling out of DVs.

In general, there has been a significant amount of studies found regarding issues with driverless vehicles, the literature is generally easy to acquire. Literature in this area is reliable, coming from industry experts and academic research.

Analyse Opportunities and Threats

The analysis of DVs have been neglected with no or sparse existing SSM found. Literature used in this section focused on Brian Wilson's (2001) book to understand the concept of SSM and its modelling. This is where my original work can add value to the research of DVs.

3 Background

3.1 What Are Driverless Vehicles?

Driverless vehicles, also recognised as autopilot vehicles, self-driving cars, uninhabited autonomous vehicles (UAV) and automated guided vehicles (AGV) are referred to as intelligent machines. The word ‘autonomy’ most commonly used, comes from ancient Greek combining ‘auto’ meaning ‘self’, and ‘nomos’ meaning ‘law’. The Greek word ‘autonomia’ meaning ‘self-law’ is a concept where one gives its self its own law (Glancy, 2012). There is not an exact definition for DVs. However, driverless vehicles are described as robotic vehicles that move from one destination to another without a human operator. It was Alan Turing who asked the question ‘can machines think’ in his research paper computer machinery and intelligence (1950). This question raised many arguments and discussions about what thinking is, and whether artificial thinking is superior to human thinking. If a vehicle can be manoeuvred by a human could a computer manoeuvre it more precisely?

Some autonomous features have already been implemented in vehicles that exist on the market such as lane assist, cruise control, anti-lock brakes and active parking assist (Schaub & West, 2015). Vehicles of today already show us where to go, self-steer and apply brakes, however, a fully autonomous vehicle is yet to be manufactured and distributed. DVs use a host of different hardware and software including GPS data, sensors and radar and video cameras (Automobile Association Developments Limited, n.d.).

3.2 Brief History of Driverless Vehicles

Many people think of DVs as a new innovative idea however, in the late 15th century Leonardo Da Vinci designed a self-propelled cart with the ability of programmable steering (Scribner, 2014). Leonardo Da Vinci’s sketch of the wooden contraption is stored in page 812R of his Codex Atlanticus. As the incomplete sketch of the contraption puzzled experts for years they decided to recreate it to see exactly how Leonardo’s design worked. This recreation took many years to complete as experts interpreted the build of contraption in the wrong way. However, leading scholar Carlo Pedretti figured out that they were using wrong springs to propel the contraption which resulted in the fully moving recreation of Leonardo’s invention. Springs used under high tension were used to power the cart whilst steering was set in advance (Kennedy, 2004).

According to Anderson et al. (2014), the advancements in the past 25 years can be described in three phases of development:

Phase 1: Foundation Research

Between 1980 and 2003, parties such as university research centres and automotive companies studied the basic concepts of driverless transportation. The results from this era of research found two technology concepts. Firstly, researchers studied the development of driverless highway systems, where the highway infrastructure would guide the vehicles via magnets in the highway and V2V communications. This concept was tested in 1997, on a 7.6-mile highway in California. The DEMO 97 program demonstrated eight vehicles that formed a platoon whilst being guided by the magnets (Anderson et al., 2014). Secondly, the researchers thought of developing semi and fully driverless vehicles that don’t depend on the highway infrastructure as much, if at all. From 1980 to 2000 Carnegie Mellon University developed several vehicles from NavLab 1 to NavLab 11. NavLab 5 was the breakthrough as it

successfully drove across America in the ‘No Hands Across America’ tour with driverless steering 98 percent of the way, the human operators only controlled the breaks and throttle.

Phase 2: The DARPA Urban Challenge

In 2003, DARPA (Defence Advanced Research Projects Agency) announced a challenge to develop a fully autonomous vehicle with the ability of navigating around a desert at high speeds (Buehler, Iagnemma, & Singh, 2009). Teams across the globe designed and developed hardware and software capable of navigating a car without a human operator around obstacles, handling intersections safely and successfully merging with other vehicles on the road. The purpose of this challenge was to ultimately provide safe transport in military operations such as supply convoys. Furthermore, with the development of autonomous vehicles for this challenge this would promote and accelerate the need for driverless vehicles in everyday life.

In 2004, the first grand challenge was held set with the challenge to drive the autonomous vehicles 142 miles from the desert in Barstow, Calif to Primm, Nev. However, not one vehicle finished the journey indicating the technology needed further development to navigate through the rough terrain and harsh conditions. With the furthest distance being 7.5 miles, DARPA announced a second challenge would be held in 2005 to improve technology and learn from previous mistakes. A total of 195 teams entered but only 5 completed the course in the Southern Nevada desert. With the winner being ‘Stanley’, Stanford University’s entry completing the course in a total of 6hrs and 53mins. The prize was a staggering 2 million dollars (Darpa, 2014).

DARPA decided to hold a third challenge with the aim to further develop the autonomy of the vehicles to navigate in complex city environment, Victorville, Calif. With previous success in the grand challenges, 89 teams entered for the opportunity to develop and navigate their autonomous vehicles in an urban environment from experts in the field to academics. The challenge was to navigate at speeds of 97km whilst adhering to traffic rules and regulations (Buehler, Iagnemma, & Singh, 2009). The vehicles needed the ability to navigate around other moving vehicles and obstacles, displaying the capability that autonomous vehicles could prove to be the next change in real life transportation.

For the opportunity to compete in the final challenge the teams had to undergo a series of tests to prove the capability of their developed vehicle. The teams were given the opportunity to write a paper explaining how their vehicle would manoeuvre and navigate in an urban environment. The teams were then narrowed down to 53 teams which exhibited their vehicle to DARPA through a series of basic challenges. Out of the 53 teams, 36 passed the tests and were given the opportunity to compete in qualification round for the final urban challenge (Buehler, Iagnemma, & Singh, 2009).

In 2007, the final urban challenge was held with a total of 11 teams qualifying. Only 6 teams managed to complete the course. The winner being the ‘Tartan racing tram’ from Carnegie Mellon University. Tartan racing team’s autonomous SUV, Boss successfully navigated 55 miles of urban environments beating second place by 20 minutes (Carnegie Mellon, n.d.).



Figure 3: Tartan racing team's autonomous SUV named Boss, winner of the DARPA urban challenge (Source:).

Phase 3: Commercial Development

The DARPA urban challenges were potentially the major breakthrough to push the development of driverless vehicles. Vehicle manufacturers later wanted the collaboration with researchers in the education sector, which led to many developments such as partnerships between Volkswagen and Stanford University, also GM and Carnegie Mellon University. Google's driverless car initiative changed research vehicles into commercial vehicles, by noticing the calibre of educational personnel Google successfully built a fleet of driverless vehicles shortly after the DARPA urban challenges. With Google developing driverless vehicles, many other companies realised the open market, today in 2018 nearly every car manufacturer is developing their own vehicle.

4 Systems & Algorithms

To implement a fully DV with the ability to operate in urban situations, many real-time systems must be achieved; systems including perception, localisation, planning and control (Rezaei & Klette, 2017). In general, driverless vehicles are composed of diverse technologies. Multidisciplinary collaboration is required to achieve the overall solution hence, researchers and development teams working together (Kato, et al., 2015). The purpose of this section is to introduce some systems that combine to create a driverless vehicle. Not all systems and algorithms will be discussed in this paper due to the sheer amount of algorithmic work included in a sophisticated driverless system.

To set the scene, DVs use rotating lasers that build a detailed picture of the surrounding world. According to Collingwood (2017), the lasers take about a million readings per second, with additional technology such as radars and cameras to capture more data about the surroundings. Furthermore, the vehicles require cellular or wireless networks to alert vehicles of potential hazardous conditions and provide real time traffic updates.

4.1 How Driverless Vehicles Work

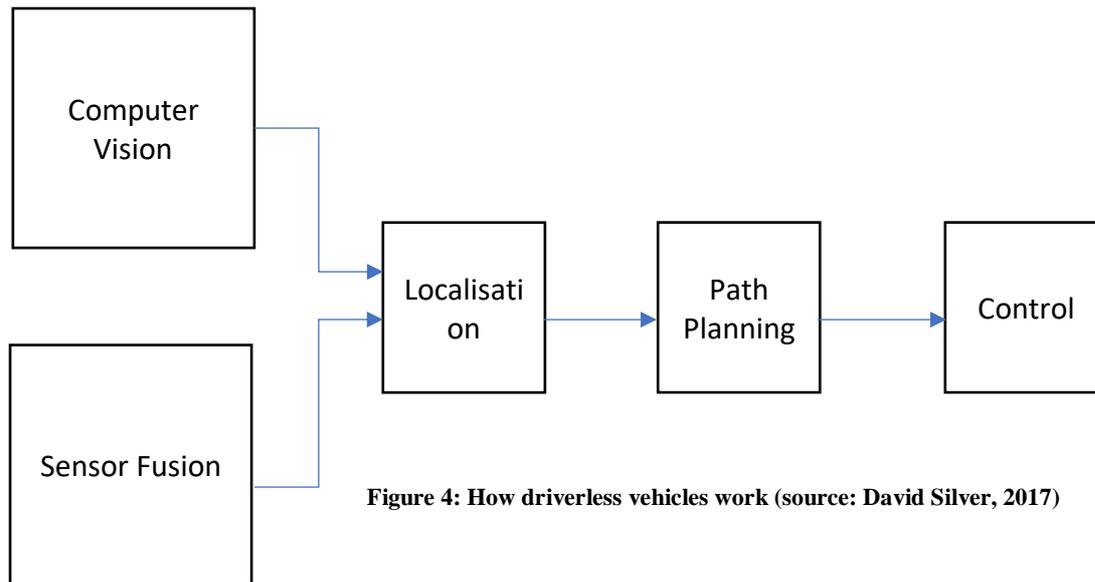


Figure 4: How driverless vehicles work (source: David Silver, 2017)

Computer Vision – Different video camera methods used to see the surrounding environment.

Sensor Fusion – Lasers and radars are fused with video camera data to build an understanding of the surrounding environment. Sensors are very useful for identifying measurements such as velocity and distance - cameras struggle to do so.

Localisation – The vehicle calculates where they are in the world by using mathematical algorithms, GPS other methods.

Path Planning – Once the vehicle knows where it is in the world, its next step is to figure out where it is travelling to. This also concerns the surrounding environment such as what other vehicles on the area are doing.

Control – Once the trajectory of the path planning is calculated the vehicle needs to control the vehicle appropriately to reach the destination. This involves the many road obstacles on route, which required stopping, accelerating, slowing down, speeding up, turning etc. depending on what is on the road e.g. pedestrians, vehicles, road infrastructure.

4.2 Hardware & Software

DVs rely on many components of hardware, hardware being the physical elements used for perception and navigation. The hardware is composed of three different components, actuators, processors and sensors. Actuators are any hardware that allow the driverless technology to steer, break and change gear. The processors handle data incoming from sensors which then communicate with the actuators to direct the vehicle. Sensors are the crucial part of the process, detecting and perceiving the world around them. Hardware related to sensors are any components that read the world outside of the car, sending information to the processors which ultimately move the vehicle. Hardware is relatively easy to acquire, the issues surrounding hardware focus on aesthetics and construction on the vehicle as there are many components that need to be combined for success. Software is combined with sensors to detect obstacles and predict real-time road behaviour to ensure safe driving is achieved. The software implemented includes many different algorithms, systems and frameworks. However, there is yet to be an open source software for a fully road legal DV.

4.3 Sensing

With the development of sensor technology expeditiously progressing, the need for in vehicle technology and infrastructure is becoming more important. New sensor technologies are being developed to increase sensor capabilities such as more range, accuracy and robustness (Meyer & Beiker, 2016). Furthermore, sensors are being constantly developed to become smaller and smarter in the way they work to enable maximum design space. The outcome of improved sensors allows more data to be sent to the in-vehicle systems consequently, more effective decisions autonomous vehicles can make.

The recent advances of microprocessors have enabled sensor data to be analysed, providing control systems with essential information. Meyer & Beiker (2016) states that microprocessors enable sensor fusion, improving efficiency and the development of many automated features. Cloud based systems are used to analyse real time data collected from sensors, providing the necessary ability to develop safety applications.

Ultrasonic Sensors – These sensors are useful for detecting obstacles at short distances. For example, they are useful when using park assist systems as they can warn the driver or vehicle if they are about to hit an obstacle (vehicle, post, curb etc.).

Radar Sensors – These sensors emit radio waves, and then later analysing the bounced wave through a receiver. Radar sensors are usually used to detect a moving vehicle's speed and distance.

Camera Sensors – Camera sensors are cheap compared to other sensors, they are usually used to detect, process and classify objects in complex urban situations. For example, detecting a pedestrian crossing the road.

Data Collection – Data collection via sensors can communicate with external sensors such as satellites, wireless sensor networks and GPS to assist the driver/vehicle with real-time traffic and route information. These sensors also have the capability to communicate with surrounding vehicles and infrastructure (V2V/V2I) within a 5km radius to collect information such as recent accidents, traffic updates, road closures etc.

LIDAR – Emits pulses of infrared light, the vehicle then measures how long these pulses take to come back indicating the distance of the object creating a 3D map. LIDAR can be used for long or short distance detection, but can be affected by extreme weather and bad lighting.

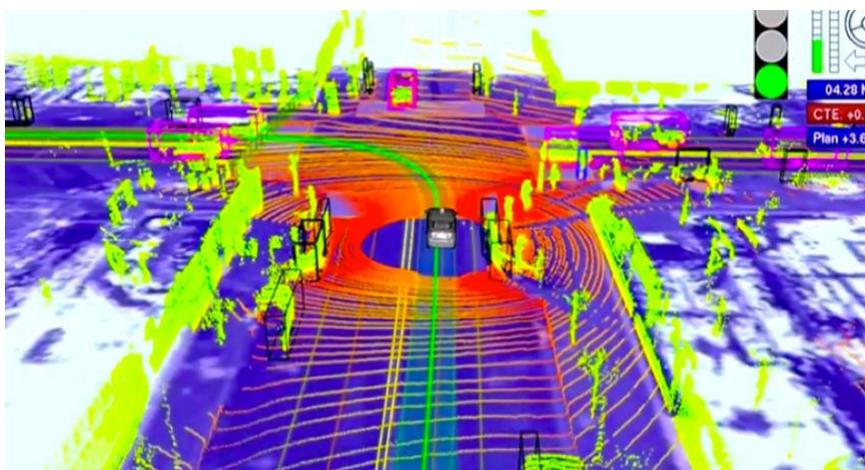


Figure 5: LIDAR sensing its surroundings (source: Charneau, 2018).

The sensors discussed each have their individual benefits and limitations, however, a combination of these sensors provide the vehicles with a more effective solution. Hence, more expensive hardware and software to build the vehicle.

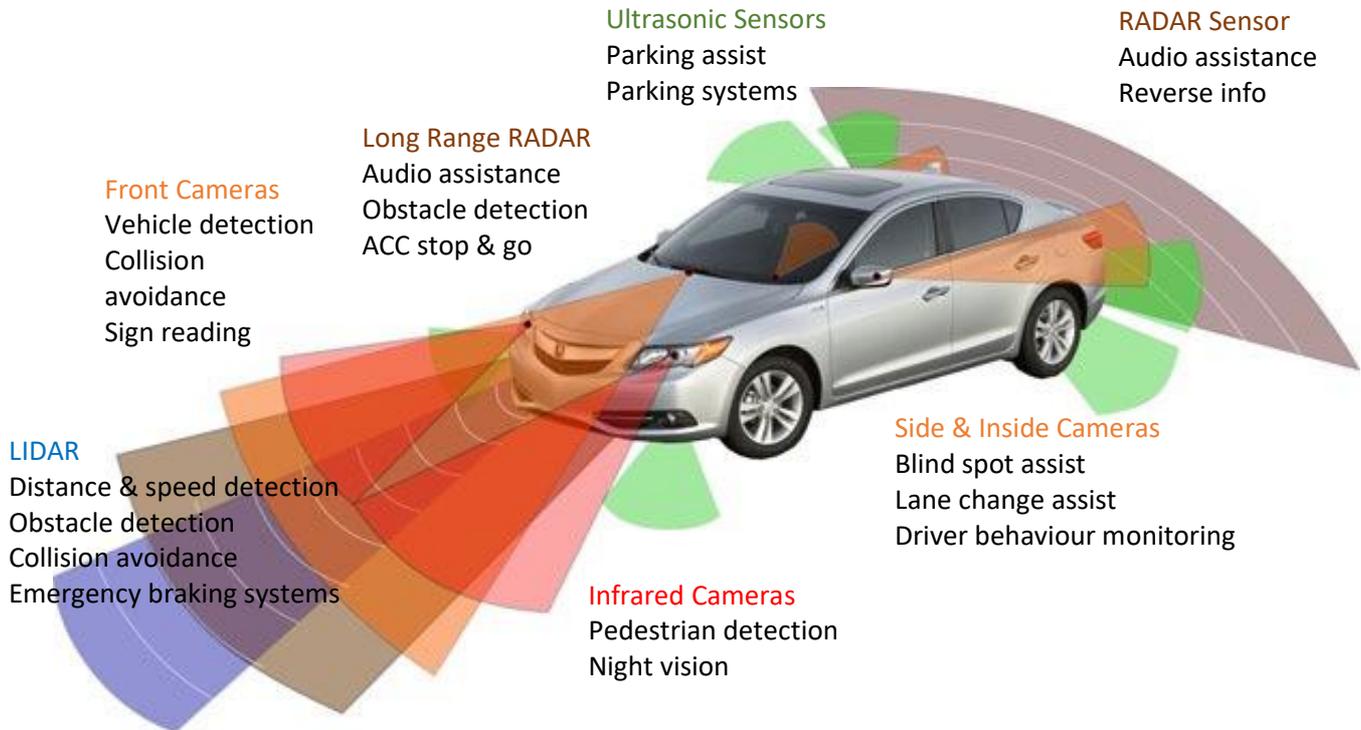


Figure 6: Combination of sensors example (Source: Rezaei & Klette, 2016).

Driver assistance systems (DAS) collect information with a host of different sensors to determine whether the moment being perceived could lead to an accident. Vision based driver assistance systems (VB-DAS) use a combination of cameras and sensors to assist the driver to make decisions, signal warnings and automatically take action to ensure vehicle and passenger safety (Rezaei & Klette, 2017). Some VB-DAS features:

Speed Adaptation - The vehicles rely on external cameras to detect the speed limit traffic through sign recognition alongside the basic GPS data built into the system. The vehicle will automatically adapt, normally reducing or increasing to appropriate speed. Intelligent speed adaptation (ISA) also consider factors such as road conditions, markings and situations such as pedestrians or obstacles which may cause require the vehicle to reduce in speed.

Parking Assist - Parking assist systems require a 360-degree view, using a range of sensors such as ultrasonic, close range radars, laser scanners and vision sensors (Rezaei & Klette, 2017). The system aims to detect a possible parking space and guide the vehicle into that space autonomously. Multiple systems have been developed and are currently in use by vehicles such as the Mercedes C class saloon, Peugeot 3008 SUV any many more.

Blind Spots - A blind spot is the area around the vehicle the driver cannot see by looking in the main rear view mirror or side mirrors, typically areas such as behind the pillars to the left and right of the windshield. Blind spots should be regularly checked when changing lanes and in urban environments e.g. before turning left. Systems that support blind spots analyse the data from video recordings communicating important information to the driver such as ‘there is a vehicle on the right’. Blind spot information systems (BLIS) was first introduced by Volvo in 2005 indicating to the driver if a vehicle was to the right or left (Rezaei & Klette, 2017).

Automated Queue Assistant - The AQuA is used when traffic is very congested in urban environments and on motorways. This feature is used to keep a specific distance between vehicles when driving in platoons. Hence, truck convoys will benefit from this significantly. The AQuA uses longitudinal distance control to control distances between vehicles, where the vehicle will automatically reduce or increase speed to keep that distance. Lateral control is also used for keeping the vehicle from hitting any vehicles either side, where the vehicle will adjust steering if need be. Can sometimes be referred to as adaptive cruise control (ACC).

Lane Warnings - In VB-DAS lane assist will provide warnings to the driver if they are in the incorrect lane, and to provide any lane changing information.

4.4 Mapping & Localisation

We look at localisation as a major problem in DVs, in urban environments the reliability of driverless vehicles heavily relies on localisation (Kato, et al., 2015). DV navigation requires accurate localisation. Despite general GPS systems already implemented within vehicles, autonomous driving in urban environments requires more advanced localisation. Stanford's Junior uses a combination of GPS, IMU and LIDAR sensors generate data that is used to create a high-resolution infrared remittance ground map that can be used for localisation (Levinson, et al., 2011). They model the environment, rather than relying on a fixed special grid of values, this allows the system to improve maps over time by machine learning. Using pre-recorded simultaneous localisation and mapping systems (SLAM) offline in parallel with the real-time LIDAR data, Junior has a robust understanding of its surrounding environment. However, mapping and localisation can further be improved by implementing situational data within road infrastructures that communicate with the vehicles.

4.5 Obstacle Detection

Häne, Sattler & Pollefeys (2015) suggested obstacle recognition system consists of three stages. They use monocular fisheye cameras rather than normal binocular stereo cameras as they can see more of the vehicles surroundings and detect objects that are close to the vehicle. The first stage consists of their obstacle recognition framework involves extracting a depth map from each camera on the vehicle, by using multi view stereo matching of the recorded frames. These depth maps are used to see a 3D view of the surrounding environment. Secondly, they suggest extracting the free space and obstacles found in the depth maps. To detect the objects, they use 2D imaging as objects are those that protrude from the ground (Häne, Sattler & Pollefeys, 2015). In the third step, the obstacles detected are fused over many camera frames to provide a more detailed understanding of the object. Below is the overview of the detection system framework.

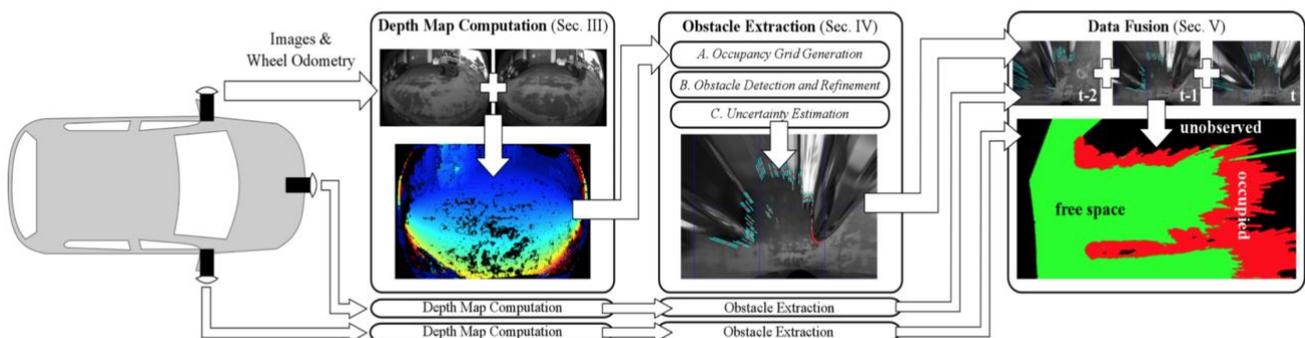


Figure 7: Overview of obstacle detection system (source: Häne, Sattler & Pollefeys, 2015).

Vehicle Detection & Tracking

Vehicle tracking is crucial to successfully implement collision avoidance systems. There are many methods for detecting vehicles such as computer vision and taillight segmentation. The driverless vehicle will analyse the trajectories of surrounding vehicles in order to understand where each vehicle is moving, avoiding collisions. Tracking can be carried out by constantly detecting vehicles. Rezaei & Klette (2017) suggest it is beneficial to use stereo vision results alongside monocular data in a tracking process. Tracking is a complex procedure, due to external factors such as lighting and reflections however, it is thought to be easier than tracking pedestrians as vehicles are easier to model as they have recognisable features such as bumpers, lights, line segments, visual symmetry etc.

Pedestrian Detection & Tracking

Pedestrian detection and tracking is a very complex area, as the vehicle must detect and track those pedestrians on the side of the road not just those crossing the road. Pedestrians that could potentially cross the road suddenly or accidentally throw objects into the road such as balls and toys. Rezaei & Klette (2017) identify the following method, firstly a bounding box is located at the region of interest, in this instance it would contain a pedestrian. A classifier is then applied to this bounding box to detect a pedestrian, a histogram of oriented gradients can be used to detect a pedestrian within the bounding box. Once the histogram of gradients has been derived the classifier can decide whether a pedestrian is within that bounding box. These histograms of oriented gradients can be used within a random decision forest (RDF) to classify the pedestrians. An RDF being a supervised classification algorithm, this is based on a relationship of how many trees there are in the forest and the results it can get. The more trees in the forest the more accurate the results.

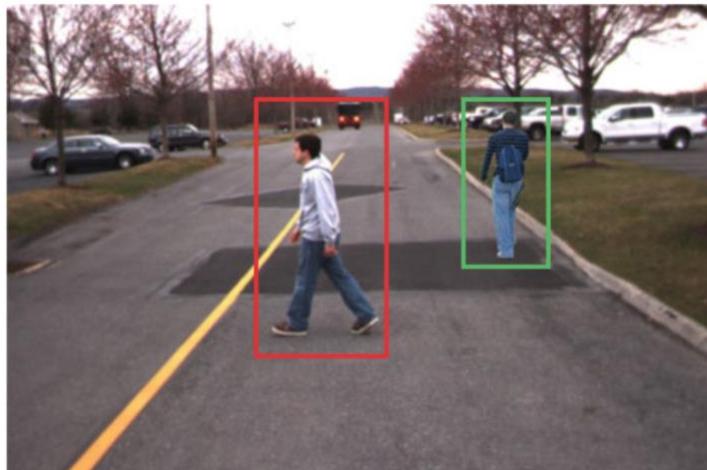


Figure 8: Example of bounding boxes to detect pedestrians in an urban environment (Source: Rezaei & Klette, 2017).

Free Space Detection

Free space is defined as the area of the road that the driverless vehicle can safely drive. Free space can generally be calculated using an occupancy grid, where the occupancy grid will represent a map of the surrounding environment detecting the presence of any object in that grid. Recent methods to calculate occupancy grids use stereo vision.

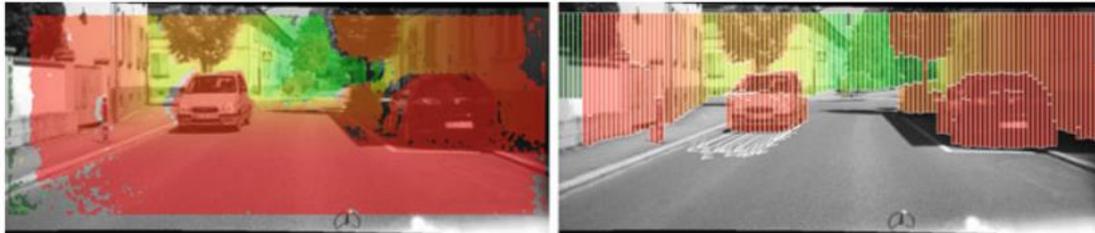


Figure 9: Left: depth of data calculated by stereo matching. Right: Calculated stixels (formed occupancy grid, based on the stereo matching. Source: Rezaei & Klette, 2017).

4.6 Curb Detection

Curbs are identified as structures found in urban environments that set the boundaries of the road. Curb detection is a crucial component of driverless vehicle algorithms, to aid path planning and determine localisation of the vehicle. There are many different ways of detecting the curb, such as stereo cameras and 2D LIDARs. Hata, Osorio & Wolf (2014) suggest a 3D LIDAR system, which can be used to detect the curb through a ‘dense point cloud’. This method will enable the vehicle to recognise more of the curb than other methods, resulting in more efficient feedback to make decisions. Hata, Osorio & Wolf (2014) method uses a multilayer LIDAR which intercepts flat planes to identify the curb. The LIDAR uses many laser emitters that return concentric rings to identify each measurement. In order to detect the curb, the algorithm will analyse the returned rings to check if the adjacent ring points are lower than the threshold. The measurements that match this are then classified as curbs, whereas those that don’t satisfy the conditions will be filtered to remove false positives. Such methods are not accurate for roads that have no curbs, for example in rural areas, roads with no curb or damaged roads.

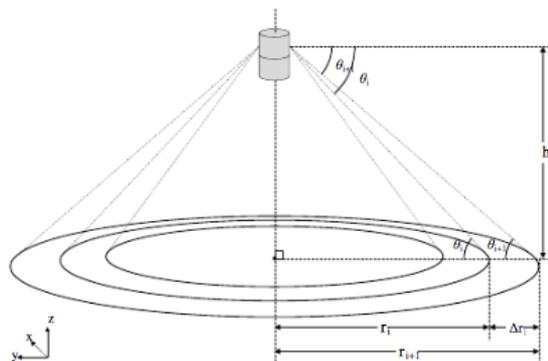


Figure 10: LIDAR rings intercepting flat plane (source: Hata, Osorio & Wolf, 2014).

4.7 Dynamical Modelling & Control

Modelling and control is defined by taking the trajectory as an input and applying necessary physical actions (throttle, brakes, steering), to guide the vehicle to the destination as an output. The software processes the laser and video inputs and sends them to the actuators, which control the vehicle through model predictive control (MPC) and other physical well-known

models. Vehicle modelling and control systems are composed of longitudinal and lateral controllers – longitudinal controllers regulate the velocity and lateral controllers direct the vehicle for path planning (Filho, Wolf, Grassi Jr, & Osório, 2014). Longitudinal models for vehicles can be expressed by Newton's second law:

$$m_v \dot{v} = F_{ice} + F_{brake} + F_{air} + F_{rr} + F_{gr} + F_{int}$$

Figure 11: Newton's second law

- F_{air} – Drag
- F_{int} – Internal resistance
- F_{rr} – Rolling distance
- F_{gr} – Gravitational force
- F_{ice} – Engine force
- F_{brake} – Braking force
- M_v – Vehicle mass

The bicycle model can be used to calculate the lateral model for the vehicle:

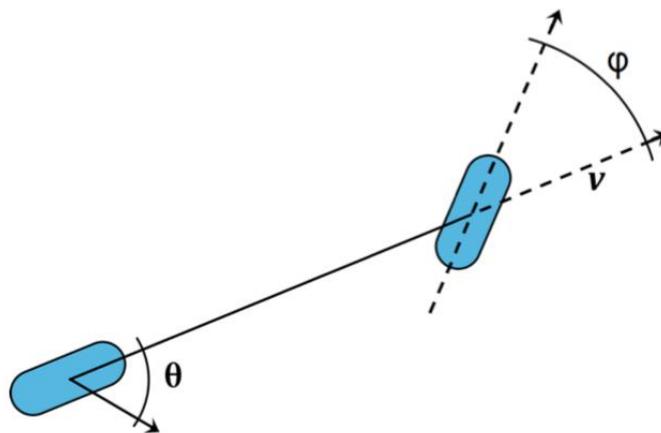


Figure 12: Bicycle model (Source: Filho, Wolf, Grassi Jr, & Osório, 2014).

Where the front and back wheels are both separately represented by one wheel, this makes it easier as only two parameters need to be considered. Assumptions have been made in this case that the rear wheels do not steer the vehicle (Filho, Wolf, Grassi Jr, & Osório, 2014).

4.8 Roundabout Manoeuvring

Roundabouts consist of sharp turns, lane changing and avoiding traffic, therefore technology to master this is difficult. Raaijmakers (2017) has developed the multi-hypothesis road representation to solve the roundabout manoeuvre. In order for a vehicle to travel on a roundabout, the geometry relative to the vehicles location is required. Raaijmakers created an algorithm for the environment perception system, which identifies the island of the roundabout. He proposed the system is combined of sensor data and digital map data. The algorithm is split into four steps.

Algorithm:

1. **Neighbour Based Splitting** – The point sequences are split into separate sequences only if the distance between the two sequences is smaller than a specified maximum.

Splitting happens as only large distances between neighbouring points occur when the laser is parallel to the tangent of the island.

2. **Semi-Convex Partitioning** – Each sequence with concave points are split, this is where the curvature changes and points towards the vehicle. By splitting the concave, the sensors will only have the border of the island remaining.
3. **Curvature-Based Partitioning** – A circle has a constant curve, therefore Raaijmakers split the semi convex segments where the object can no longer be constant.
4. **Circle Fitting & Constraint Checking** – After the third step, a point sequence is left with the semi-convex segments and where the curvature is small. Segments which have less than n_{min} points are discarded. The remaining segments are then used to calculate the least square circle using the Newton-based implementation of the Taubin fit.

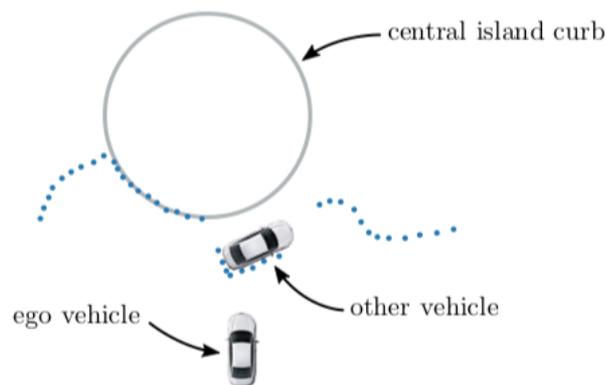


Figure 13: Scenario where the lasers scan the curb of the island, a vehicle on the roundabout and the road. Blue points are points measured by the laser (source: Raaijmakers, 2017).

Overview of the algorithm in relation to the scenario in fig.13:

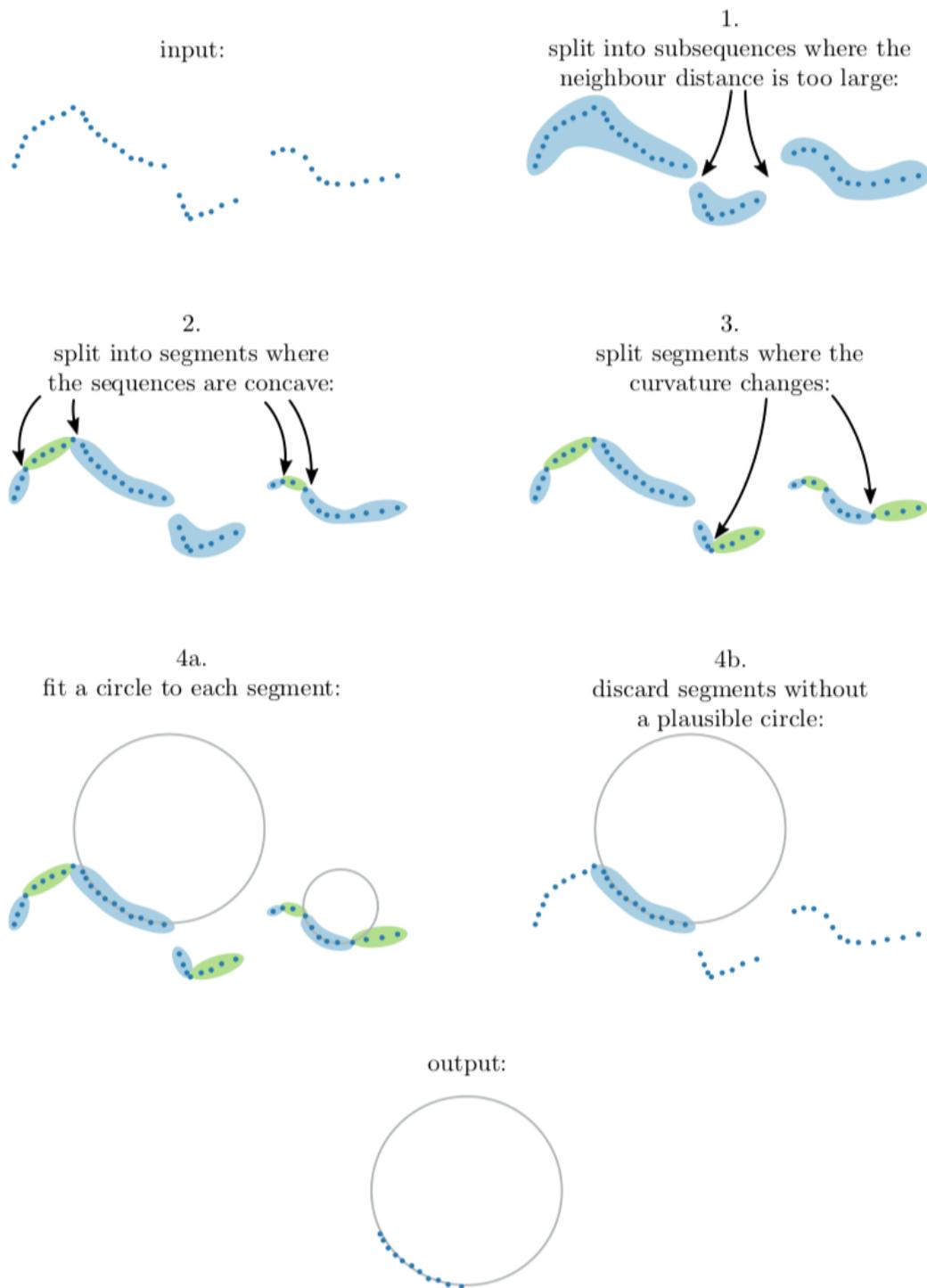


Figure 14: Overview of the algorithm for the environment perception system (source: Raaijmakers, 2017).

4.9 Traffic Sign Recognition & Detection

Traffic sign recognition and detection in DVs uses a computer based system that identifies the type of road sign, and reacts to it in the appropriate way e.g. detecting a school sign and slowing down to 20mph. Traffic signs on the roads are currently identified as bold colours and shapes in order to attract the driver's attention. Signs are in place to warn the driver of possible hazards or situations on the road, therefore the driverless vehicle must be able to identify these to comply with the rules of the road. The four types of traffic signs are warning, prohibition, obligation and informative. Warning signs are usually white equilateral triangles with a red border. Prohibition signs are either white or blue circle with a red border. The warning and prohibition signs have yellow backgrounds when there are temporary works. Obligation signs are circles with blue backgrounds, and informative signs are indicated by blue signs (Hossain & Hyder, 2015). The computer based systems that are used to identify these signs need to be of standard, as there are some factors that will make sign detection significantly difficult such as external conditions e.g. dust, rain, snow, lighting. The introduction of DVs may result in the standardisation of road signs to ensure they can be detected.

Wu, Chen, & Yang, (2005) developed a two-step heuristic approach, where the system will first identify the traffic sign, and then once identified it will detect the text inside the traffic sign. This works by extracting data from the 2D text that is integrated with the 3D geometrical structures found alongside the road, in the recorded videos. However, this approach may result in false detection as structures such as advertisement boards could be picked up. The classification of road signs may need standardisation of signs, focusing more on shape or colour to detect them. For example, Rezaei & Klette suggest circles can be detected using the Hough transform or a radial symmetry approach. The system flow chart to the right illustrates how the detection of a sign can be carried out.

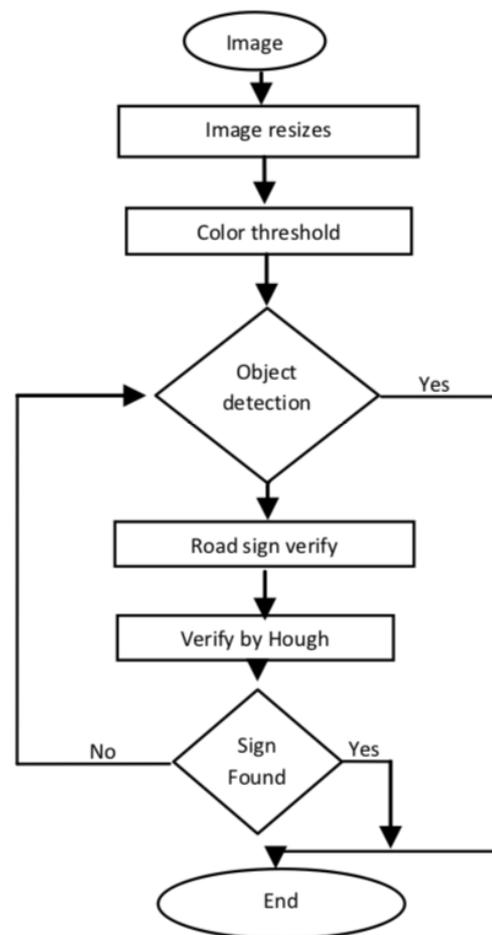


Figure 15: System flow chart of how a sign is detected (source: Hossian & Hyder, 2015).

4.10 Traffic Light Detection

Levinson, et al. (2011) detects a traffic light using passive camera based pipeline. This method uses known traffic light localisations and vehicle detection. Stanford's research vehicle Junior, has successfully navigated through traffic lights using the following framework:

1. Pre-defined traffic light locations are defined.
2. Search for traffic lights using camera resolution and braking distance of vehicles driving in-front.
3. Region of interest (ROI) is located where the expected traffic light was detected.
4. Template matching algorithm is applied to the ROI.
5. The results are put into a histogram to analyse the situation.
6. Co-ordination of the light is reported.
7. Determine and report traffic light colour - depends on the hue of the cell determined in step 6.

4.11 Communication

To successfully implement connected vehicles, reliable communication infrastructures are required. Vehicles are now being transformed into sensor platforms, by collecting data from other vehicles and the cloud and sending the data back to the human operators or the systems infrastructure to ensure safe navigation and traffic management (Meyer & Beiker, 2016). For communications to progress, the vehicles must incorporate the IoT and Vehicle to Vehicle (V2V, or V2I), to create the internet of DVs. For this evolution of technology to advance we are relying on the introduction of 5th generation wireless systems (5G), allowing gigabytes to be transmitted across the network. However, introducing V2V technology will pave the way for cyber-attacks, therefore it will be fundamental to secure the vehicles network. Many different components will need security such as the infrastructure, encrypting all communications on the cloud as well as developing quality authentication schemes (Meyer & Beiker, 2016).

V2X – communication is key for safe DVs. V2X is broken down into four separate communication types, based on what they are communicating with:

Vehicle to Vehicle Communications (V2V)

Vehicle to vehicle (V2V) allows the vehicles to share data about their location, route and speed to other vehicles in the surrounding environment over wireless networks. The National Highway Traffic Safety Administration (NHTSA) point out this technology will allow the vehicles to 'broadcast and receive Omni directional messages 10 times per second, this creating a 360-degree view of other vehicles in the area (Forrest, 2018). This technology is important as it can sense danger, and notify the vehicle or human operator via alerts on the dashboard or by taking control of the vehicle. The V2V systems can operate as far as three hundred metres around the vehicle, using Dedicated Short-Range Communications (DSRC) to transmit the data. V2V technology is separate to driverless technology and some are implemented in today's vehicles to help avoid collisions.

Vehicle to Infrastructure Communications (V2I)

Vehicle to infrastructure involves the sharing of safety and operational data between DVs and the infrastructure around them. The purpose of V2I is improving safety and inefficiencies. Vehicles will have the capability to communicate with infrastructure such as traffic signals, signs, crossings etc. which will alert the operator or vehicle if they need to react. In addition, pedestrians who carry smartphones will be involved in V2I technology as their smartphones will be able to notify them of surrounding vehicles and threats. The IoT will play a huge role in the development of V2I with RFID readers implemented in traffic signs, traffic lights, lane markers etc.

Vehicle to Pedestrian (V2P)

The vehicle communicates with nearby pedestrian smartphones, providing updates and safety information.

Vehicle to Network (V2N)

The vehicle exchanges data with cloud services, which provides real time traffic updates and route information.

Behavioural Change

To allow V2V and V2I connected vehicles to work, the DVs must be able to react to environmental changes by changing their behaviour dynamically. In this case microsimulation methods do not provide this, therefore VISSIM COM interface is used. VISSIM COM (Component Object Model) is an API (Application Program Interface) that gives access to VISSIM models by programming methods not included in the graphical user interface. The algorithms are pre-determined to find data such as vehicle speed, location and behaviour (Department for transport, 2016).

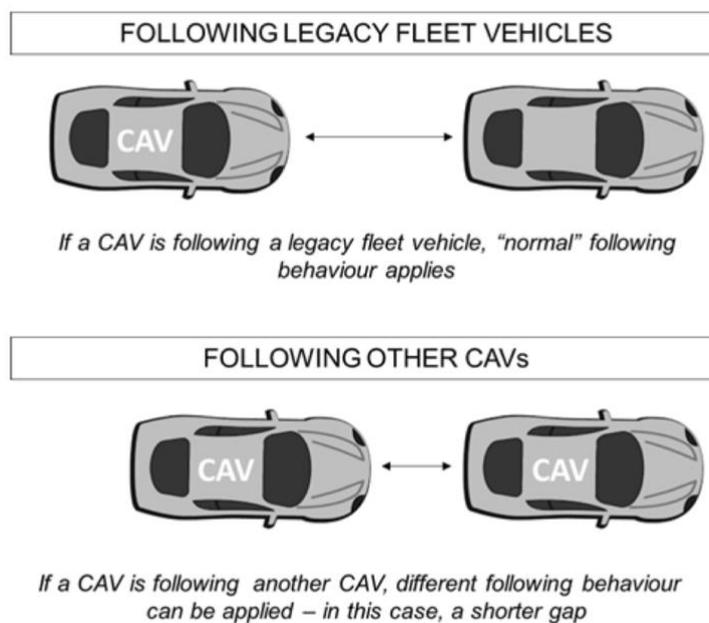


Figure 16: Different behaviour depending on the preceding vehicle (source: Department for transport, 2016).

The image above illustrates vehicle behaviour based on the type of vehicle they are following. Where the legacy fleet vehicle is a normal vehicle on the road and the CAV is another driverless vehicle. If the preceding vehicle is another DV, shorter gaps can be applied as the vehicles are connected reducing congestion and increasing road throughput. Whereas if the preceding vehicle is a normal vehicle the DV will need to monitor and react to the changes via usual driverless methods.

Smart Cities

Progression of autonomous vehicles, machine learning and the IoT are paving the way for smart cities. Smart cities are those that use ICT to improve operational efficiency by communicating with the public and services. In terms of DVs the focus will be on introducing cloud services that understand the DVs, and building infrastructure that the vehicles can communicate with. This will consist of V2X technology with cellular chips in each

communicator. The infrastructure such as signs, traffic lights and other roadside systems will share data and alert DVs in close proximity of the recommended speed limit, state of the traffic light and other information such as schools nearby. The crash avoidance system will alert the driver/vehicle about potential hazardous environments ahead through communication from the roadside infrastructure.

5 Levels of autonomy Defined

The Society of Automobile Engineers (SAE) have defined five levels of autonomy for DVs as shown in the table below. The different levels show the amount of work humans do compared to the amount of responsibility given to the vehicle.

Level	Name	Narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BACS level	NHTSA level
Human driver monitors the driving environment								
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	Highly automated	3
4	High Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes		

Figure 17: SAE International's levels of autonomy (Source: Smith, 2013).

Level 0: At level 0 automation the vehicle has no automation, and relies on the human to take control of the vehicle.

Level 1: The majority of tasks are carried out by the human operator. Whilst the computer assists the human to complete tasks.

Level 2: In level 2 automation the steering and speed are controlled by the assistance systems, whilst the human operator takes control of all other tasks.

Level 3

Level 3 automation is described to be 'autonomous driving'. The driver assistance systems are able to read and monitor the surrounding environment. These vehicles are capable of making decisions, such as overtaking slower vehicles. However, the human operator is required to take over if needed.

Level 4

Level 4 automation is defined as high automation. The vehicle will be able to handle most normal driving tasks. The human operator is only needed to take over in extreme weather conditions and tricky environments. The vehicle will have all the necessary mechanisms in the cockpit that allow the human to take control.

Level 5

Level 5 automation is defined as full automation. The vehicle will take control at all times. Humans are simply passengers, and only need to tell the vehicle where to go. There is no human intervention in level 5 automation. Timeline – within the next 2 years.

Level 2 automation is the highest level on our roads today. No vehicle on the market can be trusted to take control without human monitoring and intervention. However, many companies are testing higher levels and suggest they will be available soon.

6 Leaders of The Driverless Vehicle Industry

This section will show the leaders of research and development of DVs according to the Navigant Research Leader board conducted in 2017. The leader-board was decided by manufacturers being based on the following criteria:

- Vision
- Go-to-Market Strategy
- Partners
- Production Strategy
- Technology
- Sales, Marketing, and Distribution
- Product Capability
- Product Quality and Reliability
- Product Portfolio
- Staying Power

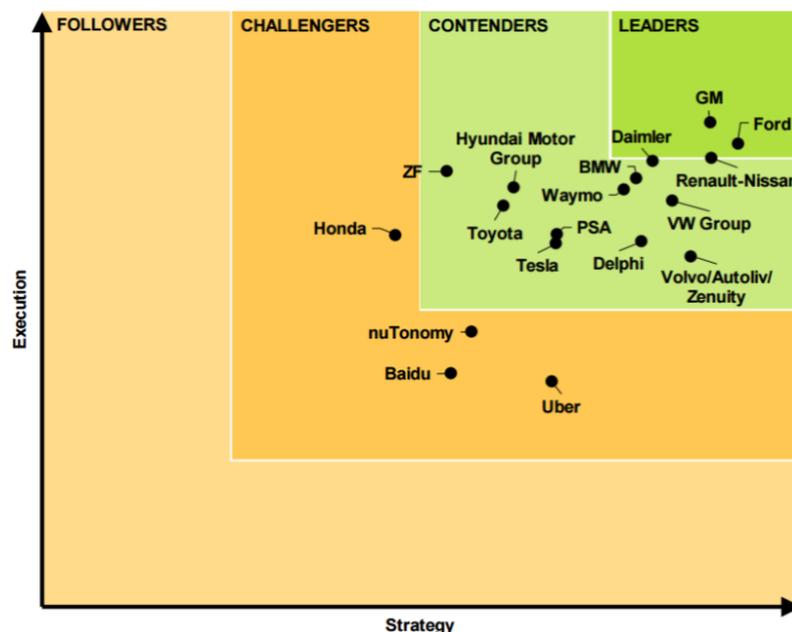


Figure 18: The Navigant Research Leader-Board Grid (Source: Navigant Research Leaderboard Report: Automated Driving, 2017).

The scores of all 18 companies considered are shown in the figure above. There are four clear leaders in GM, Ford, Renault-Nissan and Daimler as they all scored 75 or more in strategy and execution. The contenders scored above 50 in both execution and strategy but are not yet in the leader's category. The contenders have the ability to become leaders as they have the capability for long-term growth and success. Whereas challengers scored above 25 and followers scored below 25 in both execution and strategy. The leaders are already very advanced in terms of established ADAS technology, with level 2 autonomous systems beginning to roll out. The sensor tech is beginning to reduce in price as research becomes more focused on software and electronics. The two biggest leaders are discussed below (Navigant Research Leaderboard Report: Automated Driving, 2017).

Ford – Overall score 85.0

Ford were involved in the DARPA challenges developing their F-250 pick up in house rather than collaborating with universities. In 2016, Ford released a statement, announcing they will be developing level 4 DVs at mass production in 2021. Ford have also set a statement investing into supporting technology companies – they invested \$700 million in the Flat Rock Assembly Plant, which support level 4 automation. Also, during 2017 Ford invested in many other companies such as Civil Maps, Saips, Velodyne, Chariot and many more. These investments show the dedication and progress of the aspired production of level 4 DVs, also with millions spent on investing into a start-up company Argo AI (AI and robotics company) which aimed to have over 200 software developers by the end of 2017 (Navigant Research Leaderboard Report: Automated Driving, 2017).

GM – Overall score 84.8

Similarly, GM invest highly in supporting technology companies. In 2016, GM invested \$500 million in a ride-hailing company Lyft with the aim to develop DV ride-hailing services. GM specifically made an effort to employ 1100 new employees to work on DVs on top of existing staff. They also acquired a company named Cruise Automation, in an effort to combine their developed image recognition system. Cruise Automation are developing driverless kits that can be implemented onto normal vehicles to transform them into DVs (Navigant Research Leaderboard Report: Automated Driving, 2017).

6.1 Recorded Driverless Vehicle Accidents

Whilst DV's are predicted to be very safe, they can still make mistakes. Since the testing of driverless vehicles began, there have been some recorded collisions. The collisions have caused many discussions and raised many questions, resulting in bad publicity for the driverless industry. The public forgets all statistics involved once a crash is recorded, but driverless vehicles are bound to make some mistakes.

In recent months, an Uber DV hit and killed a pedestrian in the state of Arizona, USA. Whilst the nature of the accident has been widely discussed, Uber have been banned from testing their self-driving vehicles in Arizona. In the moment of the accident, the vehicle was in self driving mode with a human operator at the wheel. A 49-year-old woman, named Elaine Herzberg was crossing the road pushing a bicycle, when the DV was travelling at 38mph hit and killed her (Hawkins, 2018). It was said that even with a human operator controlling the vehicle they wouldn't have been able to stop or react, as the pedestrian seemed to step into the road. The algorithms or human reaction times wouldn't have been quick enough to react. The driver said the first sign of the collision was the sound, indicating this was not the driverless technology's fault. Furthermore, the driver said it would have been difficult to stop in any kind of vehicle whether it was driverless or not, as the pedestrian appeared from the dark into the path of the vehicle (Hawkins, 2018). However, it has been reported that Uber's self-driving vehicles were not performing efficiently, not being able to carry out basic manoeuvres. The vehicles were struggling to drive in areas such as construction sites and alongside large vehicles. Whether the person was to blame or the technology is yet to be discovered, and this is another case of the liability issues involved with driverless vehicles, as many more incidents like this will occur. This incident could potentially affect the deployment and trust of Uber's self-driving vehicles.

However, contrary to this the CEO of Waymo, John Krafcik believed their vehicle would have been able to handle the situation. John Krafcik believes their particular vehicle was built to react to situations like this one. The accident has been a major negative on the driverless industry however, perhaps it has affected Waymo more as they are about to deploy a fleet of on demand driverless services for public use in Phoenix. The staff of Waymo were particularly shocked and disheartened by the news of the Uber incident, because they are trying to solve similar problems (Ohnsman, 2018).

Since 2016, two separate drivers have been killed using Tesla's autopilot system. Tesla's autopilot system is less sophisticated than fully driverless vehicles focusing on drive assist features such as cruise control, lane assist etc. In 2016, the Model S crashed into a tractor trailer, its reported that the vehicle had indicated the driver to keep their hands on the wheel but this instruction was ignored. The vehicle hit a tractor trailer at 70mph, and the driver was killed. Tesla reacted to point out this was the first fatality in 130 million miles (Bogage, 2016).

On March 23rd, 2018, a few months after the Uber incident, a Tesla Model X SUV hit a highway barrier in California. The vehicle caught fire and was then hit by two other travelling vehicles, the driver was killed. The autopilot feature being on the market so soon, may cause the drivers to take advantage of the feature by not paying attention to the road. In this incident, the driver was reportedly not holding the steering wheel. However, the full details of this crash haven't yet surfaced but this indicates that drivers need to be alert and ready to take over the vehicle (Fischer, 2018).

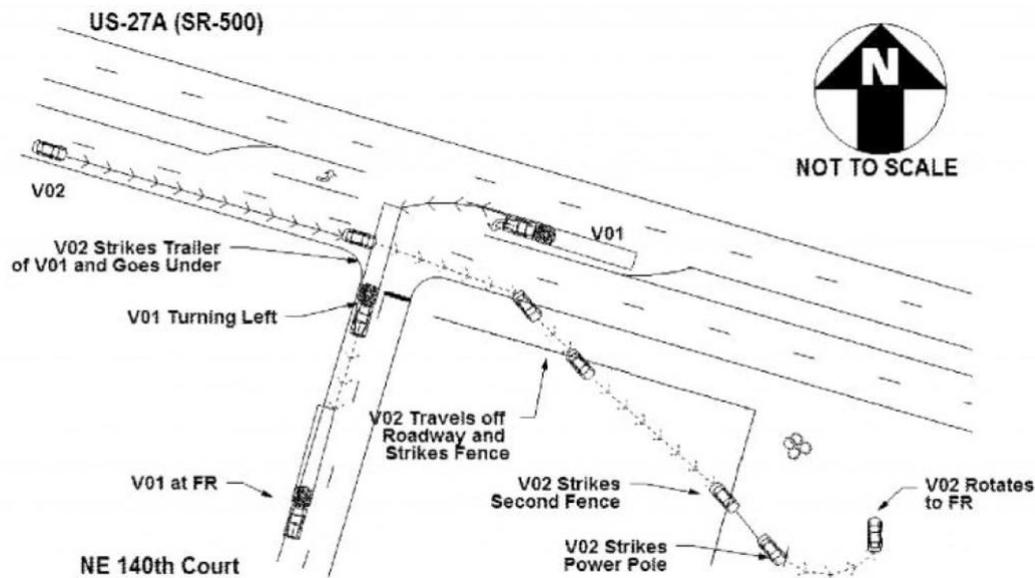


Figure 19: Tesla Model S crash scene. Where V02 is the Tesla and v01 is the trailer it collided with (source: Bogage, 2016).

Furthermore, Jeremy Clarkson, an English motorist enthusiast, TV broadcaster, journalist and writer claims a vehicle with driverless features he was travelling in, made two significant mistakes in 50 miles of the M4 which could have resulted in death. He then pointed out ‘we are miles away from it’ (Revesz, 2017).

DVs may drive too well as they comply with every rule on the road. However, they do not drive like humans, they drive like robots with humans inside. In the technology world, almost every bit of software has issues at some point malfunctioning or not working therefor should these robots be trusted to carry living human beings? Artificial intelligence is crucial to establish the trust between human and machine.

7 Social & Psychological Issues

Between all the other issues with DVs, maintaining the trust between person and machine is of utmost importance. DVs could be perfectly programmed to avoid all collisions, but if we don’t psychologically feel safe, the concept will simply not work. Drivers make many decisions whilst driving that they may not even be aware of. With human error being the cause of most road accidents, why are we reluctant to giving full control to algorithms? DVs make decisions by the machine learning process, as data comes into the vehicle they continue to develop sophisticated behaviour. Some decisions are very complex; therefore, it can be difficult to relax and give full control to the algorithms. Hosanagar & Cronk (2016) suggest machine learning is aimed to recreate the process neurons in the brain, which will in turn make vehicles make human like decisions. Many people still do not trust driverless vehicles, especially after the recent Uber incident. However, it has been suggested that people are beginning to warm to the concept.

Landau (2017) points out intel suggest one way of researching the link between human and machine trust is human –machine interface. This particular research focuses on how humans interact with machines, resulting in better understanding of how to program DVs. In 2017, Yurdana and Jack Weast, the chief systems architect of Intel’s Autonomous Driving Group

conducted a test where members of the public came in and experienced travelling in a driverless vehicle for the first time. The drive consisted of five ‘trust interactions’ – summoning a vehicle, beginning a journey, changing the course of the journey, dealing with errors and emergencies and pulling over and exiting the vehicle safely. The test drive gave the participants an opportunity to see how DVs work and how they make decisions, in an aim to make them more comfortable, confident and ease their minds that the vehicle is safely under control. Weast pointed out most participants felt nervous and apprehensive before the test drive, but most left with a confidence boost. Waytz, Heafner & Epley (2014) tested a theoretical determinant of trust – anthropomorphism. Anthropomorphism is where non-human entities acquire human traits, emotions and intentions. The study consisted of people testing three groups of vehicles, a manual car, a driverless car and the same driverless car but with anthropomorphism features. Whilst testing the cars an unavoidable accident was carried out. The results show the participants preferred travelling in the driverless car with anthropomorphism features rather than the normal driverless car and even the manual car. Also, participants seemed to blame the driverless car with anthropomorphism features less. This indicates a vehicle with the ability display human like interactions can potentially solve trust issues with driverless vehicles. Travelling in a driverless vehicle may be scary, but if the vehicle can interact with its passenger for example, initiating conversation asking which route they would like to take can soothe the passengers (Landau, 2017).

Future scenario

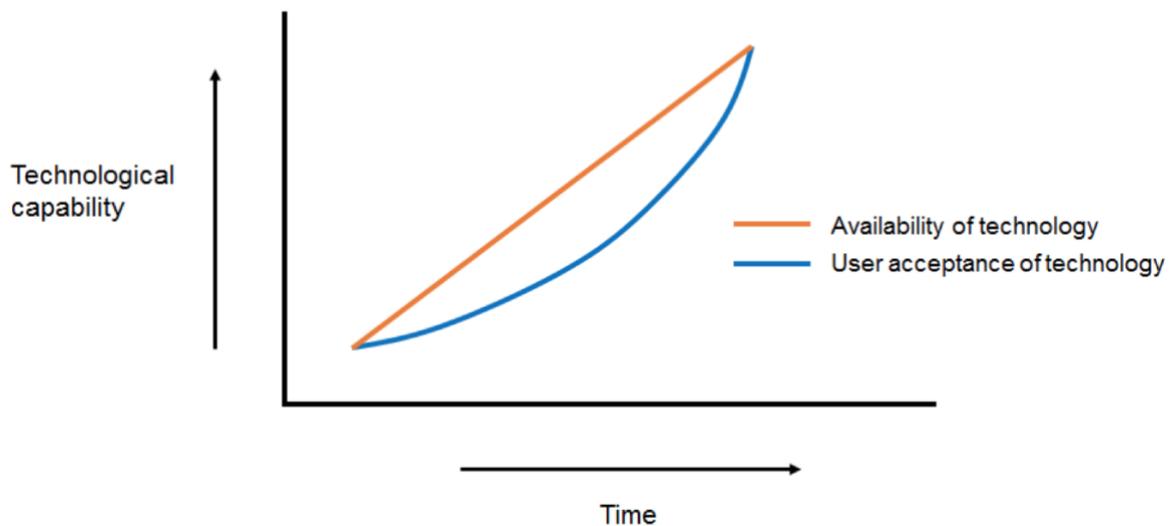


Figure 20: Availability and user acceptance connection (source: department for transport, 2016).

Users at this moment are not confident in the technology however, as driverless vehicles and connected vehicles will likely become more available as the years pass. As the users see more of this technology, thoughts will change and people will begin to adapt and accept this new technology.

8 Questionnaire – Social and Physiological Findings

This questionnaire is a study of the related social and psychological issues facing DVs. This questionnaire is about what individuals of the public think of driverless vehicles, and how they will impact their life's. The results will help the researcher analyse the psychological and social issues that need addressing before the widespread adoption of DVs. It will also help the researcher understand what the current situation is, and if the public are becoming more enthusiastic about the concept rather than more concerned.

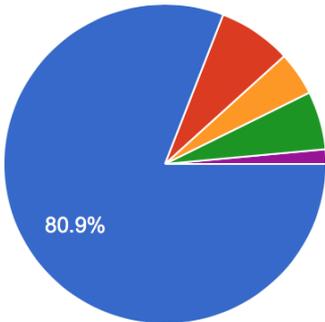
8.1 Statistical Analysis

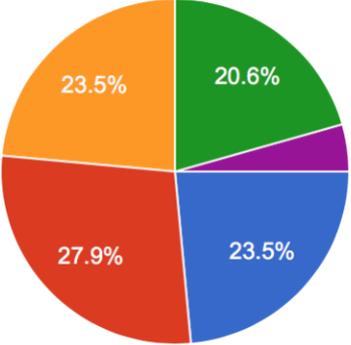
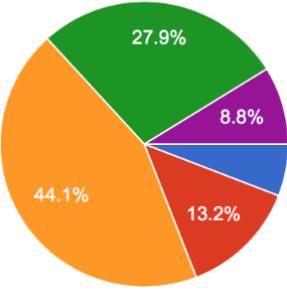
It would be desirable to obtain questionnaire results from all people across the university, also as many online answers from the shared questionnaire possible. However, as the population is very high and certain people will not agree to participate this is not practical in the timeframe given therefore the results will be based on a sample. Sampling is a process used in statistical analysis where a sample represents the entire population. In this instance, random sampling will be used by sending the questionnaire by email to years 1, 2, 3 and mcs students. The questionnaire will also be shared online in forms such as social media (Facebook & Twitter). This method will ensure the population have an equal chance to participate. This questionnaire was voluntary and anonymous.

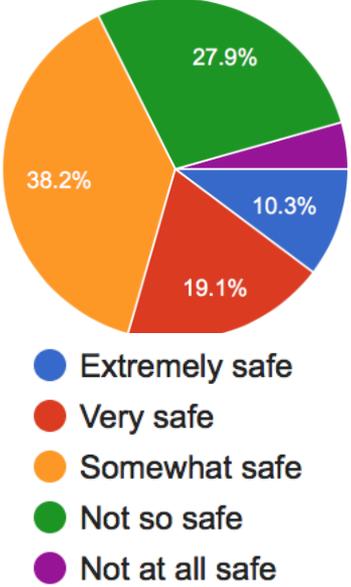
8.2 Demographics

Some demographics were included in the questionnaire including age group and gender which will allow the researcher to analyse and identify patterns that may arise and if problem areas and issues are linked to a particular set of the sample. A total of 68 people participated in this questionnaire. Out of these 68 participants, 75 % (51) were males, and 25% (17) were female. The majority of the participants were in the 18-24 age category, with 80.9% (55).

8.3 Sample Results

<p>2. What is your age?</p>	 <p>80.9%</p> <ul style="list-style-type: none"> ● 18 to 24 ● 25 to 34 ● 35 to 44 ● 45 to 54 ● 55 to 64 ● 65 to 74 ● 75 or older ● Prefer not to say 	<p>Out of the 68 participants, 80.9% (55) were in the 18-24 category. This is because my questionnaire reached mostly students and similar age groups on my social media friends list. Other age group percentages:</p> <p>25 to 34 – 7.4% (5) 35 to 44 – 4.4% (3) 45 to 54 – 5.9% (4) 55 to 64 – 1.5% (1) 65 to 74 – N/A (0) 75 or older – N/A (0) Prefer not to say – N/A (0)</p> <p>In future, more people from other age groups could be targeted.</p>
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<p>6. Would you travel in a driverless vehicle?</p>	 <p> ● Definitely ● Probably ● Maybe ● Probably not ● Definitely not </p>	<p>Definitely not (3) – All from the 18-24 age group, all 3 hold driving licenses.</p> <p>Probably not (14) – 11 from 18-24 group, 1 from 25-34, and 2 from 35-44 group. 8 of the 14 hold a driving license.</p> <p>Maybe (16) – 12 from the 18-24 age group, 1 from the 25-34 and 3 from the 45-54 age group. 9 of these hold full UK driving licenses.</p> <p>Probably (19) – 16 from the 18-24 age group, 1 from the 25-34, 1 from the 45-54 and 1 from the 55-64 age group. 15 hold driving licenses.</p> <p>Definitely (16) – 13 from the 18-24 age group, 2 from the 25-34 and 1 from the 35-44 age group. 12 hold driving licenses.</p> <p>In summary, more than half of the participants would definitely or probably travel in a driverless vehicle. Some are unsure which is predicted at this stage of development, but companies must continue to gain trust.</p>
<p>7. How concerned would you be travelling in a fully self-driving vehicle?</p>	 <p> ● Extremely concerned ● Very concerned ● Somewhat concerned ● Not so concerned ● Not concerned at all </p>	<p>Extremely concerned (4) – 3 from the age group 18-24 and 1 from the age group 35-44. 3 hold driving licenses.</p> <p>Very concerned (9) – 8 from the 18-24 group and 1 from the 25-34 age group. 6 hold driving licenses.</p> <p>Somewhat concerned (30) – 23 from the age group 18-24, 2 from the age group 25-34, 2 from the age group 35-44 and 3 from the age group 45-54. 19 hold driving licenses.</p> <p>Not so concerned (19) – 16 18-24 year olds, 1 from the 25-34 age group, 1 from the</p>

		<p>45-54 group and 1 from the 55-64 age group. 15 hold driving licenses.</p> <p>Not concerned at all (6) – 5 from the 18-24 age group and 1 from the 25-34 age group. 5 hold driving licenses.</p> <p>In summary, the older participants were not very concerned with everyone over the age of 44 saying they were somewhat concerned or not concerned.</p>												
<p>8. As a driver or passenger, how safe would you feel sharing the road with driverless vehicles?</p>	 <table border="1"> <caption>Safety Level Data</caption> <thead> <tr> <th>Safety Level</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Extremely safe</td> <td>10.3%</td> </tr> <tr> <td>Very safe</td> <td>19.1%</td> </tr> <tr> <td>Somewhat safe</td> <td>38.2%</td> </tr> <tr> <td>Not so safe</td> <td>27.9%</td> </tr> <tr> <td>Not at all safe</td> <td>4.5%</td> </tr> </tbody> </table>	Safety Level	Percentage	Extremely safe	10.3%	Very safe	19.1%	Somewhat safe	38.2%	Not so safe	27.9%	Not at all safe	4.5%	<p>Extremely safe (7)- 6 participants from the 18-24 age group and 1 from the 25-34 age group. 6 hold driving licenses.</p> <p>Very safe (13)- 12 from the 18-24 age group and 1 from the 55-64 age group. 8 hold driving licenses.</p> <p>Somewhat safe (26)- 19 from the 18-24 age group, 4 from the 25-34 age group, 1 from the 35-44 age group and 2 from the 45-54 age group. 19 hold driving licenses</p> <p>Not so safe (19)- 15 from the age group 18-24, 2 from the 35-44 age group and 2 from the 45-54 age group. 11 hold driving licenses.</p> <p>Not at all safe (3)- all from the 18-24 age group, and all hold full UK driving licenses.</p> <p>In summary, it was expected that the older age groups and the drivers would feel less safe. However, the results are distributed and there seems to be no link. The oldest participant would feel ‘very safe’.</p>
Safety Level	Percentage													
Extremely safe	10.3%													
Very safe	19.1%													
Somewhat safe	38.2%													
Not so safe	27.9%													
Not at all safe	4.5%													

See full results in Appendix A.

8.4 Summary of Findings

The questionnaire results illustrate a variety of answers across all questions. Firstly, the results show that age may not be a factor, with participants in the older age groups not so concerned about driverless vehicles and their safety. The oldest participant said they would feel ‘very safe’ as a driver or passenger sharing the road with other DVs. These results indicate that the decision-making and thought process is more relevant than demographics. However, with 80.9% of participants being in the 18-24 age group it was difficult to identify if these patterns were statistically significant. With 42.6% of participants saying they would browse the internet or use social media in their spare time whilst travelling. This indicates a negative effect on social issues, as we humans begin to live less in the real world and more in technology. Whilst 38.2% of participants said they would most likely use DVs as a means of travel to and from work, indicating this could be a stress-free period before and after work. One other major finding was that users would initially assume the manufacturers or software company were liable for collisions; however, this indicates the users have lack of knowledge about how DVs operate with many other companies and services involved e.g. service providers and network companies. Overall this questionnaire found that people have varied opinions on DVs whether they are young or old, the deciding factor will be whether DVs can incorporate features that allow users to trust their systems.

In the future, this questionnaire would need more variety of age groups. With statistically significant data, it would be easier to see trends and anomalies. But from the current participants, older people seem to be open minded than we first thought. Also, participants who hold a full UK driving license were assumed to be more concerned than non-drivers as they have experience in decision making whilst driving. However, there seemed to be no link as the drivers were distributed over answers. DVs are some time away from proving themselves to those who are unsure or against the concept.

9 Impact on Stakeholders

9.1 SWOT Analysis on key Stakeholders

This section of the paper includes four SWOT analyses of some key stakeholders of DVs. The analysis will identify the strengths, weaknesses, opportunities and threats each stakeholder has regarding the introduction of DVs. This SWOT analysis will help identify areas that the industries need to address or exploit to better their business into the transition of driverless vehicles and technology.

Vehicle Manufacturers

Strengths	Weaknesses
<ul style="list-style-type: none"> - Financial capability to produce large advertisement campaigns. - Different manufacturers have different USPs. - Consumer loyalty. - Manufacturing warehouses already established. - Customers have trust in vehicle manufacturers as they already produce manual vehicles. This 	<ul style="list-style-type: none"> - High vehicle prices. - Target market is high end – limiting potential consumers. - External company collaboration is required to use the technology. - Vehicles being re-called due to technical issues will affect publicity of particular companies. - More staff/machinery will be required to build the vehicles.

having an advantage on tech company vehicles as trust between company and customer is already established.	<ul style="list-style-type: none"> - Bad working environments – over worked factory workers to build vehicles up to standard and in the timescale.
Opportunities	Threats
<ul style="list-style-type: none"> - Research and development provide new ideas and technology. - Large companies pursuing driverless vehicles such as Uber etc. will need a distribution of vehicles. - Driverless vehicles allow design teams to design new innovative vehicles as lifestyle and comfort will be a key area. - Market expansion e.g. disabled, elderly etc. 	<ul style="list-style-type: none"> - Competitors, such as other car manufacturers developing better or cheaper driverless vehicles. - Technology companies such as Google and Apple developing their own vehicles with driverless technology. - Government regulations. - Negative economic conditions mean consumers are likely to purchase cheaper vehicles or non-autonomous vehicles. - Negative online reviews or articles about vehicles.

Technology Companies

Strengths	Weaknesses
<ul style="list-style-type: none"> - Developed driverless technology can be sold, rented or used. - Increase profitability of the company. - Strong advertisement campaigns especially companies such as Google, Samsung, Apple, etc. 	<ul style="list-style-type: none"> - Copyright and patents may hinder the use of some code and force developers to work around that issue. - Scale of expansion will require more IT help and specialists to maintain and fix software issues. - Large companies such as Google and Apple dominate the market making it difficult for new companies to compete. - Manufacturing own vehicles will be challenging and costly. - New entrants to the market unlikely.
Opportunities	Threats
<ul style="list-style-type: none"> - Expand company areas e.g. manufacture their own driverless vehicles. - Research and development producing new technology and features. - High demand for driverless technology. 	<ul style="list-style-type: none"> - Competitors such as other technology companies, also car manufacturers dominating the market. - Software malfunctions may cause loss of users/bad publicity. - Security must be strong to avoid cyber-attacks and hackers from accessing the technology.

Insurance Companies

Strengths	Weaknesses
<ul style="list-style-type: none"> - A range of insurance are already offered e.g. health insurance, life insurance etc. meaning if new driverless insurance fails they have other types of insurance to offer. - Fraudulent claims will reduce. - Insurance will always be needed to some extent. 	<ul style="list-style-type: none"> - Fewer individual vehicle owner's due to the innovation of fleet based ownership and public transport. Meaning less people need insurance. - Accidents will be rare - premiums could reduce as much as 75% (Forbes). - Dealing with liability issues.
Opportunities	Threats
<ul style="list-style-type: none"> - New forms of insurance such as product liability, cyber security, infrastructure insurance, level of autonomy etc. - The shift to fully self-driving vehicles will be gradual meaning there will be time to adapt. - Specialise in big data analytics from DVs. 	<ul style="list-style-type: none"> - Lose profitability and growth due to fewer owners meaning lower overall premiums, also most accidents are human error meaning accident and insurance claims will drop. - Competitors, such as other insurance companies. - No drivers, meaning people may not require insurance.

Users

Strengths	Weaknesses
<ul style="list-style-type: none"> - Increased comfort and lifestyle. - Safe transportation. - Stress free travelling e.g. no road rage. - Transportation and independency for disabled, young and elderly. - Time to spare whilst travelling to do other activities. 	<ul style="list-style-type: none"> - Lack of social interaction. - Driverless vehicle prices are predicted to be costly. - Lack of young people learning to drive, if driverless vehicles have issues and need to be re-called people will have no skills to drive. - Confusion of whether the vehicle needs taking control of and when. - Users that enjoy driving will not be interested in using the technology, therefor there will still be drivers on the road that could potentially cause human errors.
Opportunities	Threats
<ul style="list-style-type: none"> - Use of driverless public transport. - Emission control. - Ownership of vehicles may not be necessary due to shared vehicles and driverless public transport (TaaS). - Journey time could reduce due to less congestion and higher speed limits. 	<ul style="list-style-type: none"> - Psychological and social issues e.g. users not trusting driverless vehicles. - Privacy concerns. - One software malfunction can result in an accident, resulting in bad publicity and users being scared to further travel in driverless vehicles. - Liability issues if collisions occur. - Cyber-attacks taking control of the software and vehicle.

10 Soft Systems Methodology (SSM)

10.1 CATWOE Analysis & Root Definitions

Car Manufacturers & Dealers

Root Definition: A vehicle manufacturing company-owned system, operated by the staff of the vehicle manufacturers and car dealers, aims to Increase company profit and lead the driverless vehicle industry, by providing and selling driverless vehicles that are attractive to consumers through using the latest driverless technology, techniques and vehicles through standardised processes, whilst adhering to the GOV regulations and standards driverless vehicles need to be sold.

CATWOE:

C – Consumers

A – Vehicle manufacturers, vehicle dealers (company staff)

T – Increase company profit and lead the driverless vehicle industry

W – Provide and sell driverless vehicles that are attractive to consumers through using the latest driverless technology, techniques and vehicles

O – Car manufacturers

E – GOV regulations and standards e.g. safety regulations, emission standards etc.

Technology Companies

Root Definition: A technology company-owned system, operated by skilled professionals, aims to expand company areas of speciality and compete with other technology companies, through providing quality driverless technology to car manufacturers or create their own brand of driverless vehicles, whilst adhering to relevant copyright, patents, GOV regulations and standards.

CATWOE:

C – Consumers

A – Skilled professionals (company staff)

T – Expand organisation and diversify into new markets

W – Develop and provide quality driverless technology to vehicle manufacturers, consumers or create own brand of driverless vehicles

O – Technology companies

E – Copyright and patents, GOV regulations and standards

Insurance Companies

Root Definition: An insurance company-owned system, operated by skilled professionals within the company, to provide the appropriate form of insurance to the users, through offering various forms of insurance depending on the users' needs, whilst adhering to the rules and regulations of the Financial Conduct Authority (FCA).

CATWOE:

C – Driverless vehicle users, companies e.g. Uber

A – Skilled professionals (company staff)

T – Insure driverless vehicles and lead the industry

W – provide various forms of new insurance depending on the users' needs

O – Insurance companies

E – Rules and regulations of the Financial Conduct Authority (FCA)

Users

Root Definition: A system owned by vehicle owners, operated by the passengers, aims to fulfil passenger experience by considering all the components involved with travelling in a driverless vehicle, whilst adhering to safety regulations.

CATWOE:

C – Passengers

T – fulfil passenger experience

W – Considering all the components involved with travelling in a driverless vehicle

O – Vehicle owners

E – safety regulations

Users – Trust (Additional)

Root Definition: A system owned by vehicle owners, operated by passengers, aims to help decide whether to trust and lose all sense of control to driverless vehicles, through using past experiences, research and data, in which the system will operate under the constraints of the thinking process.

CATWOE:

C – Passengers

T – Decide whether to trust and lose all sense of control to driverless vehicles

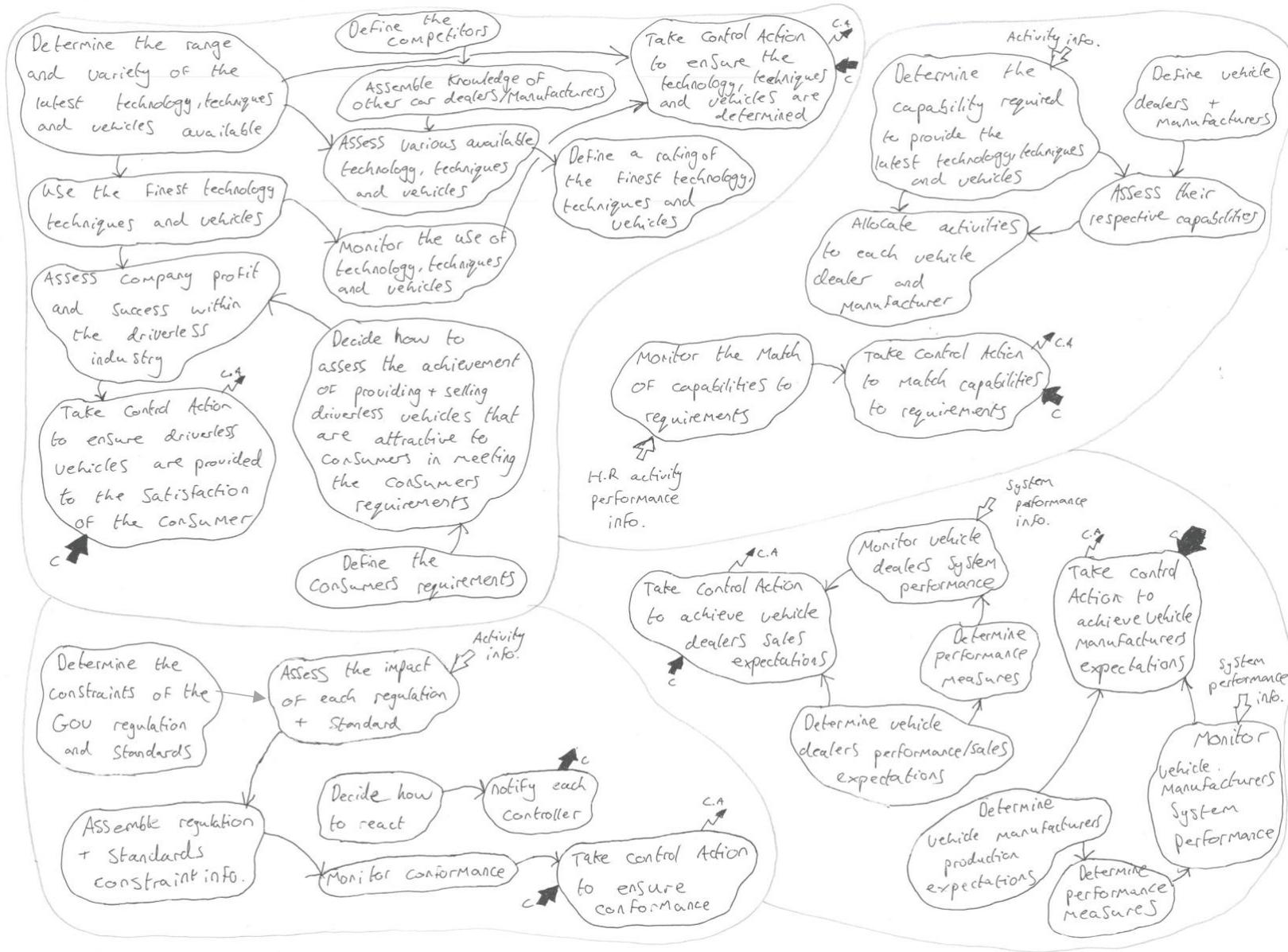
W – Using past experiences, research and data

O – Vehicle owners

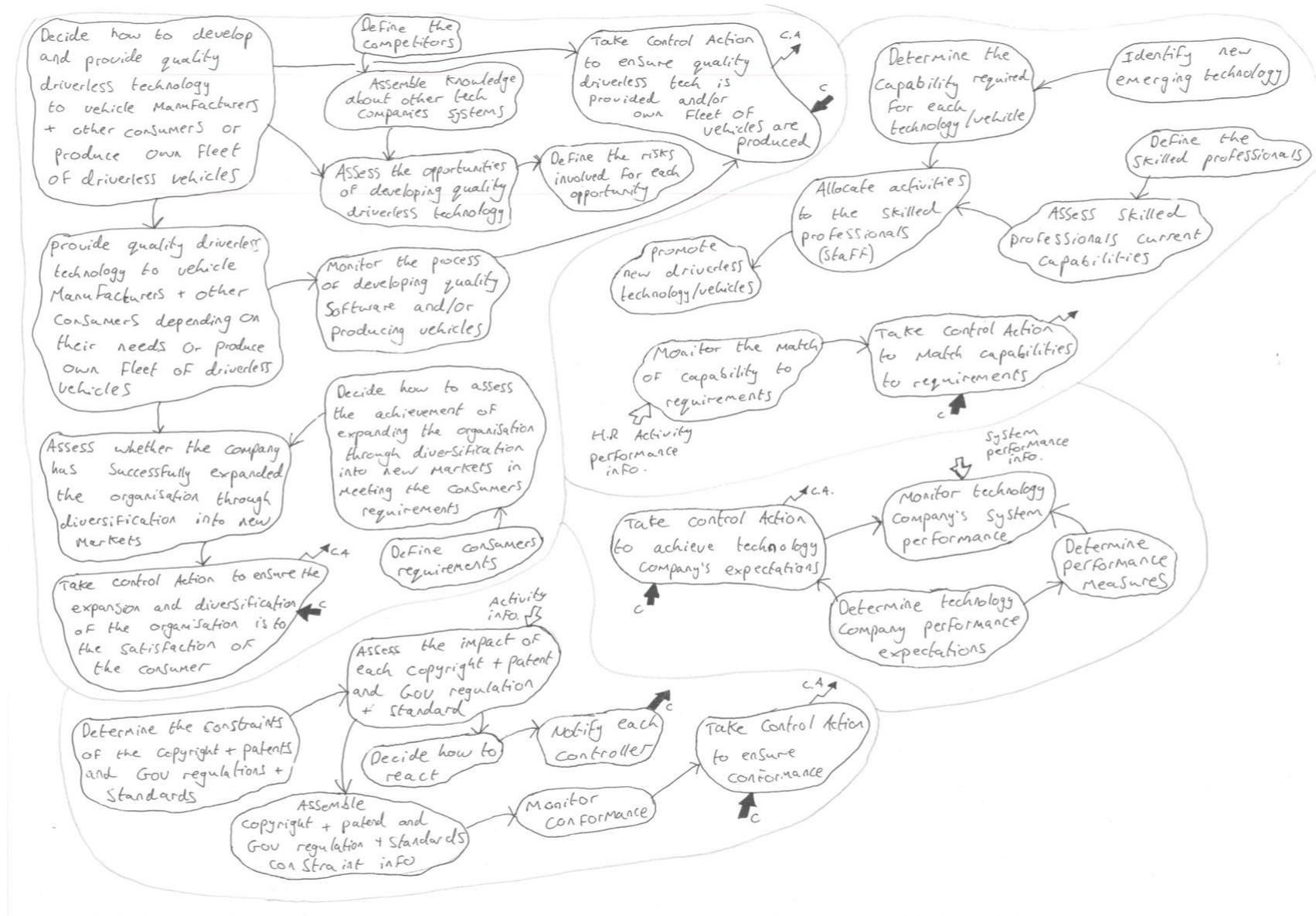
E – Thinking process

10.3 Conceptual Modelling

Vehicle Manufacturers/Dealers



Technology Companies



Users



10.4 Gap Analysis

In the following section, three qualitative gap analyses will be provided for three of the key stakeholders. Each gap analysis will be used to determine where each industry is currently at, what they need to improve and where they want to be in the future in regard to DVs.

Vehicle Manufacturer/Dealer

Activity from Conceptual Model	Current Situation	Future State & Actions to Take
<p>Determine the range and variety of the latest technology, techniques and vehicles available</p> <p>Assess various available technology, techniques and vehicles</p>	<ul style="list-style-type: none"> - Limited technology with only drive assist available in selected vehicles - Lack of proven techniques as driverless tech is relatively new - Vehicles are not implemented with driverless technology on the market - Technology is being tested - Techniques need to improve to produce quality technology - Different manufacturers are at different stages of development 	<ul style="list-style-type: none"> - Vast range of driverless technology companies to collaborate with - access, sell and implement the tech - Techniques will be proven to work - All vehicles will have driverless features - Vast range of technology to assess by quality and reliability - Techniques to be improved and training provided - Increase the number of driverless vehicles produced by manufacturers
<p>Assemble knowledge about other vehicle manufacturers/dealers</p>	<ul style="list-style-type: none"> - Companies already selling features such as drive assist e.g. Tesla - Industry leaders with established ADAS features e.g. Ford, GM (Navigant Research Leaderboard Report: Automated Driving, 2017) 	<ul style="list-style-type: none"> - Most vehicle companies will be selling fully driverless vehicles – also, there will be new entrants to the market
<p>Define the competitors</p>	<ul style="list-style-type: none"> - Lack of competition within the market as only few have driverless features - But competition in developing DVs are high, with companies being divided into four groups - leaders, challengers, contenders, challengers and followers 	<ul style="list-style-type: none"> - Most established companies will be selling driverless features (vehicle and tech companies) - Many competitors however, large companies are predicted to lead - New entrants hope to capture the market with their technology
<p>Define a rating of the finest technology, techniques and vehicles</p>	<ul style="list-style-type: none"> - Current technology is rated not good enough, due to recent accidents (Uber) and lack of tech on the market 	<ul style="list-style-type: none"> - Technology will be rated highly with difficulty to choose between them - Each company will have its benefits and issues

Take control action to ensure the technology, techniques and vehicles are determined	- Lack of research and proven technology	- Dealers ensure they sell new models of driverless vehicles - Manufacturers increase quality of vehicles and building techniques
Use the finest technology, techniques and vehicles	- Dealers fail to recognise the current driverless features available - Consumers are not interested in these features - Only high-end vehicles are available with driverless features (Tesla, BMW, Mercedes)	- Dealers sell quality, affordable driverless vehicles - Manufacturers increase number and range of vehicles produced - Workforce are skilled and qualified to sell and build the new vehicles
Monitor the use of technology, techniques and vehicles	- Lack of used driverless features due to limited vehicles sold and trust to use the new features	- Users increase use and purchases vehicles with drive assist + driverless vehicles - Company strategy and operations to monitor will be different in each company
Assess company profit and success within the driverless industry	- Lack of success within the market as it stands - Investment costs are currently high	- Companies selling driverless vehicles will increase profit and sales - Companies have share's in supporting technology companies
Decide how to assess the achievement of providing & selling driverless vehicles that are attractive to consumers in meeting the consumers requirements	- Lack of attractive, affordable drive assist systems - No driverless vehicles for sale	- Provide a range of vehicles for the consumer – levels of autonomy, size, colour, technology etc. - Consumers will re-buy and update driverless vehicles
Define requirements	- Safety is the main requirement - Requirements are somewhat irrelevant due to consumers not knowing what they want as of yet	- Once safety is established, requirements will be more focused on comfort and productivity within the vehicle when travelling - Vehicles are sold in local dealerships - The department of transport (2015) suggest event data from on board cameras should ensure liability issues are fair
Take control action to ensure driverless vehicles are provided to the satisfaction of the consumer	- Consumers cannot be satisfied or unsatisfied at this stage	- All consumers are satisfied with their driverless vehicle purchase

		<ul style="list-style-type: none"> - Researchers and development teams work together (Kato, et al., 2015) - Implement anthropomorphism features Waytz, Heafner & Epley (2014)
Determine constraints of the GOV regulations and standards	<ul style="list-style-type: none"> - No driverless regulations are yet approved for driverless vehicles - Discussions are taking place 	<ul style="list-style-type: none"> - Comply to the many GOV regulation and standards whilst selling and building the vehicles - Many new regulations and standards are introduced that manufacturers must comply with when building the vehicle
Assess the impact of each regulation and standard	<ul style="list-style-type: none"> - No impact as of yet - Standard vehicle rules and regulation only 	<ul style="list-style-type: none"> - Impact will not affect the ability to sell and build driverless vehicles - Some regulations and standards will affect time management
Assemble regulation and standards constraint info	<ul style="list-style-type: none"> - Not Available 	<ul style="list-style-type: none"> - Recognise all rules and regulations in regard to the building & selling vehicles
Decide how to react	<ul style="list-style-type: none"> - N/A 	<ul style="list-style-type: none"> - Build and sell the vehicles according to the rules and regulations - Stay alert for changes
Notify each controller	<ul style="list-style-type: none"> - N/A 	<ul style="list-style-type: none"> - Each branch will recognise the rules and regulations
Monitor conformance	<ul style="list-style-type: none"> - N/A 	<ul style="list-style-type: none"> - Every vehicle is build and sold whilst conforming to the rules and regulations
Take control action to ensure conformance	<ul style="list-style-type: none"> - N/A 	<ul style="list-style-type: none"> - Staff employed to specifically ensure conformance
Determine the capability required for each activity	<ul style="list-style-type: none"> - Lack of capabilities to produce the vehicles 	<ul style="list-style-type: none"> - Increased capabilities and training
Assess their respective capabilities	<ul style="list-style-type: none"> - Capability not met 	<ul style="list-style-type: none"> - Required capability is met
Define vehicle manufacturers/dealers	<ul style="list-style-type: none"> - Lack of dealers/manufacturers selling and building DVs 	<ul style="list-style-type: none"> - Dealers/manufacturers are selling the vehicles increase due to change of market and need for DVs
Allocate activities to each vehicle manufacturer/dealer	<ul style="list-style-type: none"> - Lack of staff with skills to sell driverless vehicles due to limited knowledge 	<ul style="list-style-type: none"> - Each company will allocate roles to branches and staff appropriate to their skills

	- Activities carried out to build DVs are not known	- Internal operations will run smoothly
Monitor the match of capabilities to requirements	- Increase in DVs to sell will promote the need for staff in this area - Currently match isn't aligned	- Each branch or staff member will be able to handle the required role without major issues - More defined roles and skills needed
Take control action to match capabilities to requirements	- Capabilities are currently weak as driverless industry has not been fully commercialised	- Employ or train new staff with required skills - Relocate staff to match their skills with the appropriate role (HR)
Take control action to achieve vehicle dealer sales	- Lack of vehicles to sell - Sales persons skills to sell driverless vehicles are non-existent	- Promote driverless vehicles - Employ and train staff to the highest quality
Determine vehicle dealer's performance/sales expectations	- Lack of future driverless vehicle sales expectations	- High expectations for increased overall sales and staff reaching sales targets
Determine and monitor dealer's performance measures	- Not known due to internal company strategy and processes	- Increase number of customers and their satisfaction – resulting in customer retention - Increase profit in all regions - Increase Net Promoter Score (NPS)
Take control action to achieve vehicle manufacturers expectations	- Lack of commercially available driverless technology to implement into vehicles - Workforce only build normal fleet vehicles	- Produce more driverless vehicles by employing more staff, gaining contracts and expanding the company - Collaborate with tech companies
Determine vehicle manufacturers production expectations	- Lack of production expectations	- High expectations for large number of quality vehicles produced
Determine and monitor manufacturers system performance measures	- Not known due to internal company strategy and processes	- Increase number of vehicles produced - Vehicles are purchased and sold in more regions

Insurance Companies

Activity from Conceptual Model	Current Situation	Future State & Actions to Take
<p>Decide how to provide various forms of new insurance depending on the users' needs</p> <p>Assess types of new insurance opportunities</p>	<ul style="list-style-type: none"> - Regular vehicle and drive assist insurance is provided only - Discussions as to what needs to be insured on DVs 	<ul style="list-style-type: none"> - Companies provide many different forms of insurance - Consumers requirements will be identified in terms of what they want insuring
<p>Assemble knowledge about other insurance companies</p>	<ul style="list-style-type: none"> - Lack of knowledge about other company's plans for driverless insurance 	<ul style="list-style-type: none"> - Knowledge will be available via research of insurance provided by other companies - Companies will match what others are providing
<p>Define competitors</p>	<ul style="list-style-type: none"> - Many existing insurance companies, therefore equal opportunity to expand into driverless insurance - Insurance companies based on cheapest insurance or more cover 	<ul style="list-style-type: none"> - Competitors based on quality insurance instead of price as premiums are predicted to decrease
<p>Take control action to ensure new insurance is being provided to users depending on their needs</p>	<ul style="list-style-type: none"> - Few companies offer DV insurance, with Adrian Flux being the first to offer insurance from cruise control systems to full DV 	<ul style="list-style-type: none"> - Loss or damage - Hacked systems - Satellite failure - software malfunctions - Offered with regular cover - Trained professionals to suggest suitable forms of insurance to each user
<p>Provide various forms of new insurance to users depending on their needs</p>	<ul style="list-style-type: none"> - Regular vehicle insurance is provided - Drive assist insurance is beginning to surface - Currently Adrian Flux are offering insurance for different vehicle types such as modified, high performance, kit car, classic cars, 4x4 and off-road. 	<ul style="list-style-type: none"> - Insurance companies will provide many new insurance types e.g. product liability, cyber security, infrastructure insurance, level of autonomy etc.
<p>Monitor the process of providing insurance to users</p>	<ul style="list-style-type: none"> - Not available 	<ul style="list-style-type: none"> - Use similar processes of providing regular insurance but adapted to suit the new types - Gradual process of adapting to new insurance types

Assess the achievement of insuring driverless vehicles and the company's position within the market	- Some companies are beginning to think about insurance with Adrian flux offering DV policies	- Increase number of new customers after rolling out of new insurance - Number of customers compared to other insurance companies measured
Decide how to assess the achievement of insured driverless vehicles and whether they are leading the driverless insurance industry	- Not available	- Policy sales growth after providing new insurance - Net income ratio is calculated to determine success
Define the users and buying companies requirements	- Current requirements include cheap insurance and third party or comprehensive cover preferences	- Companies may offer different types of insurance - Sales will depend on customer service and website quality/ availability
Take control action to ensure driverless vehicles are being insured to the satisfaction of the users and buying companies	- Not available	- Low customer issues and complaints - Feedback and customer surveys
Determine the constrains of the rules and regulations of the financial conduct authority	- No insurance has yet been suggested therefor there are no constraints applicable	- Company handles constraints with internal procedures in place - Policies are documented and written in align with the constraints
Assess the impact of each rule and regulation	- N/A	- Company has documentation of all relevant rules and regulations they must comply - Each type of insurance has a different impact with different rules and regulations
Decide how to react	- N/A	- Internal procedures and trained staff in that area of expertise
Notify each controller	- N/A	- Each manager and branch knows of the relevant rules and regulations
Assemble rules and regulation constraint information	- Constraints for regular insurance are only in place	- Look at GOV and internal documentation
Monitor conformance to rules and regulations	- N/A	- Effective compliance program consider: Pre-compliance monitoring, Regulatory agencies,

		Legislative actions, Judicial decisions (Wiest, 2011)
Take control action to ensure conformance to rules and regulations	-N/A	- Implement compliance program, with a post compliance validation by internal (audit) or external (regulatory examination) (Wiest, 2011)
Determine the capability required for each insurance type	- Lack of knowledge on the capability required with limited or no DV insurance available	- The company and staff are fully capable of providing insurance policies - Capability needs to match other companies to keep competition and advantage in the market
Identify new insurance range needed for users	- Lack of knowledge about how DVs will operate as standardised DVs are unlikely - Different companies will have different systems therefor insurance must accommodate all vehicles/systems	- New technology is recognised and insurance companies know the different components of DVs – insuring them
Define the skilled professionals	- Staff that sell regular vehicle insurance	- Staff increase as more departments are made to specialise in certain areas of DV
Assess the skilled professional's current capabilities	- Lack of knowledge about the opportunities of new types of insurance	- Staff will be trained to provide all types of insurance, it will become normalised
Allocate activities to the skilled professionals	- All professionals sell all insurance	- Professionals will have specialised areas of insurance to sell and improve
Promote new insurance	- Television and online ad's - Price comparison websites e.g. comparethemarket.com	- Not much need to promote insurance as customers will keep brand loyalty and know the best insurance companies
Monitor the match of capability to requirements	- Need to identify new insurance required capabilities	- Sales performance and targets are all met by each member of staff
Take control action to match capability to requirements	- Current capabilities required are matched to requirements e.g. regular insurance	- Employ or train new staff with required skills - Relocate staff to match their skills with the appropriate role (HR)

Take control action to achieve expectations	- N/A	- Increase budget for new policies through operating cash surplus
Determine & monitor performance measures	- Not known due to internal company strategy and processes	- Increase policy types - Increase customers & those retaining policies
Determine the insurance company's performance expectations	- Not known due to internal company strategy and processes	- High expectations to sell insurance policies for all types of new DV insurance - Match and exceed competitions performance

See further gap analysis for users in Appendix B.

Thoughts & Reflection

Each gap analysis gave valuable insight into the current gaps, and what needs to be done to allow the introduction of DVs in each separate industry. Each company within the industries will work differently however, there will be a general consensus as analysed in the above section. As DVs have not been commercialised, some aspects are not clear e.g. competitors within the market will be better analysed once DVs are in public use. Some activities were difficult to analyse as they are directly related to the different industries/company internal operations, processes or strategies. This information was not available due to no sources and/or aspects that are addressed internally, therefore some assumptions were made and some were left as N/A or not available.

11 Porter's Five Forces

Porter's five competitive forces (driverless vehicles in general):

1. Supplier power
2. Buyer power
3. Competitive rivalry
4. Threat of substitutes
5. Threat of new entries

Supplier Power - Low

Supplier power will be low, as DV sales are predicted to be very high. Therefore, the suppliers (software/tech companies and vehicle parts) will be very interested in partnership with big companies such as Ford. Many companies will be available due to the fact driverless technology is the new revolution in the automobile industry, many companies are developing vehicles and software. Also, many of the large companies will be capable of developing parts of their own hence, low supplier power. Supplier power will only be high if one company's technology is far greater than other and has been approved. With limited working technology, the suppliers will have far more power as vehicle companies will want to cooperate to be the first DV on the road.

Buyer Power - Low

Initially, the buyer power will be low because there will be limited vehicles on the market to purchase. However, with the progression and introduction of more DVs the buyer power will increase, with more vehicles and services available. The companies will then need to meet consumers expectations or they will go elsewhere.

Competitive Rivalry - High

Competitive rivalry will be high with various companies trying to lead the brand new driverless market. Marketing campaigns will be crucial with the aim to entice consumers to buy their first driverless vehicle. Many different types of companies will be trying to compete such as technology companies e.g. Waymo, Panasonic, Samsung and vehicle manufacturers/dealers e.g. Ford, Nissan, BMW etc. Therefore, the USP of the driverless vehicles must be considered and proved.

Threat of Substitutes - High

Threat of substitute will always be high as manual vehicles exist and will continue to exist. Consumers will always have the option to purchase a manual vehicle instead of the new DV, both do the same job in getting you from destination to destination. This could be ineffective for some companies that supply both driverless and manual vehicles however, technology companies such as Waymo will be affected.

Threat of New Entries - Moderate

Threat of new entries is moderate, with driverless technology being a new concept there will be many questions of how they should work. Many companies will develop their own DV in what they think it should do. The barrier for entry is high due to the many regulations, standards and high cost of developing software and building the vehicles. Also, many large, well-known companies such as Ford will dominate the market. Start-up companies will have little input into the market, as consumers will not purchase a DV off someone that hasn't even proven they can build a reliable, manual vehicle.

12 Benefits

12.1 Safety

Safety has been at the forefront of discussions promoting the development and widespread adoption of DVs. Introducing level 4 and 5 DVs is thought to improve road safety by reducing the number of accidents, injuries and deaths by responding to malfunctions and hazards without human intervention (Hicks, 2018). A crash causation survey carried out by the NHTSA in 2008 found that almost 90 percent of accidents were caused by human error (Lari, Douma & Onyiah, 2015). Volvo describe these mistakes by the driver as the 4Ds, distraction, drowsiness, drunkenness and driver error (Lari, Douma & Onyiah, 2015). As driverless vehicles would not have an issue with any of the 4Ds they should reduce human error, reducing accidents and deaths. Nevertheless, humans are surprisingly very capable drivers more so than we expect, they recognize and classify objects, resolve conflicting messages, drive in various conditions and have real-time planning (Lari, Douma & Onyiah, 2015). If DVs are to be deployed they must meet and improve these standards. As many accidents are caused by human error, many are avoided by human split-second decisions.

How safe are driverless vehicles?

DVs will never be drunk, distracted or tired, these three areas count for 41, 10 and 2.5 percent of road crashes (Kalra & Paddock, 2016). Furthermore, perception, decision making and execution will be more efficient than human drivers thus, increasing their performance. However, not all road accidents will be avoided as extreme weather conditions and complex driving environments will be a major challenge. With both risks and benefits, policymakers need to decide how safe driverless vehicles need to be before they are allowed on the road for consumers to use.

Kalra & Paddock (2016) have conducted a statistical analysis of the number of miles DVs need to travel before they can provide accurate crash rates. Crashes caused by humans are relatively rare, Kalra & Paddock point out that the 32, 719 crashes in 2013 correspond to a failure rate of 1.09 fatalities per 100 million miles travelled. The calculations span across 5 different orders of magnitude:

From 1.6 million miles (95% confidence that the maximum crash rate is 190 per 100 million miles travelled).

To 11 billion miles (95% confidence with 80% power to detect a 20% improvement over the human fatality rate of 1.09 per 100 million miles).

The calculations suggest it will take 84 years for 1000 DVs that travel an average of 6 hours per day at 60mph, to reach 11 billion miles. Given the number of miles humans have driven there is no way to statistically make significant comparisons. Klara & Paddock (2016) researched into this by asking, 'how many miles are enough?'. The analysis asked three questions, but in particular:

How many miles would autonomous vehicles have to be driven to demonstrate that their failure rate is statistically significantly lower than the human driver failure rate?

To solve this, Kalra & Paddock (2016) came up with the following equation, with the need to solve x and n:

$$x = \left(\lambda_{alt} \frac{Z_{1-\alpha}}{\lambda_0 - \lambda_{alt}} \right)^2$$

$$n = \lambda_{alt} \left(\frac{Z_{1-\alpha}}{\lambda_0 - \lambda_{alt}} \right)^2$$

For example, if a DV fleet had a fatality rate of 20% lower than the human driver fatality rate 1.09 per 100 million miles (0.872 per 100 million miles). The following equation demonstrates how we can calculate the number of miles that need to be driven to successfully show statistically significant difference with 95% confidence (Kalra & Paddock, 2016).

$$n = 0.872 \times 10^{-8} \left(\frac{1.645}{1.09 \times 10^{-8} - 0.872 \times 10^{-8}} \right)^2 = 4,965,183,486$$

This calculation shows it will take about 5 billion miles of driving to show the difference. This would take 225 years of 100 driverless vehicles driving 24 hours a day, 365 days of the year, at a speed of 25mph. Therefore, due to the extreme amount of observational data required to carry out these tests, simulations and other laboratory tests can be useful. Billion years of virtual travel can be run over the course of days or weeks, whereas real-time driving could take centuries.

12.2 Emissions & Energy

The focus of reducing carbon emissions has been an important topic for many years, with drastic climate change effects happening. Therefore, it is crucial to analyse the effects DVs may have on climate change. Driverless technology will not directly affect carbon emissions however, the introduction of DVs will significantly change how people travel from destination to destination. Whether driverless vehicles will be a positive or negative impact on carbon emissions depends of three factors, the total miles travelled, congestion impacts and fossil fuel consumption and fuel efficiency (Kearns, Peterson, & Cassady, 2016). A study carried out in 2014, by the National Renewable Energy Laboratory has concluded that there are many positives and negatives regarding the effect DVs (Wallis & Wadud, 2016) will have on carbon emissions. The positives focus on introducing electrical vehicles which will be more lightweight. Whereas, negative effects to carbon emissions are revolved around increased travel demands with more people being able to access such technology e.g. elderly, young and disabled individuals will have more freedom and independence. The University of Leeds suggest the new user groups could increase energy consumption from 2% to 10% in the USA, with similar rises happening in the UK.

In addition, the University of Leeds (University of Leeds, no date) have identified how energy consumption can be reduced form the adoption of DVs:

- Streamline of traffic flow optimize fuel consumption.

- The ability for vehicles to drive close together on motorways, creating convoys or platoons that reduce aerodynamic drag and fuel consumption.
- Driverless vehicles can be programmed to drive in eco mode.
- Vehicles can be designed and built to be more lightweight, as collisions are predicted to reduce.

Fuel efficiency can be controlled by the following:

- Higher speed limits, as driverless vehicles will be deemed as very safe.
- Driverless vehicles will enable lower engine performance, which will decrease fuel consumption.

Energy usage can be calculated by the following equation:

Energy = Energy Efficiency of Travel * Travel Demand

Wallis & Wadud (2016) point out much more research must be done to make DVs green. The encouragement of shared car ownership and mobility service must be explored as an alternative to private ownership. Furthermore, policies can be introduced by the government to support new local mobility services by delivering open data protocols, supporting the incubation of technology and providing resources. Wallis & Wadud (2016) also suggest new regulations or policies will encourage vehicle manufacturers to produce energy efficiency features such as eco-driving, eco-routing, platooning or energy saving algorithms for driverless vehicles.

12.3 Traffic Congestion

The introduction of DVs could see a significant reduction in traffic congestion. However, research is unsubstantiated as there are many factors that simply cannot provide feedback in this moment of time. Anderson et al. (2014) point out the three areas DV will directly impact congestion – Vehicle miles travelled, greater vehicle throughput and reducing delays from vehicle collisions.

Vehicle Miles Travelled

There's no doubt that DVs will affect VMT, however it's unclear how it will be affected. It is predicted that they will result in more miles travelled by vehicles rather than less. Firstly, travel costs are likely to be reduced such as insurance, fuel, maintenance and parking (Anderson et al., 2014). Smooth travel patterns will ensure improvement in the fuel economy, leading to fuel being cheaper in the future. In addition, DVs will change parking, by dropping passengers off to a location then driving themselves to a cost-free parking space, reducing travel costs but increasing VMT. Some people choose to live in urban environments due to travel costs, therefore more people are likely to move to rural areas if travel costs less and is more available. The availability of DVs will be influenced by the driverless taxi or TaaS concept (later discussed in ownership section). Driverless taxis will enable users to summon them door-to-door, instantly, with the reduced cost of having no human taxi drivers. However, car-sharing will be widely encouraged to reduce total VMT. Car-sharing programs will allow people from different households to travel together in an aim to reduce emissions and VMT. To summarise, DVs are likely to reduce travel costs which will increase total VMT (Anderson et al., 2014). Also, the introduction of driverless taxis will almost certainly have a negative effect on total VMT per capita.

Throughput

DVs will lead to increased throughput on roads. As the vehicles use sensors and other technologies to monitor their surrounding environment, they can effectively respond with acceleration, deceleration and braking at the correct time. This will allow the vehicles to travel at higher speeds more smoothly reducing the gaps between vehicles, forming platoons. These platoons could increase lane capacity by 500 percent. Furthermore, humans tend to unnecessarily accelerate and brake, known as stop-start driving. With high amount of traffic on the motorways stop-start driving will increase as throughput continues to increase at slower speeds.

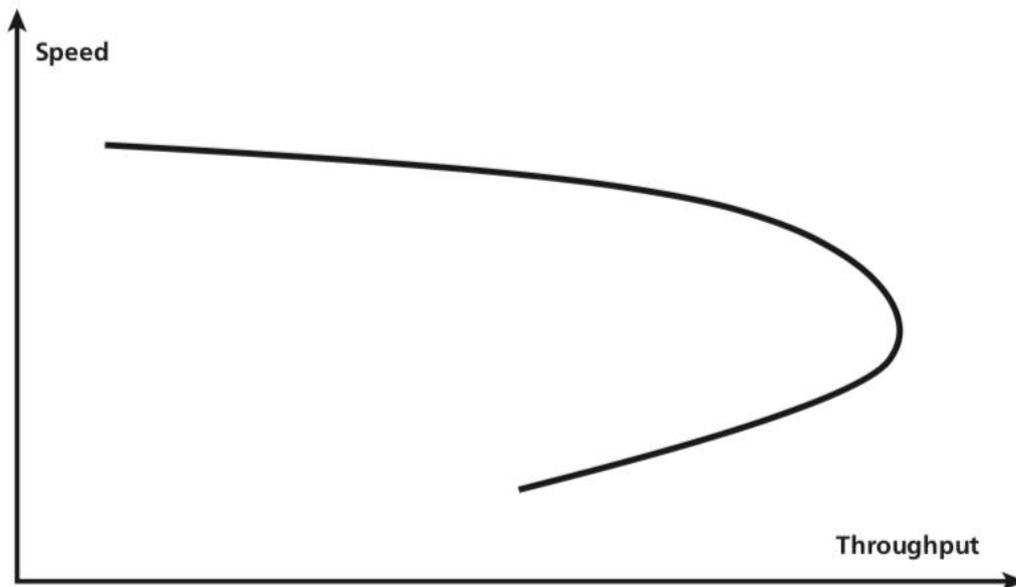


Figure 21: Relationship between roadway speed and roadway throughput, from State Route 91 in Southern California (source: Anderson et al., 2012).

The graph above illustrates that consistent speeds will reduce congestion and increase throughput. With less stop-start driving, the driverless platoons will allow smooth driving.

Reducing Delays from Vehicle Collisions

Anderson et al. (2014) suggest there are two main categories involved with congestion – recurrent and non-recurrent delays. Recurrent delays are those that happen regularly in the same place, at the same time which can be monitored by travel patterns. The number of vehicles using the road at that time is too large to handle, building congestion. Whereas non-recurrent delays are individual events or those that do not pose a long-term effect such as construction, extreme weather conditions, large events (sport matches, music concerts etc.), broken down vehicles or a vehicle collision. These events will further decrease the available road capacity. The Federal Highway Administration (FHWA) point out that non-recurrent events correspond to half of the delays caused by congestion. Small collisions counting for 50%, weather 30% and construction or roadworks counting for the remaining 20% of re-curent delays (Anderson et al., 2014). In addition, traffic incidents correspond to 25% of total congestion delays. Vehicle crashes will cause more of a delay than small collisions and will result in more congestion. Driverless vehicles will reduce the related congestion, reducing crashes as they are predicted to be safer than human drivers.

12.4 Lifestyle & Comfort

DVs can improve lifestyle and comfort in many different ways. Litman (2018) suggests driverless vehicles will reduce stress, and the vehicles can become moving bedrooms, playrooms or offices as illustrated below.



Figure 22: Driverless vehicles can become bedrooms, playrooms and offices (source: Litman, 2018).

This will enable passengers to be more productive whilst travelling, being able to carry out activities such as working, sleeping, eating etc. This can be very useful particularly for busy individuals for example, a business person could work on their pitch whilst travelling to the board room or regenerate energy by eating or sleeping before the meeting.

Contrary to this, there has been research to show new travel anxieties could arise such as access anxiety. Grush & Niles (2016) argues that DVs will not be able to access all locations because of weather and unmapped roads. Therefore, most consumers would be more interested in buying semi-automated vehicles over fully automated vehicles to ensure they can take control of the vehicle if need be. It is predicted only after 2070 will we see a fully autonomous vehicle with 100% access to all locations (Grush & Niles, 2016).

In addition, whilst DVs will offer a better lifestyle comfort could be an issue within public transport. To avoid vandalism of driverless public transport, the vehicles could be built with limited accessories and comfort with more cameras and ‘hardened interiors’ (Litman, 2018). However, privately owned or car shared DVs will increase comfort significantly.

Social Inclusion

DVs will allow many more user groups as mentioned earlier (in the emissions section) to travel. With users such as young people not old enough to drive, elderly, and the disabled this can reduce stress on family members not having to chauffeur them around and will ultimately give them more independence. Litman (2018) suggests this can increase the opportunities to access education and employment. Whereas, people living in rural areas may purchase privately owned vehicles, people living in urban environments may rely on driverless public transport and shared vehicles.

Travel Experience

Panasonics concept of the DV shown below, allows passengers to control the vehicle if needed but also spin the seat around and play games and activities on a table made up of four 20in Ultra HD tablets. This concept shows the future of driverless vehicles with the living room esc cabin. In addition, the material on the farthest window is semi-transparent which will have the ability to display the vehicles route and location. Panasonic suggest this concept it far away and won’t be implemented until driverless vehicles are proved to be safe and productive.



Figure 23: Panasonic mock-up interior (source: Charlton, 2017).

DVs will enable passengers to relax, watch television and work. However, safety is still paramount as passengers will need to wear seatbelts (Litman, 2018). In the future, vehicle manufacturers are likely to build vehicles with beds and offices inside.

Driverless public transport will be cheaper than human operated services however, this comes with lower quality service. The buses will likely be very busy and space will be abused. With previous traveller's waste and dirt still in the vehicle. In addition, like all public transport passengers will need to share the space with others, some individuals may be unpleasant and ruin the journey. Furthermore, public transport will encounter drop off and pick up delays, especially for the new user groups such as elderly and disabled. Litman (2018) suggests once the novelty of the DV wears off, they will be seen more like elevators rather than spaceships. In summary, the experience will be far more enjoyable with a privately-owned vehicle. (Litman, 2018)

Panasonic also wanted to show that they are more than just an electronics company. For their 100th anniversary and for CES 2018 they showcased a DV living space. Panasonic asked the question 'what happens when we are no longer driving?'. This supports the idea that no longer will we be predicting whether DVs will be deployed but rather how companies can design and get the best experiences out of them. Panasonic suggests passengers will want to be comfortable once the vehicle takes control, and info systems are likely to play a large role.



Figure 24: Panasonic living space autonomous cabin, showcased in CES 2018 (source: Barnett, 2018).

Panasonic team state once level 5 automation is reached, their design can combine solutions and expertise for a better life, that have been refined by the living space and automotive system technologies (Barnett, 2018). The concept shows a modern, luxurious open space for passengers. This Panasonic concept gives three options of living styles, which include a living room style, business, and relaxed style (Barnett, 2018).

General Driverless Vehicle Benefits & Costs:

Benefits	Costs & Problems
<ul style="list-style-type: none"> - Stress is reduced and productivity is increased. Passengers can rest, work or do other activities while travelling. - Transportation for non-drivers. People such as young, elderly and disabled have independence to travel. - Reduce driver costs, as there will be no public transport drivers. - Safety is increased, therefore reduced insurance premiums. - Road capacity increased. Resulting in more traffic throughput, less congestion and narrower lanes. - Fuel efficiency increased, meaning pollution levels should decrease. - Parking costs reduced, as vehicles can drop off the passengers and search for a space. - Vehicle sharing is supported, meaning less vehicle ownerships, associated costs will reduce. 	<ul style="list-style-type: none"> - Increased costs. Vehicle equipment, road infrastructure and other services. - New risks such as system failures, weather conditions, platooning and higher speeds and lightweight vehicles. - Security and privacy risks. Vehicles can be used for terrorism and illegal activities. Information can also be abused and used. - Convenient travel may cause increased travel and external costs. - Social equity, other transportation services may be affected by the convenience of driverless vehicles. - Job losses due to technology taking over, especially professional drivers. - Discourage other cost effective, reduced pollution transportation solutions such as walking or cycling.

13 Challenges and barriers

13.1 Privacy issues

A substantial amount of data is recorded when DVs travel from one destination to another. Once the data is associated with an identifiable individual it becomes personal information hence, a privacy risk (Collingwood, 2017). Furthermore, estimations have suggested one gigabyte of data is recorded by DVs every second. With a huge amount of data being recorded and stored either in vehicle technology or in an external database, many privacy fears appear. Glancy (2012) identified three areas of privacy concern, personal autonomy, personal information and surveillance. Once DVs are deployed these three areas of concern will heavily influence the public's acceptance. Also, the concerns will enforce legal restrictions that will affect the way the vehicles are designed and operated. These privacy risks will raise important political discussions, considering human freedom and individual liberties (Glancy, 2012). Nevertheless, where humans are involved the vehicles must comply to the Data Protection Act 1998, and the Privacy and Electronic Communications Regulations 2003 (Department of Transport, 2015).

Personal Autonomy Privacy

Personal autonomy privacy interests are concerned with the user's control and self-determination. Thus meaning, users have the ability to make their own decisions, avoiding being manipulated by others. Users will ultimately make the decision of whether they want to travel in a driverless vehicle. Glancy (2012) suggests people psychologically identify their choice of vehicle resulting in power, control and choice. With questions of ownership of vehicles and the idea of driverless public transport, the psychological connection between the person and the vehicle may decrease. Personal autonomy privacy is about the user's control and how they will be able to control factors such as where they are, where they are going, when they will reach the destination, with who, what outcome they predict and future travel decisions (Glancy, 2012). Many people think of this issue as a binary all or nothing control, but in this instance the independence of choices and decisions must be ensured. Humans are viewed as autonomous, therefore friction may arise when two autonomous entities collaborate. However, the driverless vehicles can be seen as agents, where humans can delegate some tasks for them to do. For example, the vehicle may have control of the speed and route but the human passenger will select the destination. The user will effectively have high level control over the vehicle, deciding whether to travel in the vehicle allowing the vehicle to control the technical decisions.

In summary, anonymity features need to be considered to avoid personal autonomous privacy concerns. A choice of whether to use DV may rely on the fact that some users do not want others to know their location. However, this may be a challenge as V2V interconnected networks will stop anonymous travelling. Issues such as misbehaving users, technology and illegal activities will be recorded in driverless vehicles. A group of individuals such as criminals or people involved in suspicious activities will therefore not use the vehicles, as regular destinations may be recorded and used for prosecution. The personal autonomy privacy concerns must be addressed to state what the vehicles will control and vice versa.

Personal Information Privacy

DVs will have the ability to generate and record a large amount of data. This data will be classed as personal information if it can be associated with individuals (Glancy, 2012). The challenge in this instance will be to legally cope with large amounts of personal data. Users will need to be notified of any data collected, as some individuals may not agree to this and in future

not use DVs. Also, a major challenge will be to avoid the collection and usage of data without the users knowing. Personal information concerns will focus on where, when and how users travel from destination to destination. This data will need to be stated on how it is used, why it is being recorded and collected, how long it will be kept and who will have access to it (Glancy, 2012). The concerns with personal information privacy are somewhat more important to address. Information can be used to disturb an individual, the opportunity to stalk and harass individuals will increase. Furthermore, the vehicles may be used as an instrument to advertise services or products to targeted groups of people. Whereas, the government and other law enforcements will use this information to track and find suspicious individuals for further investigation and or prosecution. The ability to predict frequent journeys and find patterns will appear from the collected data. Another concern that may arise is the ability to locate where the vehicle is parked overnight that could be used to create user profiles e.g. locating wealthy individuals, resulting in targeted advertisements or criminal activities. However, stakeholders are aware of these personal information privacy concerns in advance of deployment, with the opportunity to minimise the risks.

Surveillance Privacy

Surveillance privacy concerns is about people's unwillingness to be watched, monitored or tracked when travelling from destination to destination in a DV. To elaborate, surveillance privacy concerns will not only have impact on personal autonomy and personal information, but it will affect political and social aspects of the community. Furthermore, if surveillance is not controlled efficiently this may cause a hostile relationship between the government and the public. Whilst surveillance is used as a means to collect information in a surreptitious way, it also can be referred to as watching something or someone with the aim to modify their behaviour (Glancy, 2012). An illustration of overt surveillance, as red lights sit at intersections to modify the behaviour of drivers. Hence, if driverless vehicles are monitored passengers are more likely to conform to the rules and regulations of the road as well as individual inappropriate activities in vehicles such as smoking or having sexual activity. In order for manufacturers to implement surveillance features in vehicles a government regulation would need to be in place. However, a more discreet surveillance will be more likely to occur as the vehicle collects information remotely with the majority of users not realising the vehicle is collecting information. The surveillance involved are mass surveillance and targeted surveillance.

Targeted surveillance tracks and monitors a particular individual that does not know they are being watched. This involves collecting personal information about the individual secretly from the vehicle, this enables the individual to be located at any point of time without consent. However, this information will compromise both autonomy and personal information privacy concerns if the information is being collected by those unknown to the individual. Data that communicates across autonomous vehicle networks could be useful for surveillance techniques unless this information is encrypted. The information could be used by law enforcements and other parties to remotely locate individuals through the autonomous vehicle interconnected network. With the network being the third party involved, Glancy (2012) states law enforcements may not need a probable cause or warrant to access and search the network. This form of surveillance impacts the individual's autonomy.

Mass surveillance concerns the extensive collection of personal information from all individuals in a certain area. This method of surveillance controls the behaviour of individuals within that area. An illustration of this is Jeremy Bentham's Panopticon, Greek for 'all-seeing' this architectural design allowed prisons, schools, asylums and workhouses to have limited supervisors. This design allowed constant surveillance of inmates in a prison with the guards

in the centre. The inmates would not know if an officer was watching and therefore would have to conform. Bentham believed this approach could work in any manner where surveillance is involved such as cameras (Warriar, Roberts, & Lewis, 2002). Mass surveillance may collect personal information that is used to create user profiles of driverless vehicle users and their behaviour. This information could then be used to predict typical DV users, their individual behaviour and to find anomalies in the driverless vehicle behaviour patterns. Mass surveillance allows the collection of information on a large scale without affecting the patterns of human behaviour. For example, all number plates are recorded by cameras but only those who speed are noted and fined. However, contrary to this Glancy (2012) argues anonymous surveillance is suitable for management and planning road uses such as calculating traffic flows and road usage rather than identifying the vehicles and drivers. The introduction of DVs could support mass surveillance as this would allow the tracking of all vehicles on the network for security issues. However, measures need to be taken to ensure anonymity and security of personal information or this information could lead to manipulation of users and their vehicles.

13.2 Cybersecurity

Vehicles in the past used to be built through mechanically connected steering and throttle controls with hydraulic operated brakes (Department for Transport, 2015). However, nowadays cars are connected via the internet, known as ‘connected cars’ they use electrical control systems which can be hacked and used for malicious activities. Once the vehicle is hacked, the hacker has the ability to disable brakes, air bags and locks to cause harm or steal the vehicle. As DVs begin to surface this raises major issues in how these computers on wheels can be kept secure from hackers.

DVs are composed of several different components that communicate together to move the vehicle. This includes the communication between other vehicles or infrastructure on the road. Many points of entry for hackers have been already been identified such as Bluetooth, WI-FI, radio frequencies and passive key entry systems (Shaikh & Cheah, 2017). In 2015, a team of cybersecurity researchers hacked into a vehicles network and disabled it whilst it was travelling on the motorway (Cave, 2017). DVs will be more of an issue as they will have more entry points for hackers than non-autonomous vehicles that have been hacked in the past. Systems will be made up of millions of lines of code, with different styles, software and companies. Therefore, issues that arise may be challenging to address and identify whether they comply with the rules and regulations. The sheer amount of data stored within DVs will be a cybersecurity risk. GPS systems could store data such as addresses, contact information, and even financial data allowing cyber attackers to steal this information.

To resolve this issue the information sharing and analysis centre have developed several automotive cybersecurity best practices which automotive manufacturers must follow. The Auto-ISAC best practices cover ‘governance, risk management, security by design, threat detection, incident response training, and collaboration with appropriate third parties’ (Cave, 2017). In addition, the government have issued a guidance to the automotive industry in order to improve and minimise cybersecurity risk. In 2016, the National Highway Traffic Safety Administration issued a set of guidelines, failure to comply with the guidelines may result in major security issues and vehicle re-calls will be necessary (Cave, 2017).

13.3 Liability

DVs have many stakeholders, therefore who will claim liability in the event of a collision when the vehicle is in control? According to department of transport (2015) vehicle manufacturers will continue to take responsibility for mechanical and system failures. The challenge to identify and prove which component of the vehicle initiated the collision as well as if the driver or vehicle was in control at that exact time will prove to be a difficult task. The department of transport (2015) suggest event data should handle this issue for example, on-board cameras and recording systems. However, this is an ongoing discussion.

When level 3 autonomous vehicles and below are involved, which still require human operation the liability depends of what caused the collision. Whereas when fully DVs are involved in a collision there can be many parties responsible – manufacturers, software company, vehicle owner and the service centre/provider. The manufacturers can be liable for issues with the design fault, the software company for bugs in the system, the service provider for inadequate service to the vehicle and the owner for neglecting the recommended software updates. To ensure the liability is claimed by the correct party, data from the on-board sensors can be used. The risk in this being the parties may be able to access and sway the blame to another party by changing sensor data. Block chain technology can be used to ensure tampering is avoided, by allowing only parties with permission to record and access information from the sensors (Jurdak & Kanhere, 2018). Block chain technology ensures the stored sensor data cannot be changed without detection. The parties that will be allowed permission consists of two groups. Group 1 is the operational partition, whereas group 2 are the decision partition who make the liability decisions.

Group 1: Manufacturers, software companies, service providers, insurance companies and the vehicle itself.

Group2: Government transport authority, legal authority, insurance company.

Block chain framework ensures the vehicle owner remains anonymous throughout the decision process. Only the decision partition will have permission to the identity of the owner when making the final decision. This framework will ensure a fair and reliable decision is made, with no biases from the parties.

13.4 Ethics

Fortunately, DVs do not have road rage, fatigue or the ability to drink drive but they can make mistakes. The most likely reason for collisions would be if the vehicles sensors fail to identify or interpret data from the surrounding environment correctly. Not all crashes can be avoided, the vehicles must make ethical decisions. The software must be able to make real life decisions for example, if a child runs out onto the road and the vehicle cannot stop in time, does the vehicle attempt to stop or swerve and possibly cause fatal injuries to the passenger or hit another vehicle. The vehicle cannot value one life more than another, but it must be programmed to make ethical decisions. Figure 10 below illustrates some ethical decisions that a vehicle may be presented with.

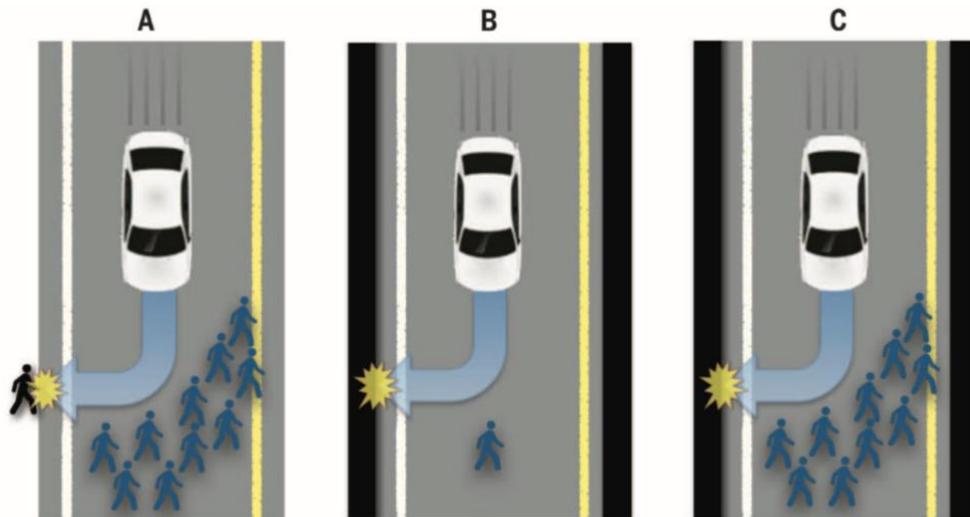


Figure 25: Three traffic situations with unavoidable harm (source: Bonnefon, Shariff & Rahwan, 2016).

The vehicle must decide between: (A) Killing several pedestrians or one passer-by, (B) killing one pedestrian or the passenger inside, (C) Killing several passengers or the passenger inside. (source: Bonnefon, Shariff & Rahwan, 2016).

These situations may never occur however, the decisions must be made before the widespread adoption. Research shows that a utilitarian approach should be implemented, meaning the vehicle should swerve to reduce the number of fatalities. However, this decision may cause outrage with passengers, after all DVs are being built to be safer for all road users. The moral algorithms must be aligned with human values, Bonnefon, Shariff & Rahwan, (2016) carried out six surveys to determine the thoughts of participants on DV ethics. The results showed a social dilemma, whilst most agreed a utilitarian approach would be the most appropriate, few would be happy to travel in one. The results show if both utilitarian vehicles and self-protective vehicles were commercially available, most would choose the self-protective vehicle. This issue may be resolved by regulation however, regulators face two main issues – people would not agree to a regulation that enforces utilitarian vehicles. Also, regulation could potentially stall the deployment of vehicles which could lead to more deaths from human errors in due course (Bonnefon, Shariff & Rahwan, 2016).

Moral algorithms must be implemented to make very intricate decisions, for example determining if the probability of a pedestrian surviving the collision is lower than the pedestrian on the road. Liability issues can also be affected by users specifically choosing a certain vehicle by moral choices, if the manufacturer allows this information to be a key decision maker. However, who should be blamed if a collision then occurs, with the user's choice affecting the decision made? Implementing an ethically approved vehicle is one of the most challenging aspects of DVs, regulations and decisions must be made prior to their introduction. With different views and cultural morals, this is a major challenge and the public's opinion must be considered.

13.5 Ownership of Vehicles

Waymo have recently put in an order for several thousand Chrysler Pacifica minivans, with the intent to deploy driverless taxi's around many cities in the USA in 2019 (Kurman & Lipson, 2018). The taxi's will be easily accessible and cheap, therefore will vehicle ownership numbers decrease in time? Some big questions are still yet to be answered, the biggest being whether

privately owned vehicles will still dominate the automobile industry, or whether transportation as a service (TaaS) will replace them. Vehicles are very expensive to buy and maintain, considering they spend the majority of their time parked up. As the fleet of driverless taxis become universal, it is thought that people will no longer need to purchase vehicles and will rely on the driverless taxis to travel. If a luxurious DV can be summoned instantly why would we need to own a vehicle?

The main reason to rely on TaaS is simply economic advantages. The report conducted by Tony Seba and James Arbib for RETHinkX points out that a subscription to a TaaS model could save the average consumer \$5,600 per year, and an estimated further \$1 trillion saving for the economy by 2030 (Grover, 2017). As vehicle owners, we spend large amounts of money on maintaining the vehicle, filling up with petrol, tax, insurance and MOTs. Furthermore, by choosing an alternative TaaS model which is convenient, cheap and zero emission the average consumer can save a lot of money.

One study by a market research organisation RETHinkX, predicts the introduction of DVs will reduce the demand for purchasing vehicles by 70 percent (Kurman & Lipson, 2018). Of course, this prediction is optimistic, despite the fact driverless taxis will be widely accessible and beneficial there are many reasons why privately owned driverless vehicles could be worth the money. Some predictions have shown that the sales of DVs will increase with time, once established on the market they will become cheaper, more efficient and versatile. However, economics has to contend with cultural norms, humans don't base the purchasing process on a rational, economic basis. Humans can easily get attached to a vehicle, and thus comes the economic irrationality aspect (Grover, 2017). Vehicles are bought from choice, if decisions were made purely on economics everybody would be cycling or driving cheap hatchbacks. The best-selling car in the USA, being the Ford F-150 pickup truck will not easily be knocked off its spot. Will these vehicle enthusiasts drop their love of vehicles to save money?

Some reasons why people will continue to purchase privately owned vehicles:

- Custom vehicles – Users will have the ability to work, play and relax in their vehicles. This gives them the opportunity to customise their personal vehicle with preferred accessories and the ability to store personal belongings in their vehicle. Consumers will be able to have purpose built vehicles custom made vehicles to suit their needs.
- Accessibility – Driverless taxis will be widely available in urban environments, however the wait for a taxi still applies. Also, in rural areas some taxis will not be available therefore a vehicle with instant accessibility is a benefit.
- Cost – Whilst the price may initially be high, it is predicted driverless vehicles will become affordable as they will run off electricity and will be made of lighter cheaper materials due to less collisions.

REThinkX's predictions are not concrete as there are many different variables we simply cannot predict. Our love for vehicles will not fade without a fight, but one thing is certain that vehicles in the future will be significantly different, and humans will need to adapt. The question of who owns vehicles and how we can access TaaS are yet to be confirmed and will need to be further researched.

In addition, car sharing may be a key factor regarding the ownerships of vehicles. Shared transportation is encouraged to decrease emissions, VMT and vehicle ownership. The concept is, users from different households share a DV to reach a destination, close to or on the way to the other persons destination. This would be more suitable for driverless taxi services, with the opportunity to develop apps which allow users to book taxis to their door. With new regulations

coming into place regarding emissions and driverless vehicles we may see the need for car sharing in the future. However, many people would not be so keen for this concept as they enjoy their own space and various drop off times may delay their journey.

13.6 Policies

Based on the amount of different technology and systems companies are developing, this suggests there are many questions of how the vehicles will be regulated. Each company has their own approach to developing driverless technology and vehicles, therefore policy makers will have a challenge to issue one DV policy that covers all capabilities and limitations. Policy makers could be forced to regulate different vehicle capabilities in certain situations such as highway vs urban environments, fast vs slow driving, and fully autonomous vs semi-autonomous. Anderson et al. (2014) pointed out it would be expensive for agencies to develop individual policies for specific operational conditions and capabilities for each type of vehicle. In addition, policy makers must decide how to regulate the users of each type of vehicle to ensure they know how to safely use the technology. Anderson et al. (2014) suggests tests and certificates may be required to enable users to use DVs. The tests may be similar to motorcycle tests where users will need additional tests, were users will demonstrate how to use the technology which also may have age restrictions. With different kinds of interaction with the vehicle being introduced, a standardized test may be impossible to put in place. Alternatively, policy makers may cut practical tests all together instead relying on vehicle manufacturers to introduce how to use the technology and train the users themselves.

The vast range of technology and their capabilities will need safety and performance standards. Whereas vehicles nowadays are focused on mechanical safety, driverless vehicles could introduce new safety and performance standards that specify requirements of technology such as sensing objects in specific environments, system redundancy, emergency behaviours, software communication and integrity and graceful degradation (Anderson et al., 2014). In addition, road markings will need regulation as some routes and construction may restrict the perception and recognition of the vehicle. Standardised road markings and signs would help vehicles and human drivers. Also, transportation agencies could provide online, real-time and more detailed records of construction and route issues in the systems. This would aid human drivers and DVs by providing real-time traffic and route updates, that could be used to plan other routes.

14 Future Work & Suggestions

Introducing DVs onto the roads is a major task, many challenges and barriers still need to be identified and addressed. If this paper were to be continued, many new chapters would need to be included to involve all challenges and barriers to their use. Also, systems and algorithms were briefly touched on therefore, a more in-depth explanation and analysis of different methods would be appropriate. As DVs are a very complex area of expertise, collaboration or interviews with industrial experts would be helpful to explore more areas and gain a more in depth understanding of how they work and their implications. In regard to the questionnaire, a sample of including more participants would ensure reliable results with a reduced error margin. More participants in general, but specifically more over the age of twenty-four to identify patterns and trends in the data.

The timescale of the project resulted in the researcher only discussing some concepts, issues and benefits whilst analysing some stakeholders. Hofstadter's Law was taken into account, as sections took longer than expected and time did run out quickly. To expand this project, major

work would need to be done to ensure all of the latest concepts and research is condensed to produce a full path to driverless vehicles. However, the following steps could take place in order to achieve a full up to date report:

- Research and understand more driverless systems and algorithms - discuss and explain the systems more likely to be used in future vehicles. The report currently lacks detailed understanding and explanations of the many systems available and whether they are feasible.
- Analyse the impact driverless vehicles will have on stakeholders in depth, for example, consider how they will impact different departments within the companies and/or analyse more industries.
- Conduct interviews with industry leading companies to gain a more valuable insight into how they work, the test statistics and the issues with current technology.
- Conduct a questionnaire with more participants involved to gain more reliable statically significant data. The time limits restricted the amount of time the questionnaire could be available to the public.
- With new technology and issues continually arising, constant research will be needed to identify new emerging technology or factors that affect their distribution. Hence, the project will need many volumes as new technology rolls out and new issues arise with different stages of DV progression.
- Focus more on the analysis of stakeholders rather than explaining the background info in depth. Currently the report is very broad and lengthy with some challenging concepts, whereas the report could focus more on analysing the current situation and the desired future situation. Also, by sourcing quantitate figures from leading experts, system dynamics could be carried out. The conceptual models could be richer with more activities identified within the stakeholder's organisation.
- Design of a TaaS application could be an interesting aspect for future work, where users can summon a driverless vehicle to their door or use car share services.
- Complete the gap analysis on technology companies.

15 Conclusions

To conclude, this section will include an evaluation of whether the aims and objectives have been achieved, and any limitations encountered throughout the lifetime of the project.

Review of project aims & objectives

1. *Gain an understanding of what driverless vehicles are and how they work.*

This part was moderately studied, as defining and understanding what a driverless vehicle was basic. This part discussed the various definitions driverless vehicles can come under, with Alan Turing's question introducing the concept of machine thinking. Some algorithms used in driverless technology were identified and discussed in chapter 4. Although there are various methods to how driverless systems and algorithms work, only some were discussed on the basis of available sources and understandable literature. The algorithms and systems were displayed with short explanations to the concept with relevant figures for the reader to gain more understanding. In summary, this aim was achieved through providing general overviews of systems and algorithms, although a discussion of more or alternative systems and algorithms would have been preferred if the timescale was longer.

2. *Highlight and discuss current issues that need to be addressed to enable the distribution of driverless vehicles.*

Many issues and benefits were discussed in chapters 11 and 12 related to driverless technology. Some issues and benefits were not directly linked with the technology but rather the barrier to the technology usage and the benefits of using the technology. These issues were discussed in detail, identifying issues such as privacy, cybersecurity, liability, ethics, politics and ownership of vehicles. These are some of the main issues surrounding DVs at this moment in time with many questions asked. The discussion of leading companies in the market was discussed in chapter 6, identifying the four main leaders Ford, GM, Renault-Nissan and Daimler. Also, to achieve this aim recorded DV accidents were discussed including Ubers recent incident, and two Tesla collisions. In summary, this aim was achieved by an in-detail discussion of issues and identifying the DV collisions.

3. *Social and psychological issues that must be addressed before the widespread adoption.*

Social and psychological issues were discussed in chapter 7 with a questionnaire in chapter 8. The psychological issues focused on the link between human and machine, with results showing anthropomorphism features can benefit driverless vehicles. Related social issues such as ethics were later discussed in chapter 12 (challenges and barriers). The questionnaire gathered a substantial number of participants, but unfortunately the age of the participants did affect the analysis of results. The analysis carried out intended to find a distinct connection between age, drivers or non-drivers and how many hours people travel a day to how users feel about driverless vehicles. Overall the results were varied but a fair evaluation was carried out with the data acquired. This aim was achieved through identifying the main research that has been and needs to be carried out to allow users to trust machines. Also, the questionnaire gave some input of how users currently feel about DVs, although with more time users of different age groups could have been targeted supplying the researcher with more significant data.

4. *Analyse opportunities and threats that may arise from the widespread adoption of driverless vehicles.*

To analyse the opportunities and threats, major stakeholders were identified and appropriate methodologies were used to analyse their impact. Methods used included SWOT analysis, SSM and porter's five forces. The SWOT analysis successfully identified some strengths, weaknesses, opportunities and threats for all four major stakeholders. The SSM proved to be more difficult with the majority of project time spent on building the conceptual models and analysing them with a gap analysis. As the gap analysis related to the industries as a whole it was difficult to obtain quantitative data and grasp their current situation. Although research and assumptions were made to carry out an appropriate gap analysis. Also, as driverless vehicles are yet to be introduced some activities were yet to be carried out by stakeholders therefore it was difficult to analyse these. However, overall the SSM provided the paper with in depth understanding of where these stakeholders are and where they want to be in the future. Furthermore, porter's five forces were carried out to understand the forces that shape the competition within the driverless industry. This aim was achieved with several 'appropriate' analysis methods carried out as stated in the aims & objectives. The gap analysis for technology companies was not completed, due to time restrictions and that the fact it was very similar to vehicle manufacturers. Therefore, time was focused on completing three valuable analyses.

5. Summarise whether the adoption of driverless vehicles is feasible.

The final aim was discussed in the throughout the paper with the many sections indicating the challenges to their use. Whilst there was no direct section, this question was answered throughout the paper. In regard to stating there are still many issues still to be addressed before their adoption therefore, at this moment in time DVs are not feasible. However, this paper does display DVs have had significant development in the last decade, and will be introduced soon.

Further work is still needed as the title of this project was very broad, with endless lists of issues, benefits and technology available. Some headings were less important as the project progressed hence, less information provided. With my main focus on analysing the four stakeholders. Nonetheless, this paper successfully delivered my five aims in the timescale.

16 Reflection on Learning

Problems Faced

Prior to this project I had only heard of driverless vehicles via news articles and content on social media. The topic interested me in regard to researching and writing about a meaningful topic that could potentially change the world. Throughout this project I have used and showcased many methods and techniques learnt over my three-year course.

I underestimated the amount of literature research involved. Prior to this project I had not thoroughly researched scientific papers, I have since learnt how to research in depth and identify important sections of a scientific paper. The majority of the explanation work involved research work and understanding the concepts, especially the technology and algorithms involved. As the system and algorithm section could only be found online, it made it difficult to understand some systems, with a preferred method being discussing systems with experts. The literature surrounding systems and algorithms were limited and very complex to understand therefore this section took longer than first thought by around 4 weeks, and was simply to provide an overview of some technology used.

I learned that research is crucial to writing a concise paper that portrays the information intended. Whilst I spent a lot of time during my project researching, I could only read paper abstracts to see if the content was relevant. To improve on my research skills, I would need plan and dedicate more time to researching before beginning the project highlighting important literature that would add value to my paper. Also, it would have been ideal to interview experts in the field to gain some insight and opinions. However, I decided to conduct a questionnaire to the public instead as I predicted it would be near impossible to arrange a meeting with experts in the driverless vehicle industry.

My writing skills have developed throughout this project however, looking back a recurring problem was over explaining some sections rather than producing concise points. The volume and variety of information on the internet surrounding some sections distracted me from producing concise opinions as I felt like I was missing out key information and research. The solution to this would be to arrange my material before beginning the project to know exactly what to write, where. Instead, I researched each heading as I progressed which led to frustration and lack of fluidity when writing each section.

Before the questionnaire could be distributed, ethical approval was needed. As I had not realised this until half way through the project time was limited to undertake the integrity module, submit for approval, distribute and analyse results. The submission process took many more weeks than expected with comities every two weeks. My initial retention policy was not

compliant with ISF and the requirement for record management, to solve this I stored the data on OneDrive.

Module Learning

My module for this project was the CM3203 – One Semester Individual Project, 40 credits. This project gave me the opportunity to demonstrate how I can work independently, whilst showing and improving my management and communication skills. Throughout the duration of the project I had to demonstrate my communication skills firstly, by arranging meeting every fortnight with my supervisor with additional meetings with my moderator to work on different aspects of the project. The communication was mainly through university email and discussion. I also had to show appropriate communication skills with ComSci ethics in order to gain ethical approval for my questionnaire. After my ethical form was submitted, there was some problems regarding my method of storing the data. This issue was resolved over many weeks, emails and three ethical submission forms. My management skills have progressed in terms of completing a project in time, and the amount of unexpected problems that arise. I believe this project has taught me the importance of breaking a large project into phases, by doing so the focus is on smaller sections rather than worrying about the whole project completion, which made it less daunting. In terms of time management, I didn't keep to the Gantt chart as planned as some sections took longer than expected however, I made adjustments and delivered the paper on time.

Overall Project

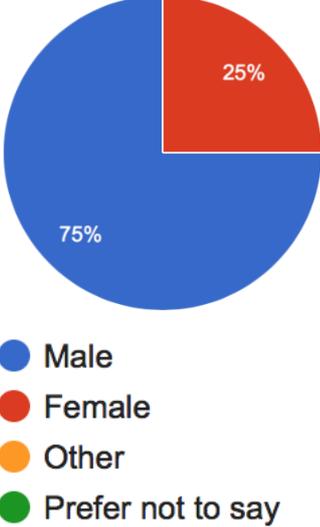
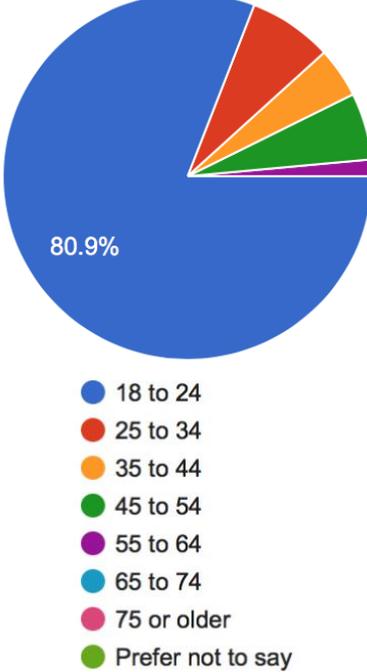
As a business information systems student, my project titles were limited, therefore it was crucial to pick a title that could display my skills learnt throughout my three years at Cardiff University. I believe the content of this project was appropriate, by showing research into complex algorithms and systems, ethics and policies, and also carrying out work in various analysis methods such as soft systems methodology, SWOT analysis and porter's five forces. As the IT industry isn't all about technology, issues such as policies and ethics are always considered therefore this project allowed me to think of indirect issues.

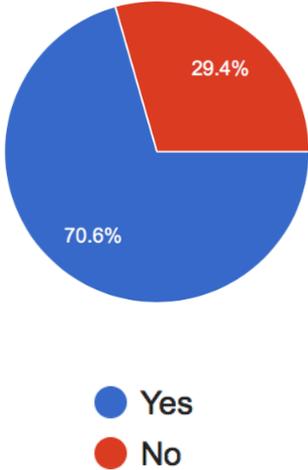
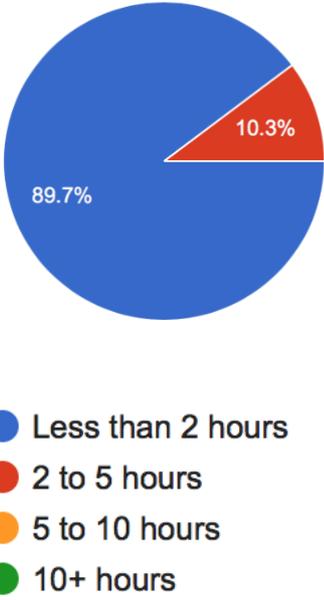
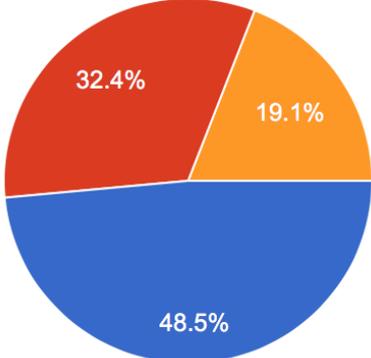
The methodologies used were appropriate for this project, however on reflection with the major stakeholders it may have been more useful to choose specific companies within that industry to analyse. Analysing the whole industry made it difficult to present quantitative data and in-depth improvements. Whereas analysing specific companies within each industry could have given me the opportunity to research specific figures and strategies.

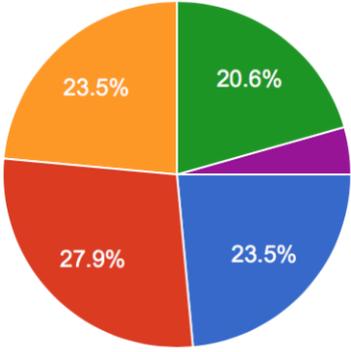
I have successfully delivered all deliverables in time. With hindsight, I could have managed my time more efficiently by spending time on more important sections of the paper. For example, I spent a large amount of time researching, understanding and explaining concepts and algorithms rather than analysing the impact they will have using SSM, SWOT, gap analysis and porter's five forces. Overall, I have thoroughly enjoyed completing a project of this magnitude, and will take this experience with me into Business.

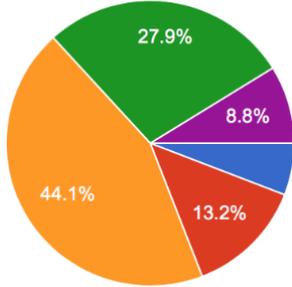
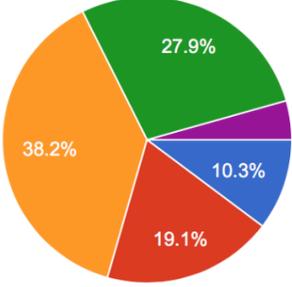
Appendices

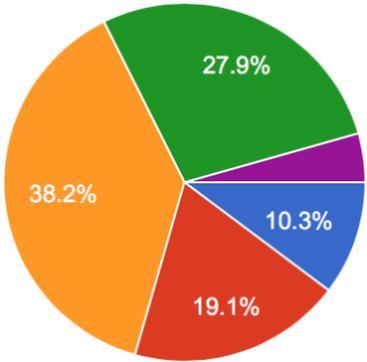
Appendix A: Full Questionnaire Results

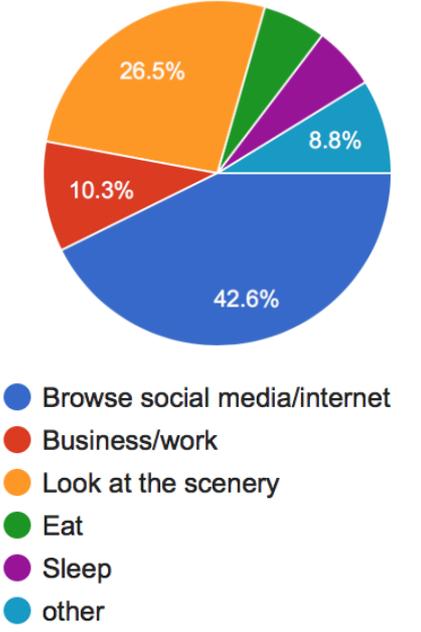
Question	Results	Findings
1. What is your gender?	 <p>A pie chart showing the gender distribution of 68 participants. The chart is divided into four segments: a large blue segment representing 75% (Male), a red segment representing 25% (Female), and two very small segments for 'Other' (orange) and 'Prefer not to say' (green) which are not visible. A legend below the chart identifies the colors: blue for Male, red for Female, orange for Other, and green for Prefer not to say.</p>	<p>Out of 68 participants, 75% (51) were male, and 25% (17) were female. This indicates the questionnaire reached more males, or more males volunteered to participate.</p>
2. What is your age?	 <p>A pie chart showing the age distribution of 68 participants. The chart is divided into eight segments: a large blue segment representing 80.9% (18 to 24), a red segment representing 7.4% (25 to 34), an orange segment representing 4.4% (35 to 44), a green segment representing 5.9% (45 to 54), a purple segment representing 1.5% (55 to 64), a cyan segment representing 0% (65 to 74), a pink segment representing 0% (75 or older), and a light green segment representing 0% (Prefer not to say). A legend below the chart identifies the colors for each age group and 'Prefer not to say'.</p>	<p>Out of the 68 participants, 80.9% (55) were in the 18-24 category. This is because my questionnaire reached mostly students and similar age groups on my social media friends list. Other age group percentages: 25 to 34 – 7.4% (5) 35 to 44 – 4.4% (3) 45 to 54 – 5.9% (4) 55 to 64 – 1.5% (1) 65 to 74 – N/A (0) 75 or older – N/A (0) Prefer not to say – N/A (0)</p> <p>In future, more people from other age groups could be targeted.</p>

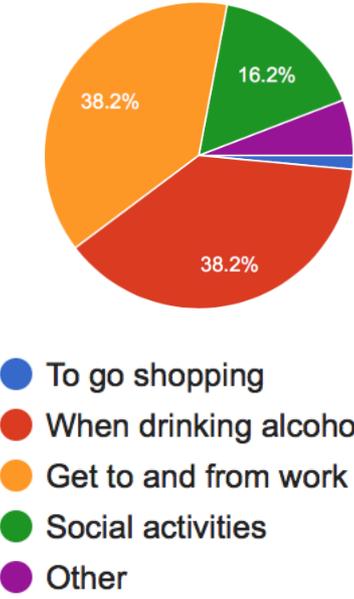
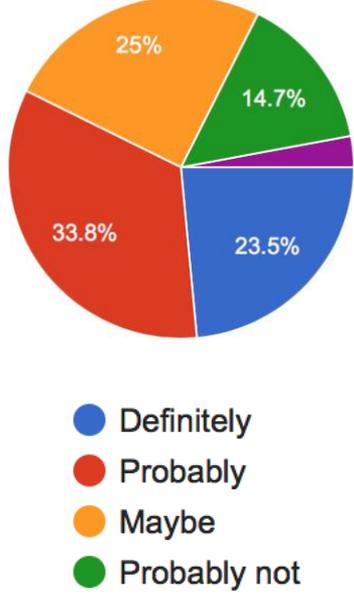
<p>3. Do you currently hold a full UK driving license?</p>	 <p>A pie chart with two segments. The larger segment is blue and labeled '70.6%' with a legend below it showing a blue circle next to the word 'Yes'. The smaller segment is red and labeled '29.4%' with a legend below it showing a red circle next to the word 'No'.</p>	<p>70.6% (48) of the participants currently hold a full UK driving license. Whereas 29.4% (20) of the participants do not hold a full UK driving license. These results will help me understand whether people who drive are more concerned about driverless vehicles than those who do not drive. By analysing each question with the percentage of drivers to non-drivers will help me identify whether there is a link.</p>
<p>4. On a typical day, about how many hours do you spend in a vehicle?</p>	 <p>A pie chart with two segments. The large segment is blue and labeled '89.7%' with a legend below it showing a blue circle next to 'Less than 2 hours'. The small segment is red and labeled '10.3%' with a legend below it showing a red circle next to '2 to 5 hours'. There are also legends for '5 to 10 hours' (orange) and '10+ hours' (green) which are not represented in the chart.</p>	<p>90.6% (59) of the participants spend less than 2 hours in a vehicle in a day. Whereas 9.4% (6) participants say they spend 2 to 5 hours in a vehicle on an average day. With the majority only spending less than 2 hours in a vehicle per day, this could be because my questionnaire reached a lot of students. However, the results to this question will help me determine whether people who spend more time in a vehicle per day will be affected more psychologically by driverless vehicles.</p>
<p>5. How do you feel about the development of driverless vehicles?</p>	 <p>A pie chart with three segments. The largest segment is blue and labeled '48.5%'. The second largest is red and labeled '32.4%'. The smallest is orange and labeled '19.1%'. There is no legend provided for this chart.</p>	<p>Out of the 22 concerned participants, 20 were in the age group of 18-24. The other two concerned participants were in the 35-44 and 45-54 age group. 33 participants were excited, 25 participants in the age group 18-24 were excited, 3 in the 25-34 age group, 2 in the 35-44 age group, 2 in the 45-55 and 1 in the 55-64 age group. 13 participants said they were not bothered, 10</p>

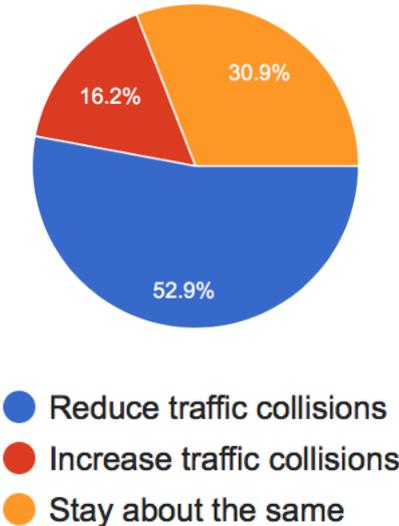
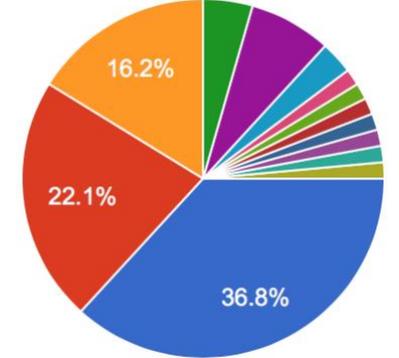
	<ul style="list-style-type: none"> ● Excited ● Concerned ● Not bothered 	<p>of those within the 18-24 age group, 2 in the 25-34 age group and 1 in the 45-54 age group. 11 of the 22 non-drivers were excited and only 15 out of the 48 drivers were concerned. Also, 4 of the 7 participants that spend 2 to 5 hours in a vehicle per day say they are concerned. In summary, it seems age does is not a big factor in this study. Also, over half the non-drivers were excited and over half the drivers were concerned. Suggesting to me there could be a link that those who spend more time in a vehicle per day are more concerned.</p>
<p>6. Would you travel in a driverless vehicle?</p>	 <ul style="list-style-type: none"> ● Definitely ● Probably ● Maybe ● Probably not ● Definitely not 	<p>Definitely not (3) – All from the 18-24 age group, all 3 hold driving licenses. Probably not (14) – 11 from 18-24 group, 1 from 25-34, and 2 from 35-44 group. 8 of the 14 hold a driving license. Maybe (16) – 12 from the 18-24 age group, 1 from the 25-34 and 3 from the 45-54 age group. 9 of these hold full UK driving licenses. Probably (19) – 16 from the 18-24 age group, 1 from the 25-34, 1 from the 45-54 and 1 from the 55-64 age group. 15 hold driving licenses. Definitely (16) – 13 from the 18-24 age group, 2 from the 25-34 and 1 from the 35-44 age group. 12 hold driving licenses.</p> <p>In summary, more than half of the participants would definitely or probably travel in a driverless vehicle. Some are unsure which is predicted at this stage of development, but companies must continue to gain trust.</p>

<p>7. How concerned would you be travelling in a fully self-driving vehicle?</p>	 <p> ● Extremely concerned ● Very concerned ● Somewhat concerned ● Not so concerned ● Not concerned at all </p>	<p>Extremely concerned (4) – 3 from the age group 18-24 and 1 from the age group 35-44. 3 hold driving licenses.</p> <p>Very concerned (9) – 8 from the 18-24 group and 1 from the 25-34 age group. 6 hold driving licenses.</p> <p>Somewhat concerned (30) – 23 from the age group 18-24, 2 from the age group 25-34, 2 from the age group 35-44 and 3 from the age group 45-54. 19 hold driving licenses.</p> <p>Not so concerned (19) – 16 18-24 year olds, 1 from the 25-34 age group, 1 from the 45-54 group and 1 from the 55-64 age group. 15 hold driving licenses.</p> <p>Not concerned at all (6) – 5 from the 18-24 age group and 1 from the 25-34 age group. 5 hold driving licenses.</p> <p>In summary, the older participants were not very concerned with everyone over the age of 44 saying they were somewhat concerned or not concerned.</p>
<p>8. As a driver or passenger, how safe would you feel sharing the road with driverless vehicles?</p>	 <p> ● Extremely safe ● Very safe ● Somewhat safe ● Not so safe ● Not at all safe </p>	<p>Extremely safe (7)- 6 participants from the 18-24 age group and 1 from the 25-34 age group. 6 hold driving licenses.</p> <p>Very safe (13)- 12 from the 18-24 age group and 1 from the 55-64 age group. 8 hold driving licenses.</p> <p>Somewhat safe (26)- 19 from the 18-24 age group, 4 from the 25-34 age group, 1 from the 35-44 age group and 2 from the 45-54 age group. 19 hold driving licenses.</p>

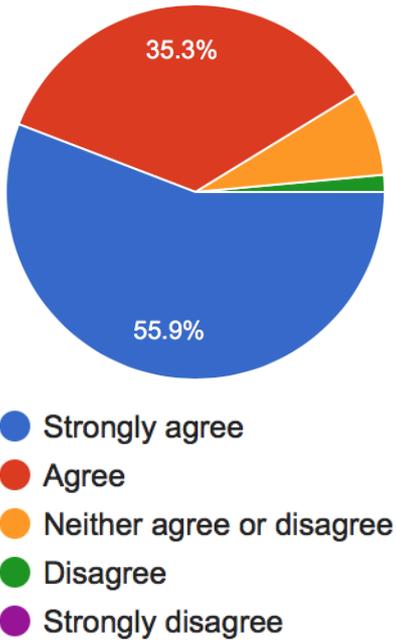
		<p>Not so safe (19)- 15 from the age group 18-24, 2 from the 35-44 age group and 2 from the 45-54 age group. 11 hold driving licenses.</p> <p>Not at all safe (3)- all from the 18-24 age group, and all hold full UK driving licenses.</p> <p>In summary, it was expected that the older age groups and the drivers would feel less safe. However, the results are distributed and there seems to be no link. The oldest participant would feel 'very safe'.</p>
<p>9. As a pedestrian or cyclist, how safe would you feel with driverless vehicles on the road?</p>	 <p>A pie chart illustrating the distribution of responses regarding safety levels for driverless vehicles. The chart is divided into five segments: 'Somewhat safe' (38.2%, orange), 'Not so safe' (27.9%, green), 'Very safe' (19.1%, red), 'Extremely safe' (10.3%, blue), and 'Not safe at all' (14.5%, purple). A legend below the chart identifies each category with a colored circle.</p> <ul style="list-style-type: none"> ● Extremely safe ● Very safe ● Somewhat safe ● Not so safe ● Not safe at all 	<p>Extremely safe (8) – 7 18-24 year olds, 1 25-34 year olds. 6 hold driving licenses.</p> <p>Very safe (10) – 8 18-24 year olds, 1 35-44 year old and 1 from the 55-64 age group. 8 hold driving licences.</p> <p>Somewhat safe (23) – 18 from the 18-24 age group, 4 from the 24-34 age group and 1 from the 45-54 age group. 15 hold driving licenses.</p> <p>Not so safe (22) – 17 from the age group 18-24, 2 from the 35-44 age group and 2 from the 45-54 age group. 16 hold a UK driving license.</p> <p>Not at all safe (5) – All from the 18-24 age group. 3 hold driving licenses.</p> <p>In summary, the results are varied and there is no sufficient evidence to say that age or driving licenses effect the decision process. However, the oldest participant said they would feel very safe. Most participants are somewhat</p>

		safe therefore unsure or don't feel so safe.														
<p>10. How would you spend your spare time when travelling in a driverless vehicle?</p>	 <table border="1"> <thead> <tr> <th>Activity</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Browse social media/internet</td> <td>42.6%</td> </tr> <tr> <td>Business/work</td> <td>10.3%</td> </tr> <tr> <td>Look at the scenery</td> <td>26.5%</td> </tr> <tr> <td>other</td> <td>8.8%</td> </tr> <tr> <td>Eat</td> <td>-</td> </tr> <tr> <td>Sleep</td> <td>-</td> </tr> </tbody> </table>	Activity	Percentage	Browse social media/internet	42.6%	Business/work	10.3%	Look at the scenery	26.5%	other	8.8%	Eat	-	Sleep	-	<p>It is clear from the results of this question that how people spend their spare time in a driverless vehicle will differ. With different personalities, culture and thought processes. However, more people, 29 out of the 68 would browse social media/internet. Reasons could include the dominant age group of 18-24 year olds which have been raised with technology. Also, nowadays many people illegally use their phone whilst driving, therefore a driverless vehicle could be a safe way to use their phone on the move. The majority of participants that answered business/work and looking at the scenery were over the age of 24. From this question, it shows companies could benefit in implementing built in devices or desks to entertain and let passengers work.</p>
Activity	Percentage															
Browse social media/internet	42.6%															
Business/work	10.3%															
Look at the scenery	26.5%															
other	8.8%															
Eat	-															
Sleep	-															

<p>11. When would you most likely use a driverless vehicle?</p>	 <p> ● To go shopping ● When drinking alcohol ● Get to and from work ● Social activities ● Other </p>	<p>Most of the participants said they would use driverless vehicles to get to and from work or whilst drinking alcohol (26 each). The option of drinking alcohol was given assuming the laws regulate alcohol drinking in a fully driverless vehicle with no manual controls. These results indicate to me that the stress of rush hour could be avoided whilst travelling to work, which also gives the opportunity to get ready or work on the way. Also, driverless vehicles could allow passengers to travel after drinking alcohol, to avoid drink driving.</p>
<p>12. Would you use driverless vehicles if they were offered as a form of public transport?</p>	 <p> ● Definitely ● Probably ● Maybe ● Probably not ● Definitely not </p>	<p>39 participants would definitely or probably use driverless vehicles as a form of public transport e.g. driverless taxi, buses etc. Only 10 participants would definitely not or probably not use this service. One participant pointed out that trains such as the DLR Light Railway are driverless. Therefore many users already use driverless vehicles that passengers may not know of. However, this question was intended for road vehicles. Again, the results prove to me that people are very unsure with 26 saying maybe.</p>

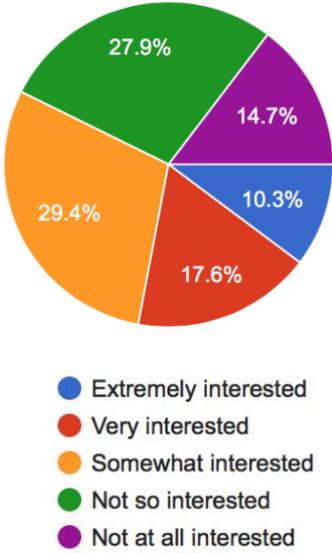
<p>13. In your opinion, how will the widespread adoption of driverless vehicles affect traffic collisions?</p>	 <p>● Reduce traffic collisions ● Increase traffic collisions ● Stay about the same</p>	<p>It is clear to see more than half of the participants (36) think driverless vehicles will result in less collisions. 21 think it will stay about the same, whereas only 11 people think it will increase collisions. This indicates to me that most of the participants see driverless vehicles as safe or at least equal to human operators. 8 of the 11 that said it would increase collisions hold a driving license. Also, all but 1 were in the 18-24 age category.</p>
<p>14. In event of a road accident whilst the vehicle is in control, who should claim liability?</p>	 <p>● Software/technology company ● Car manufacturer ● Owner of the vehicle ● The Government ● Service provider ● None of the above ● If there is no way for the driver to int... ● Depends on what was the cause of... ● There will probably still be a law requiring car insurance, so I imagine the insurers. ● Cannot decide ● Depends on the cause of the accident. ● Depends on the circumstances of the accident ● depends on the nature of the accident</p>	<p>As seen in the graph, the expected largest percentage at 36.8% (25) say the software /technology company should claim liability. However, with the option to include their own answers 7 participants said:</p> <ul style="list-style-type: none"> - If there is no way for the driver to intervene then the manufacturer otherwise the driver. - Depends on what was the cause of the accident - There will probably still be a law requiring car insurance, so I imagine the insurers. - Depends on the cause of the accident. - Depends on the circumstances of the accident - depends on the nature of the accident - One could not decide <p>Most of the participants said the manufacturer or software company should claim liability. Therefore, the results show software and manufacturers would instantly be blamed.</p>

15. Driverless vehicles should have manual back up controls?

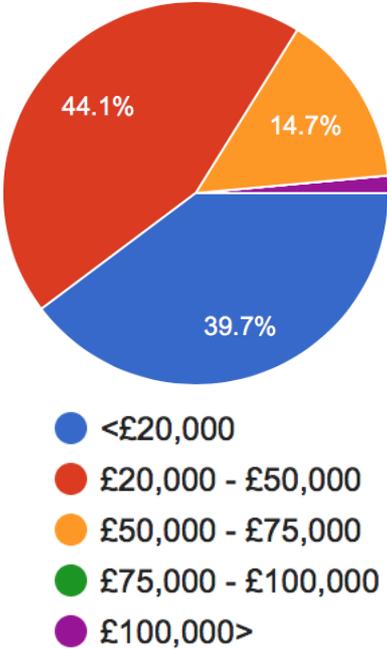
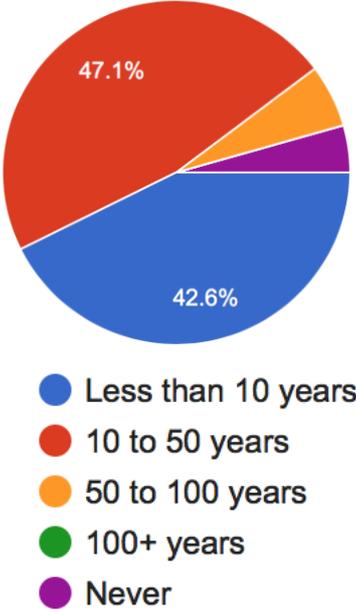


This graph clearly illustrates that 62 out of 68 participants either strongly agree or agree that driverless vehicles should have back up controls. More than half strongly agree. Only 1 participant disagreed with this statement. In summary, these results would indicate manufacturers would need to implement these features initially. Also, law regulations would need to be considered to ensure back up controls. This shows participants would only feel safe if there were manual back up controls, however at a guess the one person may have thought a driverless vehicle should be capable of driving itself as that is its purpose, hence disagreeing.

16. How interested would you be to purchase a driverless vehicle?



From these results, it indicates to me that people are unsure about driverless vehicles. 24 participants were either extremely interested or very interested. A further 29 were not so interested or not at all interested, and 20 were somewhat interested. These results are very distributed. The results show that driverless technology hasn't yet proven itself to consumers. These results were expected at this stage as driverless vehicles are yet to be introduced therefore people can only imagine the process of buying such a vehicle. As years progress I expect the participants to

		warm to the idea and become more interested.
17. If you were purchasing a driverless vehicle, how much would you be willing to pay?	 <p>A pie chart showing the distribution of responses for question 17. The largest slice is red, representing £20,000 - £50,000 at 44.1%. The next largest is blue, representing <£20,000 at 39.7%. A smaller orange slice represents £50,000 - £75,000 at 14.7%. There are very small purple and green slices representing £100,000+ and £75,000 - £100,000 respectively.</p> <ul style="list-style-type: none"> ● <£20,000 ● £20,000 - £50,000 ● £50,000 - £75,000 ● £75,000 - £100,000 ● £100,000> 	<p>The results from this question clearly show the majority of people would only be willing to pay less than £50,000 for a driverless vehicle. Only 11 people would pay more than £50,000 for a driverless vehicle. This indicates to me that most people would not be willing to pay much more than they already pay for a manual vehicle. Average car prices in the UK can range from small cars at around £10,000 to larger cars at around £25,000.</p>
18. In your opinion, how long will it be until we see fully legal self-driving cars on our roads?	 <p>A pie chart showing the distribution of responses for question 18. The largest slice is red, representing 10 to 50 years at 47.1%. The next largest is blue, representing Less than 10 years at 42.6%. Other categories include 50 to 100 years (4.7%), 100+ years (2.3%), and Never (2.3%).</p> <ul style="list-style-type: none"> ● Less than 10 years ● 10 to 50 years ● 50 to 100 years ● 100+ years ● Never 	<p>32 people think driverless vehicles will be introduced in 10-50 years, whilst 29 think it will be less than 10 years. Whereas, 4 people think it will be 50-100 years, and 3 people think they will never be introduced. From this result, it is clear to see the majority of people are aware driverless vehicles are being developed and are close to being deployed.</p>

Appendix B: Gap Analysis (Continued)

Users

Activity from Conceptual Model	Current Situation	Future State & Actions to Take
Decide how to consider all components involved with travelling in a driverless vehicle	<ul style="list-style-type: none"> - Lack of knowledge of what it feels like to travel in a driverless vehicle - Users can only imagine what they will feel like and how they will react 	<ul style="list-style-type: none"> - All components will be experienced and identified and users will know what to expect
Consider all components involved	<ul style="list-style-type: none"> - General negative thoughts about safety, ethics, trust, sense of control, stress etc. 	<ul style="list-style-type: none"> - New components they did not think of will appear once they have experienced travelling in a driverless vehicle - Users should feel relaxed and safe
Take control action to ensure all components are considered	<ul style="list-style-type: none"> - Limited opportunities to travel in a driverless vehicle - Some companies are allowing public testing and experiences 	<ul style="list-style-type: none"> - Experience of travelling in driverless vehicles will ensure all components have been covered - Most users would have travelled in a driverless vehicle hence, know how it feels like
Monitor the consideration of all components involved	<ul style="list-style-type: none"> - Not Available 	<ul style="list-style-type: none"> - Monitor how the users themselves feel whilst in the driverless vehicle
Assess whether passenger experience is fulfilled	<ul style="list-style-type: none"> - Cannot assess this until driverless vehicles have been deployed 	<ul style="list-style-type: none"> - All user journeys will be safe and stress free - Users define a fulfilled experience themselves
Decide how to assess the achievement of fulfilling passenger experience in meeting the passenger's requirements	<ul style="list-style-type: none"> - Assess on the basis of personal important components 	<ul style="list-style-type: none"> - Users will assess their own experience by successful journeys and components they think are most important
Define passenger requirements	<ul style="list-style-type: none"> - User defines what they want from driverless vehicles via market research surveys etc. also their own personal requirements 	<ul style="list-style-type: none"> - User experiences the desired vehicle, accessories and journey - Users have the choice to travel in many different driverless vehicles
Take control action to ensure passenger experience is fulfilled to the passenger's satisfaction	<ul style="list-style-type: none"> - N/A 	<ul style="list-style-type: none"> - Users requirements are met by vehicle manufacturers - Manufacturers will find it difficult to gain consumer

		requirements as component thoughts are internal - User will have the ability to choose from different vehicles, services that suit their needs
Determine the safety regulation constraints	- No regulations are yet in place	- Manual provides safety information alongside practical driverless tests/tutorials - Manual back up controls - Common sense with experience of using manual vehicles
Assess the impact of each safety regulation	- N/A	- Constraints do not affect the experience of the journey e.g. time to location, relaxation
Decide how to react	- N/A	- Users decide whether they want a DV or to travel in one
Notify each controller	- N/A	- Users will discuss with others - Users will contact relevant professional body
Assemble safety regulation constraint information	- Limited information as regulations are predicted by 2021	- Provided in manuals and online documentation - Users will undergo tests and practical tutorials of how to use the vehicle prior to usage
Monitor conformance to safety regulations	- No safety regulations are in place for driverless vehicles	- Vehicle reaches the users desired destination with no issues -Users use the vehicle in a sensible manner – do not abuse the driverless features
Take control action to ensure conformance	- N/A	- User must undertake a practical test to ensure they know how to use the vehicle safely
Take control action to achieve passenger expectations	- Users define what they want from a driverless vehicle	- Users have the ability to customise their own vehicle or choose from a wide range of vehicles with different features/accessories
Determine vehicle owner's performance expectations	- Get to the destination safely	- Get to the destination safely with the use of customised cabins e.g. work desks or a relaxation area

Determine performance measures	- Not Available due to personal beliefs and thoughts	- The vehicle performs to the satisfaction of all users' needs which is different to each person
monitor system performance	- N/A	- Overall satisfaction is achieved - Users chooses appropriate vehicle, form of transport or service

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