Will Autonomous Vehicles Prevent Fatal Motorcycle Accidents?

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ABSTRACT

Aims: This study investigates the potential effectiveness of the safety systems proposed for autonomous vehicles in the mitigation and prevention of fatal motorcycle accidents. Previous research has indicated that over 90% of crashes are the caused or contributed to by human error and some studies propose that autonomous vehicles will reduce the number of crashes by reducing the occurrence of human error.

Methods: A range of qualitative methods were used in this study to analyse the suspected performance of each autonomous vehicle in each of 4 accident scenarios. A structured approach was applied to an initial analysis to highlight the mitigation effect of autonomous vehicle features and also to identify gaps in the technology.

Results: It was found that in all scenarios, many of the influencing factors could be at least mitigated if not prevented by the technologies proposed. Autonomous vehicles provide an opportunity to mitigate the consequences of motorcycle collisions with cars, due to their technologies that detect and respond to hazards regardless of conditions and all around the vehicle, therefore eliminating blind spots. However, there are many questions that require further research to enable an automated vehicle to prevent motorcycle crashes in their entirety.

Keywords: Powered Two-Wheelers, Fatal Collisions, Autonomous Vehicles, Technology

1. INTRODUCTION

Currently, more than 90% of crashes are caused or contributed to by human error (Singh, 2015). Connected and Autonomous Vehicles (CAVs) have the potential to significantly contribute to traffic safety by eliminating some of the mistakes routinely made by human drivers (Fagnant and Kockelman, 2015). Powered Two-Wheelers (PTWs) are among the most Vulnerable Road Users, along with cyclists and pedestrians (WHO, 2009). Each year, PTW riders account for more than 15% of the people killed on the roads in Europe. PTWs lack safety protective equipment and subsequently there is an increasing number of individuals severely or fatality injured (Vanlaar et al, 2016).

Currently, interaction between passenger cars and other road users including PTWs is possible due to human's ability to interpret scenarios and make the right decision based on a range of cues. Additional interactions between vehicles, including hand gestures, horns, sirens, are additional forms of communication that assist with safe navigation, but are inherently absent in CAVs (The Conversation, 2018). This interaction is a key issue for the development of CAVs. Accident analysis by Clarke et al (2004) identified that many motorcycle accidents are due to right-of-way violations by other motorists, such as a vehicle pulling out at a junction into the path of a PTW. Typically, car drivers involved in these accidents reported they had looked before pulling out but failed to see the oncoming motorcycle, which is classified as a 'Looked but Failed to See' (LBFTS) error. Clarke et al (2004) calculated that if LBFTS errors were eliminated it would result in a fall of just over 25% of the total PTW accident rate.

This study evaluates the potential effectiveness of the proposed configurations of sensors, radars and cameras in CAVs within the context of preventing or mitigating the severity of fatal PTW crashes. The scope is limited to three autonomous vehicles and four crash case studies. It was not possible to consider all types of CAVs in this study, but the chosen approach allows for a more detailed analysis to be drawn and enables focus to remain on the differences between the case study scenarios. The chosen vehicles were Google Waymo, Tesla, and General Motors (GM) Cruise Autonomous Vehicle.

The following assumptions are relevant to the application of autonomous vehicles to the case studies. It was assumed that:

- Each of the safety systems are fully functional and in working order in each scenario.
- The safety systems are programmed to detect PTWs as well as other vehicles.

In order to meet the aims of the study the predicted actions of each of the three CAVs will individually be 'applied' to each crash scenario. The analysis will follow a structured approach which will be replicated in each scenario to allow for comparisons to be made.

2. METHODOLOGY

In order to conduct this analysis, it was necessary to examine Police fatal collision investigation reports. The reports include detailed information about the location of the collision, vehicles involved, witness statements and contributory factors. A sample of 29 reports on fatal collisions involving a PTW and a motorised vehicle(s) were initially reviewed. Four of the case studies were selected for further analysis whilst other potential case studies were excluded for the following reasons: (1) the collision involved contact with motorised vehicles other than cars, (2) there was no other vehicle involved other than the PTW, (3) the PTW involved was a scooter or moped, and (4) the collision involved a pedestrian fatality.

The second part of the analysis involved hypothetically substituting the car involved in the collision with each autonomous vehicle in turn. Three autonomous vehicles (Google Waymo, Tesla and General Motors) were chosen for the analysis. These three were chosen in particular as they have more information about their capabilities publicly available. The technology utilised by each vehicle, as advertised by the manufacturers is a shown in Appendix 1. The scenario was simulated using sketches and visual representations, with a step-by-step approach to the sequence of events for each accident. A set of key questions were developed in order to standardise the application of the autonomous vehicles to each crash scenario. The key questions are outlined below:

- Which sensors and cameras are likely to be active in this scenario?
- Is the coverage (area and distance) of the sensors and cameras adequate to detect the hazard? Are there any blind spots or obstructions?
- What are the causal factors in this scenario? Could the autonomous vehicle perform adequately considering these conditions?
- What are the likely actions of the car in response to the hazard? Would this be appropriate in this scenario?

All three autonomous vehicles were substituted into each of the four case study scenarios. The perceived performance of each vehicle in each scenario, based on published information, was compared to enable an understanding of its anticipated functioning within specified scenarios.

3. RESULTS AND DISCUSSION

2.1 Accident case study 1

Accident case study 1 took place at a junction on a dual carriageway road. The PTW was travelling northbound when the car, travelling southbound, used a slip road to commence a right turn across the path of the PTW in order to exit the dual carriageway.

The motorbike collided with the nearside front door of the car at a speed between 97mph-103mph. In this situation, the major contributing factor in the collision was identified as the speed of the motorcycle, which would have been able to stop 30 metres before the junction had it been travelling at the speed limit when the car commenced turning, thus preventing the crash. As a result, the potential reaction time and response actions of the autonomous vehicles must be considered in the analysis.

2.1.1 Google Waymo

In the first scenario, the point of collision is the front nearside of the vehicle. On the Waymo, the front left bumper is fitted with LiDAR and radar systems, which enable the vehicle to identify objects in the surrounding environment and their movement. One of the key considerations is whether the Google Waymo is able to react to the motorbike at a sufficient speed to prevent the collision or at least mitigate the consequences. The positioning of the LiDAR sensor, located near the front left wheel of the vehicle, has a potential range of 300m, which, considering the speed of the motorbike, provides the car with 7 seconds to make a decision. The likely action of the vehicle would be to apply the brakes, therefore preventing it from travelling into the motorbike's path and preventing the accident occurring. The Waymo has the capability to integrate up to 1GB of data from its remote sensing systems per second (Whitman, 2014), enabling it to quickly build an interpretable map of its surroundings.

2.1.2 Tesla

The Tesla autonomous vehicle technology includes forward looking side cameras with a maximum range of 80m and a wide forward camera with a maximum range of 60m (see Figure 1). The effectiveness of cameras installed in this position is a key consideration and an important comparison with the sensors located in the same place in the Google Waymo configuration. In this scenario, on the car's approach to the junction, the cameras on the left side of the front bumper are obstructed by the crash barrier along the central reservation. Figure 1 illustrates the potential 'blind-spot' (highlighted in yellow) caused by this obstruction and shows the area that passing traffic would need to be in to be detected by the cameras (shown in red).

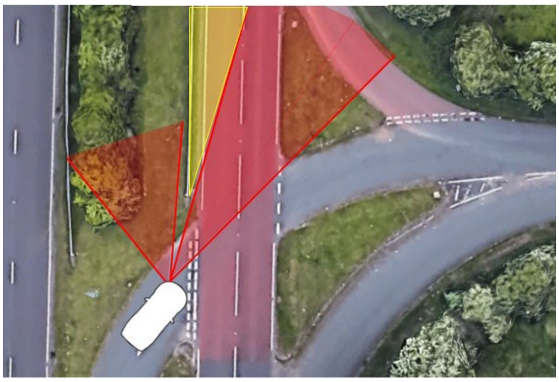

Figure 1 - Camera coverage from vehicle approach position

The result of the blind spot is a reduced area of detection in which the car will identify the motorbike. As a result of this area being considerably smaller, the time window for the vehicle to respond to the hazard is considerably shorter.

General Motors

On the front left-hand bumper of the GM autonomous vehicle is a combination of short and long-range radars. Due to the angle of the slip road that the car travelled along it is likely that both types of radar would be active in this scenario. GM do not disclose the range of their sensors; however, in their Self-Driving Safety report (2018) a brief statement of their functionality is included. This states that the long-range radars 'detect vehicles and measure velocity', whilst the short-range radars 'detect objects around the vehicle'. Based on these statements and the positioning of the vehicle, it is likely that the long-range radars would detect the motorbike and register the speed at which it is travelling. This suggests that the GM autonomous vehicle would likely be able to detect the motorbike and respond sufficiently to avoid crossing its path, therefore preventing the collision.

2.1.3 Summary

This analysis has indicated that the crash prevention and safety features on the Google Waymo and GM autonomous vehicles would be sufficient to mitigate the outcome of the collision if not prevent it completely. In comparison, the position of the cameras and sensors on the Tesla have a larger detection distance than the radar, which could result in a delay of the vehicle's response to the oncoming hazard.

2.2 Accident case study 2

Accident case study 2 took place on a single carriageway road running through a small town. The specific location was opposite a petrol station, which was the intended destination of the car involved. The car commenced a right turn across the path of the PTW travelling in the opposite direction.

As the car turned to enter the petrol station it entered the path of the oncoming motorbike, which was forced to react. There was no contact between the car and motorcycle, instead the braking of the motorbike, following the car's manoeuvre, resulted in separation between rider and bike and subsequently the rider collided with the front end of the car. The police report suggested that a possible contributing factor was the visibility of the motorbike in front of other oncoming traffic that was following it, as the accident occurred after 11 o'clock in the evening. Both vehicles had their headlights on and it is possible the PTW headlight was confused with the car behind it. This raises questions in terms of the detection capabilities of autonomous vehicles, particularly where there is obscurity in the image.

2.2.1 Google Waymo

In this scenario, the impact with the car was not a primary incident as it occurred following the separation of the motorcyclist from the bike. The point of contact between the rider and the car was the front right bumper, which is the position of LiDAR sensor and the radar system. It is feasible that the vehicle would have been able to detect the oncoming motorbike, however the ability for these systems to detect objects in front of other objects in low light conditions is unknown. Speed was also a key factor in this collision and so the car's ability to respond quickly to an oncoming hazard is important. The Google Waymo can quickly build an interpretable map of its surroundings (Whitman, 2014). The Google Waymo Safety Report (2017) states that the vehicle is fitted with back-up collision detection and avoidance systems, which are largely redundant but will slow or stop the vehicle if the primary system does not detect or act in response to a hazard. In this scenario, once the rider has separated from the motorcycle, it is likely that the Google Waymo would detect the oncoming hazard and bring the car to a stop. The accident report does not indicate whether the car was moving when the collision occurred, therefore had the vehicle been stationary, the systems of the Waymo would not have provided any mitigation. The lack of movement would mitigate the effects of the crash, as it reduces the force of the collision between car and rider. However, the ability for the autonomous vehicle to move out of the path of the rider might be more efficient in reducing the consequences of this accident, as it removes the collision altogether.

2.2.2 Tesla

In Tesla's configuration of sensors and cameras, those at the front of the vehicle have a larger distance range than those at the back. Therefore, in this situation they would be able to detect the motorbike, even though the cameras may have illusion issues with vehicles behind. The report states it was possible that the rider of the motorbike panicked in response to the movement of the car across into its path. It is suggested that with the detection systems proposed, the Tesla would have had sufficient time to both detect the motorcycle and refrain from committing to the manoeuvre. This lack of movement would prevent the reaction of the rider and subsequently reduce the likelihood of the loss of control. However, whilst this may reduce the likelihood of the collision, it cannot compensate for the speed of the motorbike which was identified as a key contributing factor.

2.2.3 General Motors

The front of the GM autonomous vehicles is mainly comprised of short and long-range radars, with a centrally positioned articulating radar which covers a long range and wide field of view. There is currently no information to suggest how the detection systems on the GM autonomous vehicle would perform in a situation where there is visual obscurity and low light conditions. However, the combination of long- and short-range radars on the front of the vehicle may provide an effective method for mapping vehicles from different distances, thus detecting the motorbike despite the visual complications.

2.2.4 Summary

The application of each autonomous vehicle in this analysis has highlighted the potential problem of visibility and the sensors' and cameras' ability to distinguish between objects, both stationary and moving. The Google Waymo and GM autonomous vehicle configurations both include radars and sensors at the front of the vehicle which are likely to be less influenced by the visual complication of the position of the motorbike in relation to the vehicle behind. Comparatively the Tesla configuration includes a camera at the front, which has a longer range than the accompanying radars. Therefore, the visual conspicuity may be an issue for mapping the surroundings until the oncoming vehicles enter the range of the radar, which does not rely on visual information. This would reduce the amount of time the vehicle has to react to the hazard and, considering the speed of the motorbike in this scenario, the reaction time is a critical element. In this scenario the motorbike rider sounded the horn in response to the movement of the car across the carriageway. If the sensors, radars and cameras on any of the three autonomous vehicles fail to identify the motorbike, only the GM has an auditory detection system which can act as a backup system to identify and respond to warning sounds or sirens.

2.3 Accident case study 3

Accident case study 3 occurred in slow moving traffic on an inner-city 3-lane road on the approach to a large roundabout. Both vehicles were travelling in the same direction, with the PTW weaving quickly between lanes to move through the congested traffic. The car commenced a manoeuvre to the right to change lanes, failing to notice the PTW advancing behind, resulting in the collision.

This scenario differs from the previous two as speed is not a key factor, though the rider was travelling at least at the 40mph road limit despite the heavy traffic. The analysis of this case study focuses on the ability of the CAV to detect moving vehicles in its surroundings with a potential contributory factor to this accident being the position of the motorbike in a 'blind spot'. The unpredictable riding nature of the motorcyclist was identified as another factor, so the analysis needs to consider the vehicle's ability to react to unpredictable road positioning by other road users. Given the close proximity of the vehicles prior to the collision the range of the sensors and cameras do not need to be considered but the position on the vehicle and coverage are particularly important.

2.3.1 Google Waymo

In this scenario the Google Waymo's 360-degree vision system would be highly active, as it works to detect the surrounding vehicles. This visual system would likely detect the motorbike, thus resolving the issue of the blind spot. However, the motorbike's irregular movements could be difficult for the system to interpret and predict its next move, which would not provide the vehicle with an adequate basis for its crash preventative action.

2.3.2 Tesla

Considering the road in this scenario runs straight for approximately half a mile, it is possible that the Tesla vehicle could be using Autopilot. The proposed enhanced Autopilot is predicted to enable the vehicles to match speed to traffic conditions, keep within lane and change lanes without requiring driver input (Tesla, 2018). These features, in theory, would enable the vehicle to safely navigate through the approach to the roundabout. In this scenario it is likely that the sensors and cameras on the Tesla would have been able to detect the movement of the motorbike, despite its irrational manoeuvres. However, the issue of the blind spot, which was identified as a possible factor in the crash, could still be an issue when control is handed over to the occupant as a result of the inability for the vehicle to operate safely. Another potential problem lies with the length of the hand-over. Studies suggest that it takes 2-3 seconds to takeover manual controls and resume driving after short periods of autonomous driving within urban environments. However, in this scenario, the 2-3 seconds of handover does not account for the time required for the occupant to have good situation awareness to assess their surroundings, identify and understand the hazard and then react appropriately.

2.3.3 General Motors

The self-driving safety report for the GM vehicles states that 'sensor diversity provides confidence that the system can detect, track and classify objects around it'. This suggests that the vehicle would be able to identify the motorcycle and its movements. The irregular movements could be identified as hazardous as they do not 'fit' with the system's preconceptions. In this situation the movements were proved to be hazardous, although reckless manoeuvres do not always result in a collision. How the vehicle deals with decision making in relation to unpredictable movements will need to be defined.

2.3.4 Summary

The analysis for all three autonomous vehicles in this scenario has raised the question of whether the systems are able to cope with the irregular movements of the motorcycle, which was identified as the key contributing factor by the investigation report. The analysis suggests that all three vehicles have the capabilities to detect and follow the movements of the bike through blind spots experienced by the driver of the car. However, their proposed ability to respond varies. The Google Waymo was identified as the vehicle most likely to have sufficient technologies to, as a minimum, mitigate the consequences of the collision, if not prevent it altogether.

2.4 Accident case study 4

Accident case study 4 occurred at the junction of a dual carriageway with an adjacent side road. The junction was signalised, with the lights being green for both vehicles. The car commenced a right turn into the side road across the path of the PTW which was travelling in the opposite direction.

The motorbike approached the junction travelling at the national speed limit speed therefore speed was not a key contributory factor in this scenario. The PTW should have been granted priority by virtue of the road layout, however investigation suggested that the driver of the car failed to comprehend that oncoming traffic was also subject to a green light at the same time as they were, instead assuming their green light was permission to turn. When approaching the junction, the driver of the car would have a view extending approximately 150m. The main contributing factor in this collision was identified as a failure by the driver of the car to allow the motorbike right of way and the key question here is whether autonomous vehicles will have the capability to understand the traffic signals combined with the road layout in this scenario.

2.4.1 Google Waymo

The Google Waymo has LiDAR and radar systems on the front of the vehicle, which have an adequate range to detect the bike up to 300m prior to the junction. Considerably further than the view distance of the driver in this position. The LiDAR is highly likely to be able to detect the motorbike from a greater distance that the driver of the car, which lengthens the period of time for decision making in relation to manoeuvres across the junction. The vision camera, positioned on the roof of the vehicle has the capability to detect colour and therefore identify traffic lights, congestion zones and warning lights. This suggests that the vehicle will be able to identify when the lights present a green signal. The safety report also explains that a process called ‘fuzzing’, the speed of oncoming vehicles is assessed, enabling the autonomous car to adequately identify a safe gap in the traffic. This information suggests the Google Waymo will have adequate technologies to navigate the junction without obstructing the path of the motorcycle, therefore preventing the collision.

2.4.2 Tesla

The Electrek report (2017), explains that the trifocal front facing camera system, when grouped with the second-generation Autopilot, is capable of reading road signs and traffic lights. However, the accuracy of this is unknown and only obtained following software updates as the current version of Enhanced Autopilot is intended for use on highways and in congestion, not at junctions. It is not possible to draw a conclusion on whether the Tesla would correctly identify and respond to the traffic signals presented at the junction. Based on the range of the forward-facing camera (250m), it is reasonable to suggest that the car would be capable of detecting oncoming traffic, including the motorbike, and identifying an adequate gap in which to cross the carriageway.

2.4.3 General Motors

Cameras located centrally above the windscreen have the ability to detect pedestrians and traffic lights. The GM Self Driving Safety Report (2018) states that the vehicle’s computers include planning, which ‘determines the desired vehicle behaviour’. It also explains that ‘planning is based upon vehicle location, other road users’ predicted actions, traffic controls, road marking, rules of the road and other external factors’. These statements indicate that the systems have been designed with the capability to detect and respond to traffic lights and plan behaviours based on the rules of the road, including the right of way. Therefore, in this scenario, it is likely that the GM autonomous vehicle would be capable of correctly negotiating the junction, without obstructing the path of the motorbike, preventing the collision.

2.4.4 Summary

The analysis of this scenario has highlighted the requirement for autonomous systems to not only have the ability to identify and adequately act to traffic signals and road markings, but also to incorporate aspects of the Highway Code (gov.uk., 2018) into the decision making. The Google Waymo and GM autonomous vehicle are considered to have the capability to comprehensively assess the green signal, whilst also understanding that it is not 'their' right of way and subsequently preventing or at least mitigating the consequences of the collision. The Tesla systems are predicted to be capable of detecting the oncoming traffic and a safe gap to pass, however the interpretation of the rules of the road is not adequately defined for a conclusion to be drawn on this aspect of this analysis.

4. CONCLUSIONS

This study analysed four fatal collisions involving a PTW and at least one car in the UK, and identified the following common causes:

- Environment (daylight conditions, other traffic)
- Speed of motorbike
- Motorbike conspicuity

The anticipated effectiveness of the cameras and sensors in the examined AVs in mitigating these factors varied as some cannot be mitigated directly. Several preventative barriers are in place within the road environment, such as speed limits and 'SLOW' road markings, however the hypothetical inclusion of an autonomous vehicle results in some of these becoming redundant. Autonomous vehicles rely more heavily on technologies including radar, LiDAR and camera systems to navigate through the road system safely and detect hazards. The Google Waymo could be considered the most consistent vehicle, with the ability to identify hazards at long range, continuously map surroundings, with behaviour prediction technology making it likely to be capable of at least mitigating each of the crash scenarios studied. In contrast, the Tesla was felt to have unanswered questions surrounding its effectiveness and reliability in these crash scenarios. The General Motors autonomous vehicle was found to have features capable of mitigating the crashes, however more information relating to performance and sensor range is required to fully conclude the effectiveness in each scenario. For all autonomous vehicles to be capable of handling a range of scenarios with a variety of different road users and pedestrians a consistency in the guidelines surrounding the design of autonomous vehicles is required. This is the only way to ensure that all autonomous vehicles have an acceptable level of safety.

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Appendix 1

Autonomous vehicles used in study

Three autonomous vehicles (Google Waymo, Tesla and General Motors) were chosen for this analysis.

The selection was based on the accessibility of information surrounding the configuration and functionality of the sensors and cameras on the vehicle as, for many companies, information surrounding such details are confidential due to the ongoing research and development.

Vehicle	**BMW**	**Mercedes Benz**	**Nissan**	**Google**	**Tesla**	**General Motors**
Key Technologies	Video camera tracks lane markings and reads road signs Radar sensors detect objects ahead Side laser scanners Ultrasonic sensors Differential GPS Very accurate map	Stereo camera sees objects in 3-D ahead Additional cameras read road signs and detect traffic lights Short and long range radar Infrared camera Ultrasonic sensors	Front and side radar Camera Front, rear and side laser scanners Four wide-angle cameras show the driver the car's surroundings	LiDAR on the roof detects objects around the car in 3-D Camera helps detect objects Front and side radar Intertial measuring unit tracks position Wheel encoder tracks movement Very accurate map	8 surround cameras for 360 degree view and 250m range Ultrasonic sensors Front, side and rear facing cameras Radar Enhanced autopilot	Several laser sensors Radar Differential GPS Cameras Very accurate map

Figure 2 - Expected specification of autonomous vehicles by 2020, based on material from Knight (2013)

2.4.5 Google Waymo

Google's self-driving car 'Waymo', has been fitted with 'sensors and software that are designed to detect pedestrians, cyclists, vehicles, road work and more from up to three football fields away in all 360 degrees' (Waymo, 2015).

The Waymo vehicle has a total of four different sensor systems (shown in Figure 2 and outlined in Table 1), which work together to create a 3D image of the surrounding environment.

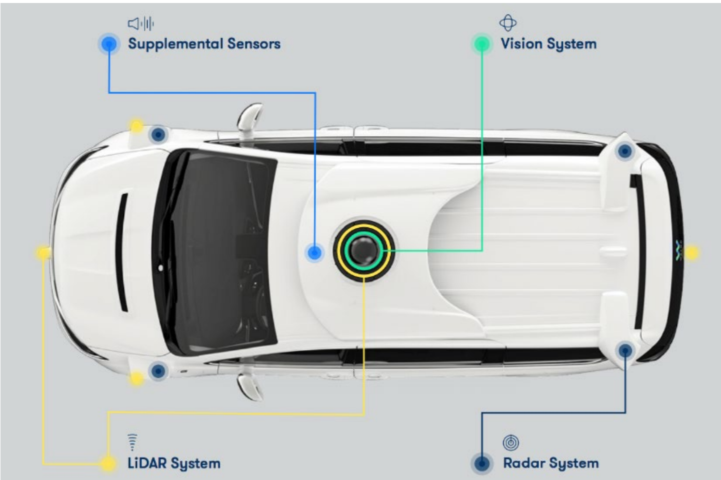

Figure 3 - Diagram showing the locations of the four different sensor types on a Waymo self-driving car (Google, 2017)

Table 1 - Details about each sensory on the Google Waymo

Sensor Type	Details
LiDAR (Light Detection and Ranging) System	Beams laser pulses and measures length of time for them to reflect off surfaces and return. Types: • Short-range – directly around vehicle • High resolution mid-range • Long range – up to three football fields (300m) distance
Vision (camera) System	High resolution camera that views 360 degrees at a time. In-built colour detection to identify features including traffic lights, school buses and lights on emergency vehicles.
Radar System	Uses wavelengths to perceive objects and movements. 360-degree view, enabling tracking of other roads users surrounding the car.
Supplemental Sensors	Including audio detection system for emergency sirens and General Positioning System (GPS).

2.4.6 Tesla

Tesla's approach is to install self-driving hardware in all of their vehicles allowing users to engage and disengage it at their discretion. Each vehicle is fitted with eight surround cameras for a 360-degree view, with a 250m range. These are accompanied by twelve ultrasonic sensors that enable the vehicle to detect surrounding objects and a forward-facing radar with enhanced processing power enabling detection through a range of weather conditions. Figure 3 shows the range of coverage by each of the cameras and sensors installed on a Tesla vehicle.

Figure 4 - Sensor coverage arcs of Tesla's autonomous systems (Tesla, 2018)

Tesla vehicles are also fitted with an Enhanced Autopilot software which maintains speed in relation to changing traffic conditions, maintains road position and changes lanes as required.

The sensors and cameras are also supported by four key pieces of safety technology: Automatic Emergency Braking (AEB), Forward Collision Warning (FCW), Side Collision Warning (SCW) and Auto High Beams.

These technologies work in conjunction with the sensors and cameras to detect surrounding objects, warn the driver of collision hazards and apply the brakes where required.

2.4.7 General motors cruise autonomous vehicle

In their design of the Cruise Autonomous Vehicle, GM have combined a series of technologies and systems to enable the vehicle to ‘perform the functions necessary to understand the world around the vehicle and make the driving decision that safely transport passengers’ (General Motors, 2018). The GM autonomous vehicle’s capabilities centre around a web of sub-systems that work together to understand the surrounding environment and inform driving decisions in a vehicle with level 5 automation (as shown in Figure 4).

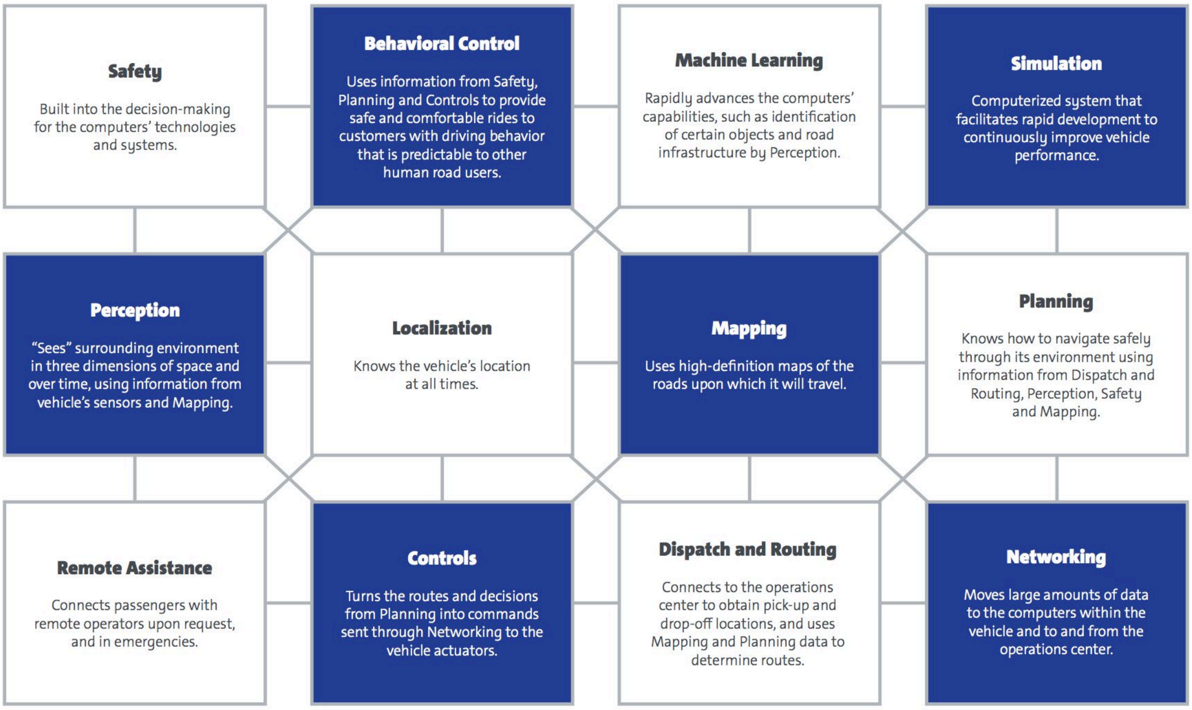

Figure 5 - Web of sub-systems in General Motor's autonomous vehicle General Motors, 2018)

The GM autonomous vehicle has a total of five LiDARs, 16 cameras and 21 radars that enable the vehicle’s perception (configuration is shown in Figure 5).

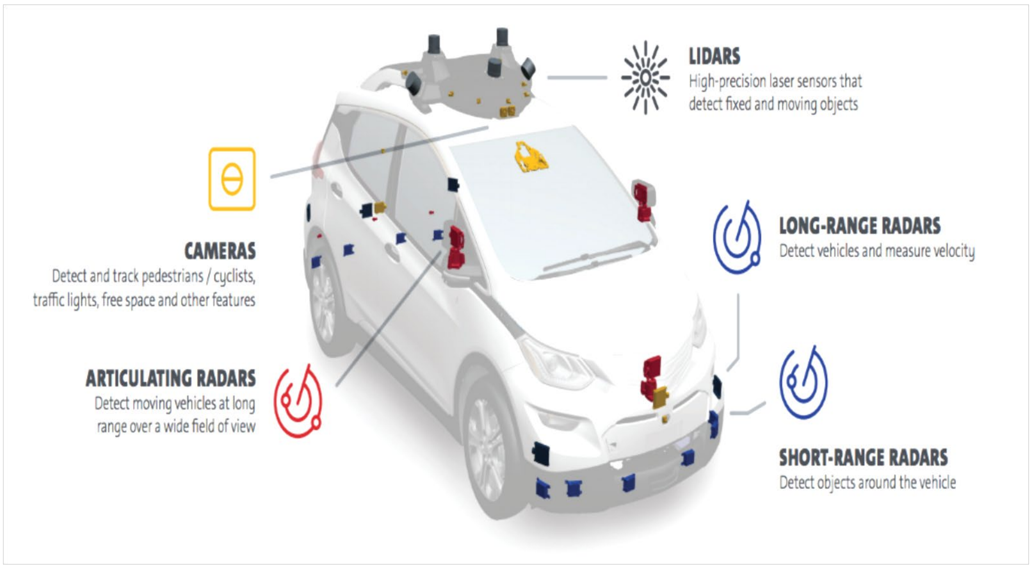

Figure 6 - GM autonomous vehicle sensor configuration (General Motors, 2018)