Driver Perception-Reaction Times in Level 3 Automated Vehicles

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Doctor of Philosophy

August 2019

EU funds for Malta 2014 2020

The research work disclosed in this publication is partially funded by the
Endeavour Scholarship Scheme (Malta). Scholarships are part-financed
by the European Union - European Social Fund (ESF) -
Operational Programme II – Cohesion Policy 2014-2020
"Investing in human capital to create more opportunities and promote the well-being of society".

European Union – European Structural and Investment Funds
Operational Programme II – Cohesion Policy 2014-2020
*"Investing in human capital to create more opportunities
and promote the well-being of society"*
Scholarships are part-financed by the European Union -
European Social Funds (ESF)
Co-financing rate: 80% EU Funds;20% National Funds

Acknowledgements

I would like to thank my supervisor, Professor George Yannis, for his dedication, patience, guidance and advice throughout this research. I would also like to thank my co-supervisor, Doctor Odette Lewis, for her invaluable guidance and encouragement throughout this process. I extend my great appreciation to Professor Liberato Camilleri and the Transport Research Team at the University of Athens for their help, guidance and support in all the statistical modeling techniques required for this research. It was a pleasure to work on this research project with such excellent professionals. I would like to express my sincerest appreciation to Engineer Fredrick Azzopardi who supported my studies with patience and understanding at my place of work.

Special thanks go to the love of my life, my daughter Francesca, and words cannot express how grateful I am for her unconditional love and support. I would not have been able to achieve this without her. Last but not least, to my loving mother who always believed in me and who ingrained her stamina in me to always move forward against all odds.

I take full responsibility for any shortcomings in this dissertation.

Abstract

In Level 3 automated vehicles the driver is allowed to engage in secondary tasks however the driver must be ready to re-engage in the driving mode if alerted to do so when roadside circumstances exceed the capacity of the automated vehicle technology. The scope of the research was to establish the Perception-Reaction Time (PRT) of drivers in a simulated Level 3 vehicle and to examine the interdependency between the person-specific characteristics in relation to different scenarios featuring different in-vehicle distractions and different type of alerts and subsequently to compare these values with those of standard specifications used in road design in different countries for the calculation of Stopping Sight Distances (SSD). Such PRT is important because the driver needs to be alerted in a timely manner, translated to sufficiently long approach distance in advance of a critical situation, to allow for the safe handover from automated to manual vehicle control when the roadside scenarios are beyond the capacity of the vehicle automation or where there is an unexpected roadside scenario such as new traffic management arrangements of road works.

The data required for the scope of this research was collected through a web-based survey which included the collection of demographic information about the respondent in the first section and a driving simulation in a Level 3 automated vehicle in the second part. The PRT of the driver was taken from the moment of the alert to the moment that the participant reacted by clicking on an on-screen box.

The results of this research document gave an average perception-reaction time of 4.23 seconds based on the 85th Percentile values of the datasets and showed that the younger age groups have lower PRTs for all scenarios than their older counterparts both for different alerts (and same secondary task) and for same alerts (but different secondary task). The results also showed that the multisensory alert advantage over the visual alert is effective only up to the point determined by the demand on the cognitive resources of the participant where, in this research, such point was reached when the secondary distraction was reading and typing of a text message.

Summary

In Level 3 automated vehicles the driver is allowed to engage in secondary tasks however the driver must be ready to re-engage in the driving mode if alerted to do so when such intervention is required due to the roadside circumstances. The scope of the research was to establish the Perception-Reaction Time (PRT) of drivers in a simulated Level 3 vehicle and to examine the interdependency between the person-specific characteristics in relation to different in-vehicle distractions, namely reading and writing a text message and watching a music video or film, and different type of alerts, namely a visual alert and also a combined visual and auditory alert, and subsequently compare these values with those of standard specifications used in road design in different countries for the calculation of Stopping Sight Distances (SSD).

The importance of this research is that, with the introduction of Level 3 automated vehicles, the driver needs to be alerted in a timely manner to allow for the safe handover from automated to manual vehicle control when the roadside scenarios are beyond the capacity of the vehicle automation.

The data required for the scope of this research was collected through a web-based survey which included the collection of demographic information about the respondent in the first section. The second section involved a driving simulation in a Level 3 automated vehicle with in-vehicle secondary tasks with different in-vehicle alert systems which the participant was required to react to. The PRT of the driver was taken from the moment of the alert to the moment that the participant reacted by clicking on an on-screen box.

The demographic results obtained from the survey showed that there was no significant gender difference in the perception-reaction time, the perception-reaction time increased with age and years of driving experience except for the P7 scenario except when the secondary task was reading and writing an sms and there was no significant difference in the perception-reaction time between the disabled and non-disabled groups of participants.

The PRT results obtained from the demographic data of the survey show that:

1. For the scenarios without a secondary task as a distraction and where the distraction was watching a video, the multi-sensory alert gave lower perception-reaction times;
2. For the cases where the secondary distraction was reading and writing an sms, the multi-sensory alert had a longer perception-reaction time than for the visul alert. This factor can be explained through research carried out by Wickens& Hollands (2000), Hole (2007), Cooper et al (2011) and Shinar (2007) who reported that higher demands on the cognitive resources of the participants results in causing the perception-reaction performance to degrade thus resulting in higher perception-reaction times where reading and writing an sms poses higher demand on the cognitive resources than watching a video;
3. the audio-visual alert advantage over the visual alert is effective only up to the point determined by the demand on the cognitive resources of the participant where, in this research, such point was reached for the reading and typing of a text message distraction. This is similar for the results obtained in the Ordinal Regression Model. However such multisensory alert is necessary because drivers are 11 times more likely to miss a visual alert whilst texting (Cooper et al, 2011);
4. The result of this research document gave an average perception-reaction time of 4.23 seconds based on the 85th Percentile values of the datasets taken as an average of the two worst-case scenarios where the secondary task was texting, thus reading and writing an sms.

The results further showed that the PRT obtained for the predictors collectively (Gamma Regression Model) yielded that:

1. gender is not a significant predictor when the distraction is reading and typing an sms
2. multi-sensory alert reduce gender difference in relation to PRT

3. the Age and Driving Experience predictors complement each other, with either or the other results being a significant predictor in all scenarios. Similarly, age was found to be a significant predictor in the Cluster Analysis;
4. the younger age groups have lower PRTs for all scenarios than their older counterparts both for different alerts (and same secondary task) and for same alerts (but different secondary task). Similarly, for each scenario, the Cluster Analysis revealed that the 18-30 year age group is statistically significant and formed one or more clusters in each scenario. This is also reflected in the results obtained in the Ordinal Regression Model.

When the PRT and SSD results of this research were compared with the values established for Conference Europeenne des Directeurs des Routes (CEDR), American Association of State Highways and Transportation Officials (AASHTO), National Cooperative Highway Research Programme (NCHRP), Design Manual for Roads and Bridges (DMRB), Austroads and German Design Standards (RAA), the results were as follows:

1. The PRT value resulting from this research for Level 3 Automated Vehicles is 4.23 seconds which exceeds the 2 second value adopted by CEDR, DMRB, Austroads and RAA and the 2.5 second value adopted by AASHTO and recommended by NCHRP and confirms the validity and the importance of the results of this research document. Also, the greatest difference in SSD values are most prominent for speeds of and exceeding 80km/h, which speeds are the most critical as they are the SSD values which lie beyond the visual capabilities of the driver for detecting small objects during daytime and for detecting larger objects with low contrast at night-time (Fambro et al, 1997);
2. The SSD values established by this research document exceed the values in the existing standards and guidelines with the exception of the SSD value in DMRB for a design speed of 120km/h because a lower coefficient of friction was used in this research document according to the recommendation of CEDR for a common European direction.

Permanent and temporary unexpected or new roadside scenarios necessitate that the distance ahead of alerting the driver is to be programmed according to adequate PRTs required to ensure that the driver resumes the driving task in a timely manner and avoids a collision. The results of this research document are important in this respect because such PRT values exceed the values in established and existing standard specifications as described above. Also, the introduction of Connected and Automated Vehicles (CAD) on the road creates a different concept of traffic management and how Road Traffic Control Centres will need to operate to receive, process and transmit data to and from nearby automated vehicles. Such revolutionized system will have a number of challenges, the most critical of which will be the processing of large volumes of data, cyber security and alerting vehicle drivers in advance on the approach to a critical roadside scenario.

For these reasons, the results of this research will attract the attention of researchers and road safety professionals in the years to come as the deployment of such automated vehicles continues to become a reality.

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Glossary

Abbreviation	**Meaning**
μ	mean
σ	Standard Deviation
ɣ	Density of air (1.15kg/m^2)
$\bar{x}$	Sample mean
a	Driver deceleration (m/s^2)
A	Projected frontal area (m^2)
AASHTO	American Association of State Highways and Transportation Officials
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Automated Driver Assistance Systems
ADD	Attention Deficit Disorder
ADHD	Attention Deficit and Hyperactive Disorder
ADS	Automated Driving System
ANOVA	One-way Analysis of Variance
AV	Automated Vehicles
BMV	Bureau of Motor Vehicles
C_W	Aerodynamic drag coefficient
CAD	Connected and Automated Driving
CEDR	Conference Europeenne des Directeurs des Routes
CEO	Chief Executive Officer
CHADD	Children and Adults with Attention Deficit/Hyperactive Disorder
CIA	Central Intelligence Agency
CUTR	Centre for Urban Transportation Research
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
DMV	Department of Motor Vehicles
DSR	Driver Steering Recommendation
DVD:	Digital Video Disc
ERSO:	European Road Safety Observatory

ERTRAC:	European Road Transport Research Advisory Council
ESC:	Electronic Stability Control
euroFOT	European Field Operational Test
f	Coefficient of braking friction
F_L	Aerodynamic drag force (N)
FCW:	Forward Collision Warning
FIA	International Transport Forum
FCW	Front Collision Warning
g	Acceleration due to gravity (m/s^2)
GLM	Generalised Linear Models
GM	General Motors
GPS	Geo Positioning Systems
HAVEit	Highly Automated Vehicles for Intelligent Transport
HMSO	Her Majesty’s Stationery Office
IoT	Internet of Things
LCA	Lane Change Assist
LDW	Lane Departure Warning
LiDAR	Laser Illuminating Detection and Ranging
LKA	Lane Keeping Assist
m	Mass of vehicle (kg)
MR	Monitoring Request
NCHRP	National Cooperative Highway Research Programme
NHTSA	National Highway Traffic Safety Administration
NMVCCS	National Motor Vehicle Crash Causation Survey
NUCPS	Northwestern University Centre for Public Safety
OTA	Over The Air
PA	(Basic) Park Assist
PBRT	Perception Brake Reaction Time
PDA	Personal Digital Assistant
PDC	Parking Distance Control
RAA	Richlinien fur die Anlage von Autobahnen
RAT	Routine Activity Theory

RoSPA	Royal Society for the Prevention of Accidents
s	Sample Standard Deviation
SAE	Society of Automotive Engineers
SARTRE	Safe Road Trains for the Environment
SSD	Stopping Sight Distances
SPSS	Statistical Package for the Social Sciences
t	Driver Perception-Reaction Time (seconds)
TOR	Take Over Request
UNECE	United Nations Economic Commission for Europe
U.S./U.S.A.	United States of America
V	Speed at any point in the deceleration manoeuver (m/s^2)
V_0	Design Speed or Initial Speed (km/h)
V2I	Vehicle to Infrastructure Communication
V2V	Vehicle to Vehicle Communication
V2X	Vehicle to Everything Communication
WHO	World Health Organisation

For the purposes of the analysis, the different driving scenarios in the survey were denoted as follows:

P2: Driving scenario without secondary task and with visual alert

P3: Driving scenario without secondary task and with visual and auditory alert

P4: Driving scenario with secondary task of watching a video and with visual alert

P5: Driving scenario with secondary task of watching a video and with visual and auditory alert

P6: Driving scenario with secondary task of sending and reading sms messages and with visual alert

P7: Driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert

CHAPTER 1: INTRODUCTION AND SCOPE OF RESEARCH

1.1 Vehicle Automation

The primary objectives for traffic engineers, policy makers and planners in these last hundred years were to provide adequate infrastructure to meet the growth in demand for travel in relation to the number of trips and vehicle kilometers travelled (ITS International, Nov/Dec 2014). The benchmarks which determined and measured the transport performance of entire cities were underlining the economic need to transport passengers and goods, the efforts to improve road safety and the solutions to address traffic congestion in urban areas through the provision of additional infrastructure.

The construction and maintenance of the road infrastructure network is funded by the central government through revenues from vehicle licenses and fuel because both are government assets. The provision of an adequate transportation system is the result of the effort of local regulatory authorities, working within a highly regulated and standardized framework, which manage the highly sensitive social, economic and political implications tied to transport systems affecting the daily lives of commuters.

The demand for transport infrastructure will change in the coming future due to the introduction of automated vehicles as part of the latest development in motor vehicle technology (Maurer et al, 2016). The changes have probably not been fully understood and appreciated (ITS International, Nov/Dec 2014). The development of the technological features to support the operation of automated vehicles (AVs) will be a result of the technological competition and business development strategies of car manufacturers rather than due to policy development at governmental levels (ITS International, Nov/Dec 2014).

The development of AVs and technology presents fascinating opportunities. Driving will become easier, road safety will be improved, emissions will be reduced and congestions will be better managed (DfT, Feb 2015). Drivers will no longer act as an operator in the vehicle and thus will be able to occupy themselves in other activities rather than driving during their trip. AVs will also be a radical accessibility potential for those unable or unwilling to drive thus improving their quality of life (DfT, Feb 2015).

In the United Kingdom, the average vehicle driver spends six working weeks every year occupied in driving (DfT, Feb 2015). Increased driver assistance in modern vehicles has still not relieved the driver of his responsibilities as vehicle operator. Highly automated AVs will change the concept of the driver from that of a vehicle operator to a vehicle supervisor. Hence, for the first time since the invention of the motor vehicle, the driver will be able to choose whether to act as operator or supervisor (Kyriakidis et al., 2017).

Road safety statistics show that 94% of road fatalities and injuries involve human error (Center for Sustainable Systems, 2018). Such errors include alcohol/drug impairment, driver distraction, following too close, failure to properly look out for other vehicles or the road itself, ignoring traffic signals or signage and excessive speeds. These errors will not be made by AVs (DfT, Feb 2015). Hence by replacing the driver, the AVs will automatically also be removing the risks resulting from human decision making and driver distraction. Hence AVs will be potentially reducing traffic accidents by offering significant improvements in vehicle safety through technology.

AVs will be equipped with sensors to constantly be aware of their immediate environment. Automated technology which is being used in vehicles today has already shown significant benefits to road safety (Litman, 2019). Such automation includes automatic emergency braking, lane departure warning and electronic stability control.

AVs will potentially maximize the use of the existing road space thus reducing traffic congestions and improving the reliability of journey times through communication with the roadside environment and with other vehicles. This is made possible through connected vehicle technology (DfT, Feb 2015). Connected vehicles would be able to communicate with roadside infrastructure such as traffic light junctions and use such information to reduce fuel consumption and emissions (Litman, 2019). Also, connected vehicles will be in a position to communicate between the vehicles themselves and with the roadside to identify more efficient routes through improved journey planning.

The motor vehicle is the key to freedom of mobility and travel and many people take driving as a given case. However, many people in the community do not have a driving license or do not have access to a motor vehicle (DfT, Feb 2015). People with a disability might not be able to drive and, as a result of the acquired physical limitations, elderly people might no longer be considered fit to drive for safety reasons. Others may not wish to drive. With the development of AV technology, and the subsequent development of door-to-door car- and ride-sharing projects, the personal mobility of these classes of people would be greatly improved thus also improving their quality of life due to increased accessibility (Metz, 2018; Litman, 2019).

1.1.1 Types and Levels of Automation

The shift towards automated driving involves different technologies and systems, some of which are based on connectivity between vehicles and the roadside infrastructure whilst others are based on sensors. However both types need exact digital representations of the roadside environment (International Transport Forum, 2015; Van Nes & Duivenvoorden, 2017).

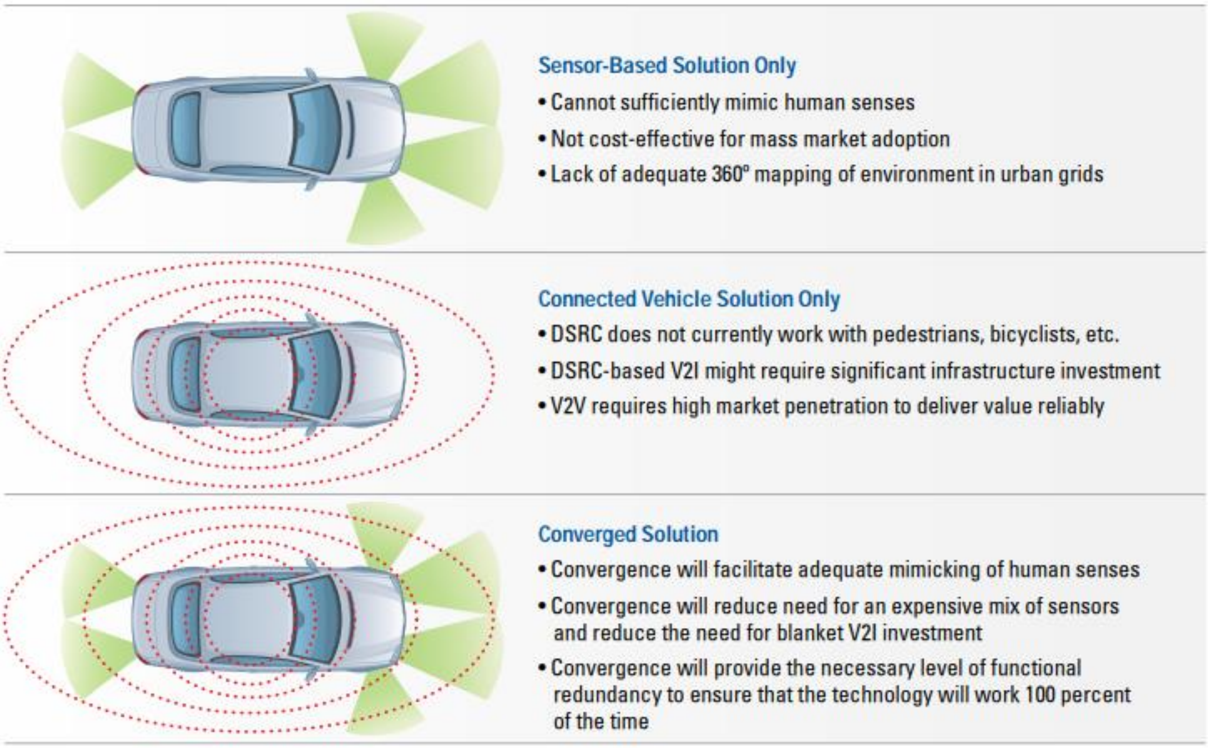
It is imperative that a distinction is made between connected and automated vehicles (Johnson, 2017) whereby Dft (2015) defines AVs as vehicles which are '*designed to be capable of safely completing journeys without the need for a driver in all normally encountered traffic, road and weather conditions*'. The driver is replaced by artificial intelligence which operates the AV using sensors and auxiliary devices to obtain information about the roadside scenario of the AV (Zmud et al, 2016). These devices subsequently relay this roadside information to the vehicle algorithms which provide driving control and decision-making. This replaces the need for the driver (Zmud et al, 2016). Hence, automated vehicles manage the driving task for, at least, some of the time during which dynamic driving occurs (Zmud et al, 2017).

Connected vehicles are conventional vehicles which have communication technology and are operated by a human driver. The technology gives information to the driver or the vehicle to enable them to connect with other road users and the road infrastructure (Winner et al, 2016; Eskandarian, 2012; Johnson, 2017; Zmud et al, 2016). The types of communication are V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure or vice-verse I2V) and V2D (vehicle-to-device or vice versa D2I) (Johnson, 2017). V2V communication enables crash preventions whilst V2I communication enables telecommunication, safety, mobility and environmental advantages (Zmud et al, 2017). V2X is vehicle-to-everything as in the Internet of Things (Zmud et al, 2017). The basis of data communication is extremely important in automated vehicles because it enables real-time warnings to the driver about imminent threats and roadside risks (Zmud et al, 2017).

A study was carried out by Schoettle (2017) and by Wolshon & Pande (2016) on the sensors of AVs and CVs and it was concluded that artificial intelligence can meet the demands of the driving task in relation to the calculation of speed, distance, power output and control resulting in a superior performance to that of humans. However, Schoettle (2017) also concluded that the aspect of rationality and perception of humans is difficult to replicate through technology. Hence Schoettle (2017) concluded that AVs which are fully connected with each other and with the roadside environment would provide the safest and most efficient performance on higher levels of automation and thus AV technology would assist the performance of both human drivers and AV drivers.

Connectivity is an essential factor in enabling the deployment of highly automated scenarios especially V2X connectivity (vehicle-to-X) which use wireless technologies in order to have real-time two-way communication between the vehicles themselves (V2V) and between the vehicles and the infrastructure (V2I) (Meyer & Beiker, 2018; International Transport Forum, 2015). There are many similarities between AVs and CVs as both involve collecting and exchanging information using V2X technology (SAE International, 2016; Zmud et al, 2017). Vehicle manufacturers of AVs develop AVs which are a combination of connected and automated technologies, known as Connected and Autonomous Vehicles (CAV) to ensure the highest possible level of safety and reliability of such vehicles (Meyer & Beiker, 2019; Johnson, 2017; Silberg et al., 2012). A systematic fusion of these technologies is necessary to adequately replace the human senses with ample operational equipment redundancies. This will reduce the required sensor and infrastructure adaptation costs as shown in Figure 1 (Silberg et al, 2012). Similarly to connected vehicles, adaptive cruise control, autonomous vehicle braking, collision warning systems and lane-keeping assistance are being adapted for integration in automated vehicles with the aim of cooperating with the driving algorithms instead of the human driver (Silberg et al., 2012). Connected and automated vehicles have similar impacts on necessary changes to infrastructural design (Johnson, 2017).

Figure 1: Benefits of systematic fusion for Automated Vehicles



Sensor-Based Solution Only

- Cannot sufficiently mimic human senses
- Not cost-effective for mass market adoption
- Lack of adequate 360° mapping of environment in urban grids

Connected Vehicle Solution Only

- DSRC does not currently work with pedestrians, bicyclists, etc.
- DSRC-based V2I might require significant infrastructure investment
- V2V requires high market penetration to deliver value reliably

Converged Solution

- Convergence will facilitate adequate mimicking of human senses
- Convergence will reduce need for an expensive mix of sensors and reduce the need for blanket V2I investment
- Convergence will provide the necessary level of functional redundancy to ensure that the technology will work 100 percent of the time

Source: Silberg et al, 2012

Car manufacturers are not waiting for the ‘smart highways’ of the future to launch Level 3 Conditional AVs and are moving ahead with the highway system available to them. In addition to baseline non-automated driving, five levels of vehicle automation have been established by the Society of Automotive Engineers (SAE) in Standard J3016, first issued in 2014 and updated in 2016 (SAE International, 2016). These levels are internationally recognized and as the level increases, the vehicles become more automated and less dependent on the human driver. However they would also require more supporting technology to operate (SAE International, 2016). The levels are descriptive and technical and do not reflect the order of market introduction and the features are the minimum capabilities for each level (SAE International, 2016). Warning and momentary intervention systems are not included because they do not provide automation to replace the driving task and thus they do not alter the role of the driver (SAE International, 2016). Such warning systems include V2V and V2I communication.

The levels of automation are as follows:

1. LEVEL 0: No Automation and the human driver operates the vehicle at all times despite having the assistance of warning or intervention systems(Meyer & Beiker, 2014; Finger & Audouin, 2019);
2. LEVEL 1: Driver Assistance through a system of either steering or acceleration/deceleration assistance (Deb et al, 2017);
3. LEVEL 2: Partial Automation through multiple driver-assistance systems where, at least, one driver assistance system of both steering and acceleration/deceleration is automated. The driver is disengaged from physically operating the vehicle but must be in a position to take control of the vehicle (On-Road Automated Vehicle Standards Committee, 2014);
4. LEVEL 3: Conditional Automation with specific performance by an automated driving system of all aspects of a driving task, including safety-critical functions, with the driver intervening instantaneously if necessary but is not required to monitor the roadside environment as for the previous levels (Finger & Audouin, 2019);
5. LEVEL 4: High Automation with performance by an automated driving system designed to perform of all safety-critical aspects of a driving task and monitor the roadside environment for the entire trip even if a human driver does not respond appropriately to a request to intervene (Finger & Audouin, 2019);
6. LEVEL 5: Full Automation with performance by an automated driving system equal to that which can be performed by a human driver (Coles, 2016).

The difference between the driver assistance systems existing today and the higher levels of vehicle automation is the role of the driver and how the dynamic driving task is split between human and machine (Stanton, 2019; International Transport Forum, 2015). The task is performed entirely by the driver for Level 0 and entirely by the automated driving system in Level 5 (Vellinga, 2017; International Transport Forum, 2015).

For Levels 0 to 2, the human driver needs to monitor the environment. From Levels 3 to 5, the monitoring of the environment is done by the automated driving system. Such levels of new technology will put an onus on the various governments to revise existing legislations which are generally based on the assumption of a driver manning a vehicle (On-Road Automated Vehicle Standards Committee, 2014).

For Levels 0 to 2, the driver still retains his place in the vehicle. Thus the driver has the role of an 'operator' in the vehicle. Level 3 is limited conditional automation where the role of the driver is not to monitor the roadway at all times but must be in a position to take vehicle critical-event control with some notice (Dorr, 2016). For automation Levels 3 and 4, the driver has the role of 'supervisor' in the vehicle thus intervening when necessary. Automated vehicles are transforming the concept of transport and mobility by changing the role of the human from operator, driver and service provider to supervisor (Morteza et al, 2018).

The majority of the vehicles in production provide driver assistance Level 1 with adaptive cruise control technology and some also incorporate the lane-keeping assistant technology enabling partial automation at Level 2 (International Transport Forum, 2015). For conditional automation at Level 3, the driver is expected to resume the driving task when alerted to do so and hence this level creates the difficulty of the human-machine interaction (International Transport Forum, 2015). At Levels 4 and 5, automated vehicles operate through the inputs from sensors of the vehicle itself or through a collection of inputs from other vehicles and from the infrastructure (Stanton, 2019; International Transport Forum, 2015; Meyer, 2015). However Level 4 still poses difficulties because the automated system can revert to a 'minimal risk condition' state if the driver does not resume the driving task when alerted to do so (Meyer & Beiker, 2015; International Transport Forum, 2015). This occurs because the highly automated vehicle is not capable of operating in all contexts or driving modes (International

Transport Forum, 2015). Level 5 automation is achieved with the vehicle being capable of operating in '*all roadway and environmental conditions that can be managed by a human driver*' (SAE Journal, 2016; International Transport Forum, 2015).

Development pathways for automated vehicles will either follow a gradual development of traditional vehicles with increases in automation technology or there will be a radical technology shift that would result in deployment of highly automated vehicles (International Transport Forum, 2015). The current and future technologies for the different levels of automation are as per Figure 2 and as follows (Kockelman et al, 2016; ERTRAC, 2015):

1. Level 0 (No Driving Task Automation)
    a. Systems beyond human capability to act which include Anti-lock Braking Systems (ABS), Electronic Stability Control (ESC), Driver Steering Recommendation (DSR) and emergency braking (Maurer et al, 2016);
    b. Lane Change Assist (LCA) which is a system that monitors the areas to the sides of the vehicles and up to 50m at its rear and alerts the driver of a critical situation;
    c. Park Distance Control (PDC) which assists the driver to manoeuver into restricted spaces and communicates distance from objects (Mikulski, 2017);
    d. Lane Departure Warning (LDW) prevents collisions due to unintentional departure from traffic lanes;
    e. Front Collision Warning (FCW) uses a radar sensor to detect when the vehicle is too close to the one in front of it.

2. Level 1 (Active Driver Assistance)
    a. Adaptive Cruise Control (ACC) has a sensor to measure the distance and speed relative to the vehicles driving before it;
    b. ACC including Stop-and-Go function which is ACC with automatic distance control and this maintains a safe distance from the vehicle ahead by activating the brakes and accelerating;
    c. Lane Keeping Assist (LKA) becomes active for speeds exceeding 60km/h and the systems detects line markings and takes corrective action if the vehicle drifts off the lane;
    d. Park Assist (PA) manoeuvers the car into and out of parallel parking bays.

3. Level 2 (Partial Automation)
    a. Partial Automated Parking into and out of a parking bay in a private or public parking area or garage where the driver can start the process remotely and the vehicle carries out the manoeuver by itself;
    b. Traffic Jam Assistance controls the forward/backward and sideways movement of the vehicle to follow the traffic at speeds not exceeding 30km/h.

4. Level 3 (Conditional Automation)
    a. Highway Chauffeur is conditional automated driving of up to 130km/h on motorways and motorway-like roads. It operates entrance and exit on all lanes and overtaking. The driver chooses to activate the system and he is not obliged to constantly monitor the system and can also over-ride or switch off the system at all times (Mikulski, 2017);
    b. Traffic Jam Chauffeur is conditional automated driving in congested traffic situations for speeds not exceeding 60km/h on motorways and motorway-like roads. The technology controls the backwards/forwards/lateral movements of the vehicle and the driver chooses to activate the system. He is not obliged to constantly monitor the system and can also over-ride or switch off the system at all times.

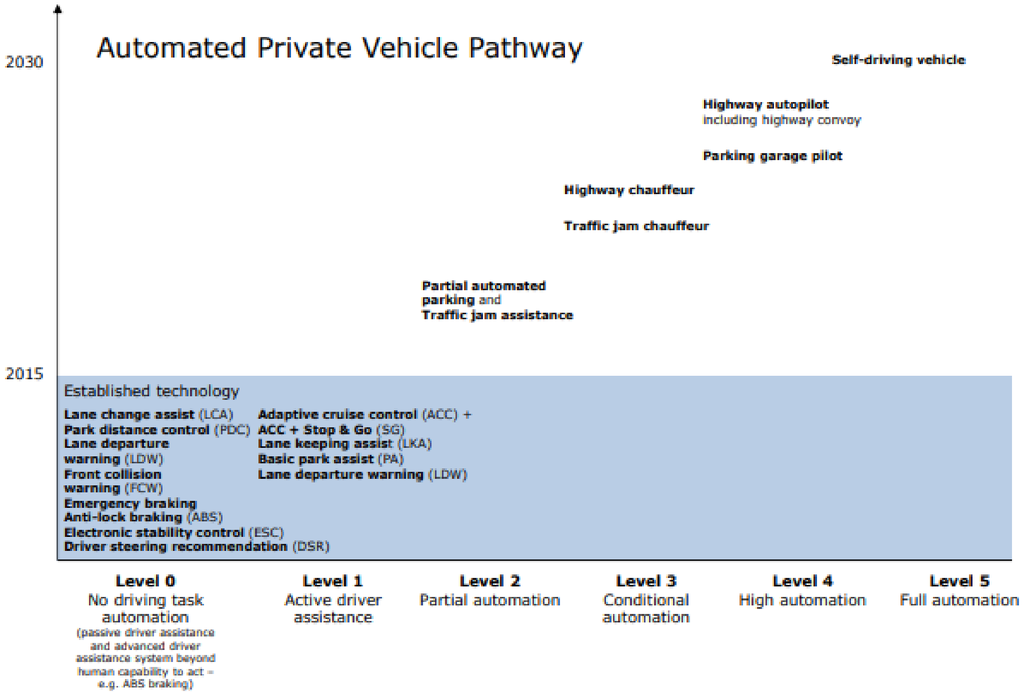
5. Level 4 (High Automation)

    a. Highway Autopilot is automated driving of up to 130km/h on motorways and motorway-like roads. It operates entrance and exit on all lanes and overtaking. The driver chooses to activate the system and he is not obliged to constantly monitor the system and can also over-ride or switch off the system at all times;
    b. Highway Convoy is automated driving with Highway Autopilot where convoys of vehicle platoons could be created provided that there are the V2V communications and cooperative systems in place;
    c. Parking Garage Pilot is a highly automated parking system which includes manoeuvering into and out of parking spaces. In this case the driver chooses to activate the system and he is not obliged to constantly monitor the system and the system is activated remotely.

6. Level 5 (Full Automation)

    a. Self-driving Vehicle which is intended to manage all the driving tasks from origin to destination without any human intervention. The driver can override or switch off the system at all times.

Figure 2: Automated Private Vehicle Pathway



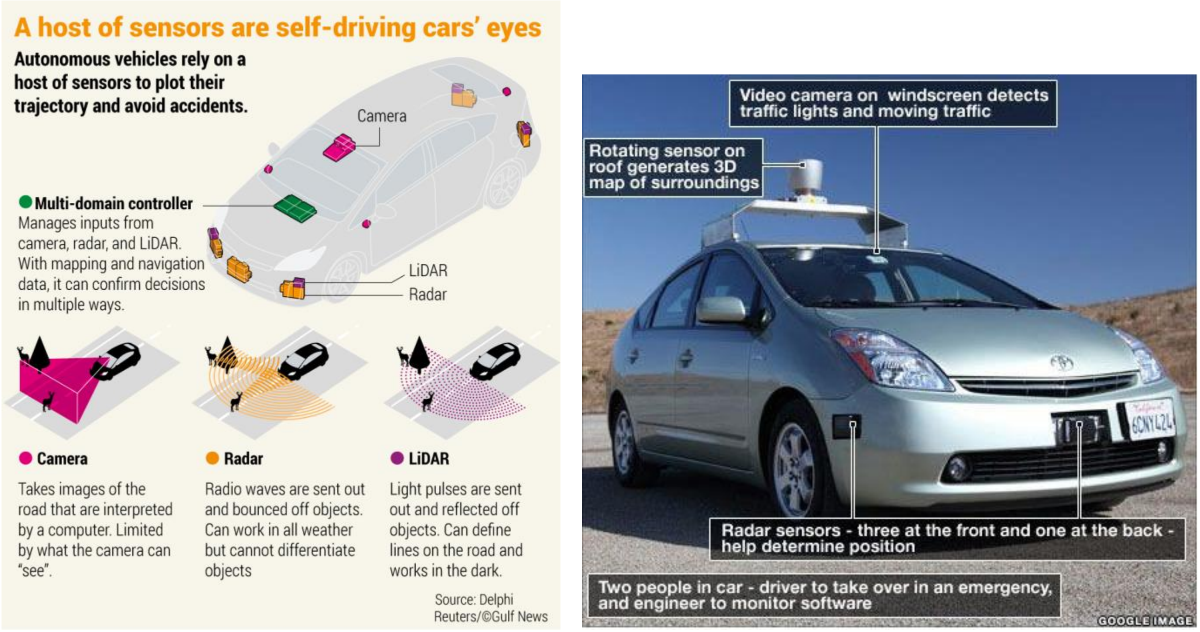
Source: International Transport Forum, 2015

AVs contain a large number of sensors all over the vehicles which are used to map out the roadside environment, road markings and alignments, deciphering of signage, recording of the location of traffic lights and pedestrian crossings and the identification of pedestrians. This roadside mapping is made possible through the use of a combination of radar and lidar cameras, ultrasonic detectors for automated parking, gyroscopes, altimeters and accelerometers for more precise geo-locationing than using Global Positioning Systems (The Economist, Apr 2013).

The AVs use the above technology, as shown in Figure 3, to construct a detailed three dimensional map of all the components of the roadside environment such as road alignments, speed limits and signage (The Economist, Apr 2013). Each time the AV passes a route, it adds more details to its recorded map. AVs have a higher sensorial awareness than the human driver because the sensor mounted on the roof of the vehicle has a 360degree view of the road environment (The Economist, Apr 2013). The biggest challenge to the AVs are inclement weather conditions and the temporary signage at road work sites (The Economist, Apr 2013).

The technology being used in AVs is not new technology. It is technology which is safe, which has already been tried and tested and of which there is ample understanding (Clark, Feb 2015). It is the software and algorithms binding the equipment together that poses the greatest challenges (Clark, Feb 2015).

Figure 3: Technology used in Automated Vehicles


A host of sensors are self-driving cars' eyes

Autonomous vehicles rely on a host of sensors to plot their trajectory and avoid accidents.

Multi-domain controller Manages inputs from camera, radar, and LiDAR. With mapping and navigation data, it can confirm decisions in multiple ways.

Camera Takes images of the road that are interpreted by a computer. Limited by what the camera can "see".

Radar Radio waves are sent out and bounced off objects. Can work in all weather but cannot differentiate objects

LiDAR Light pulses are sent out and reflected off objects. Can define lines on the road and works in the dark.

Source: Delphi
Reuters/©Gulf News

Video camera on windscreen detects traffic lights and moving traffic

Rotating sensor on roof generates 3D map of surroundings

Radar sensors - three at the front and one at the back - help determine position

Two people in car - driver to take over in an emergency, and engineer to monitor software

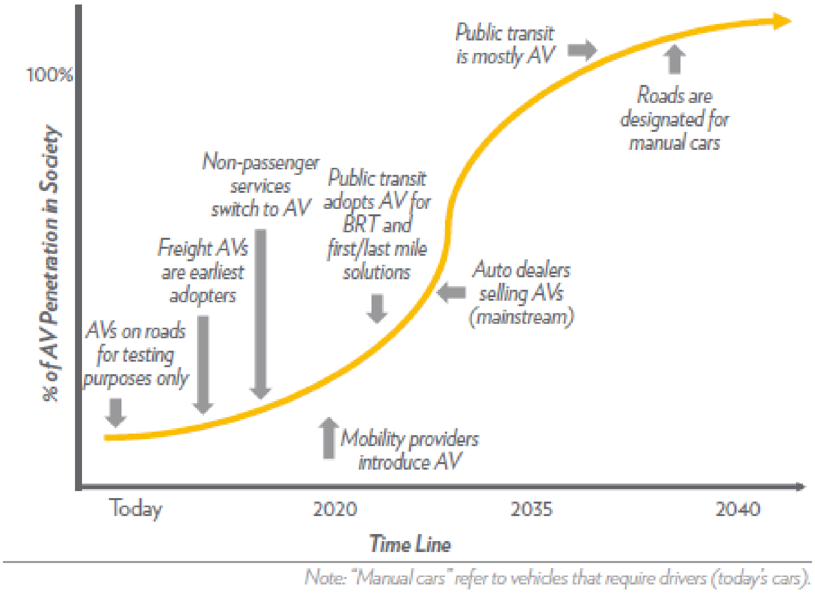
Source: https://gulfnews.com/news/americas/usa/how-do-driverless-cars-see-the-world-around-them-1.2191449

Source: https://www.treehugger.com/cars/google-experiments-with-robot-cars-that-drive-themselves.html

We do not exactly know yet how the AVs will be integrated into society. However it will be a gradual evolution which occurs over the next decades. The development of automated vehicles is progressing rapidly and the deployment of fully automated (Levels 4 and 5) automated vehicles are expected in the next 10 to 30 years (Milakis et al., 2017). This development will have a considerable impact on urban mobility and on transportation systems (Milakis et al., 2017). On the other hand, Johnson (2017) states that there is no agreement regarding the timeline of when the majority of the vehicles on the road network will be connected and automated and such timelines vary between now and the next 40 years or more. Viereckl et al. (2015) state that by the year 2025, it is optimistically estimated that 20% of the new vehicles purchased will be partly or fully automated. This value is optimistically estimated to increase to 25% by the year 2030 (Viereckl et al., 2015).

With the continuous development and testing of AVs, it is understood that the first such vehicles will be deployed in closed circuited zones, subsequently they will be deployed by freight vehicles on highways (Litman, 2019). Successively AVs will be used by public transit agencies which will identify early opportunities to test AVs with protected or fixed guided vehicle services (Isaac, 2016). Also the AVs may be identified as an ideal solution for the last/first mile connection to mass transit systems through the use of automated shuttle services (Isaac, 2016). Another development for the early use of AVs would be in services which do not include passengers such as street cleaning and delivery services (Isaac, 2016). Figure 4 below shows how this conceptual gradual introduction of AVs on the public road network might develop over time:

Figure 4: Time Line for the Deployment of Automated Vehicles

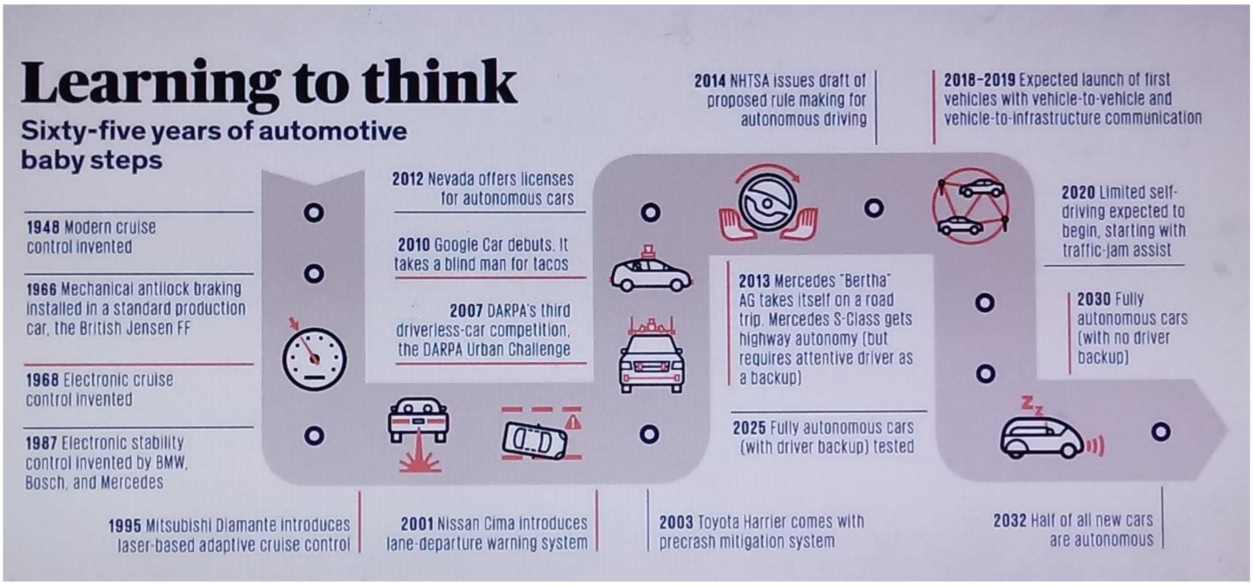


Note: "Manual cars" refer to vehicles that require drivers (today's cars).

Source: http://www.transpogroup.com/assets/driving_towards_driverless_monograph_print_friendly.pdf

Figure 5 shows a simplified pictorial development of the automobile, as researched and proposed by Ross (2014), starting from the year 1948 when the modern cruise control was invented. As explained by Ross (2014), this was followed by the mechanical anti-lock braking system and the invention of electronic cruise control in the year 1968 and the year 1987 saw the invention of the electronic stability control. Ross (2014) continues to show that lane departure warning systems were introduced in 2001 followed by pre-crash mitigation systems in the year 2003. Developments in driverless technology led to the state of Nevada offering a license to automated vehicles in the year 2012 and subsequently further developments prompted NHTSA to issue draft of proposed rules for automated driving in the year 2014. The launch of V2I and V2V communications is expected by the year 2019 (Ross, 2014). It will be followed by the expected limited self-driving to occur by the year 2020 and by the year 2030. It is envisaged that by 2030 fully automated vehicles will be in use (Ross, 2014).

Figure 5: Development over Time of Automated Vehicles



Source: Ross, 2014

A large portion of motorists may resist the introduction of Level 3 vehicles on the road resulting in a mixed traffic scenario which will create new roadside environment and traffic management challenges (Litman, 2016). It is an ongoing debate of how to mix existing technologies with automated vehicles, how to ensure pedestrian and cyclists' safety in residential areas, adjustments to existing road infrastructure and type of roads best suited for automated vehicles, (Bailey, 2015).

A new era of vehicle automation is moving towards the high to the fully automated car at Levels 4 to 5. Car manufacturers have made predictions regarding the introduction of Levels 4 and 5 automated vehicles so that technologies will be available during the 2020s years and early 2030s albeit they will likely be expensive novelties with restrictions on the conditions under which they may operate and would likely be limited to specific fleets in a controlled environment (Litman, 2016).

1.1.2 Advantages and Disadvantages of Automated Vehicles

There are arguments both in favour and against the introduction of AVs on the road network. There are also considerable challenges which are yet to be met through the evolvement and development of technology. Considerable investment will be needed to re-design existing infrastructure to order to enable connection to these AVs and such technologies may not be readily available (Aon, 2014). Also, these expenses need to be considered within the realistic scenario of the ever increasing demand for financing of basic road maintenance (Aon, 2014). Besides, a huge effort is required to establish a high level of collaboration between central governments, local governments, the automotive industry, supplies of components, infrastructure, technology developers, the industry and the general public (Aon, 2014).

The main advantages for AVs are the following:

i. there will be a reduction in road accidents as the risks associated with human errors will be eliminated for Levels 4 and 5;
ii. the mobility offered by AVs would be available for everybody including children, elderly and disabled persons;
iii. there will no longer be the need for a driver to transport a passenger;

iv. parking demand will be reduced as the AV would be in a position to alight/board passengers and park itself at any other location in the interim;
v. the management of traffic flow would be more efficient thus reducing congestions;
vi. potentially there will be less vehicles on the road as families would be in a better position to share the AV.

The disadvantages include:

i. car lovers would not be willing to give up driving as driving is considered to be sometimes much more than simply a means to reach a destination;
ii. jobs related to professional drivers would be at risk;
iii. AVs are dependent on GPS satellites and hence, should the signal be blocked, the functionality of the cars would be impaired;
iv. AV technology is still being tested and hence further development to existing technology is required to ensure safe operation of such vehicles.

1.1.3 The Driver and his Role in an Automated Vehicle

Various terminologies are being used in relation to AVs. Actual ‘driverless’ vehicles or ‘fully automated’ vehicles mean that the driver is not required in the vehicle (DfT, 2015). However such types of vehicles are not expected to be seen on the public road network until, at least, the late 2020s. Before the stage of ‘driverless’ vehicle is reached, vehicles will be available which will be in a position to carry out considerable parts of a journey ‘driverless’ albeit still necessitating that the driver assumes control of the vehicle at some point along the journey (Kyriakidis et al., 2017).

The development of various technologies, pertaining or adaptable for the use in AVs, have resulted in this radical change in the concept of the vehicle. Further developments in vehicle automation technology, which are occurring now or which will be occurring in the near future, will further make this ‘driverless’ car scenario increasingly a reality.

The main difference between the currently available ‘driver assistance’ systems and the higher levels of AV automation is that, with driver assistance systems, the driver must be ‘engaged’ at all times (Winner et al, 2016; Kyriakidis et al., 2017; Milakis, Van Arem et al, 2017). The engaged driver means that he is to be constantly following and attentive to what is happening in the roadside environment and be immediately ready to resume the full operation of the vehicles manually and be responsible for the safe operation of such (Kyriakidis et al., 2017). At higher levels of automation, the driver does not need ot be engaged in the driving operation of the vehicle (Meixner & Muller, 2017; DfT, 2015).

The norm is that a vehicle is always operated by a human acting as a driver and operating the vehicle through the use of a combination of controls such as the pedals, indicators and steering wheel (DfT, 2015). When the fully automated vehicles are available for operation on the public road network, such vehicles may not even be equipped with a driver seat (DfT, 2015).

1.2 Research Goals

This research was intended to establish the perception-reaction time in a Level 3 for the driver to resume the driving task form the moment of alert and determine how the design guidelines for SSD would need to be adjusted to safely accommodate such time period in a Level 3 AVs on the road network. This is important because the added complexity of the perception-reaction time of the driver in a Level 3 AV, especially within the roadside environment consisting of a traffic mix between Level 3 AVs and normal vehicles, might need a longer time period to accommodate longer perception-reaction times because of reduced driver alertness as a result of in-vehicle secondary tasks. This would necessitate longer distances for the vehicle to stop thus resulting in the need to revise the current standards for SSD to take this consideration into account.

Thus, given that the driver in a Level 3 AV is potentially distracted with an in-vehicle secondary task toher than driving, the perception-reaction time to resume the driving task and react to a hazard is longer than that for a driver in a Level 0,1 and 2 vehicle who is not distracted and who is performing the driving task when a hazard is perceived and a reaction is required. It is to be understood that although the AVs are equipped with sensors and radars to map the roadside scenario however the vehicle would not have information about new roadside, pedestrian, cyclist and traffic arrangements, nor about emergency works or incidents and not about sudden hazards.

Hence, in such cases where the AV potentially would alert the driver to resume the driving task, such alert needs to be provided to allow for sufficient perception-reaction time for the driver to re-engage in the driving task. Such time period translates into SSD from the position of the vehicle when the alert is given to the position of the unexpected road circumstance which cannot be managed by the AV technology and thus requires driver intervention. The AV technology needs to detect and identify the unexpected road circumstance and subsequently needs to alert the driver within the safe SSD distance to allow the driver to re-engage to perform the required reaction or evasive manoeuver. This is the problem which this research aims to investigate because such perception-reaction time is an integral part of the calculation for determining the Sight Stopping Distances which are the basis of safe road design.

A summary of the aims of this research document are as follows:

1. to examine the effectiveness of two different driver alert systems;
2. to establish the driver response times for drivers in relation to:
    a. different alert systems
    b. different age groups
    c. different driving experience
    d. different secondary tasks (distractions)
    e. disabilities which impair driver perception-reaction times;
3. to focus on the establishment of revised SSD values which determine the design guidelines for road design to safely accommodate Level 3 AVs on the road network in relation to the perception-response times obtained as part of this research;
4. to examine how the AV in-built technology can meet the demands relating to unexpected roadside events.

The key questions which this research aims to answer are:

1. Which type or combination of driver alert systems are most effective according to age group?
2. Do driving experience, disabilities and age affect response times?
3. Does the nature of the secondary task affect driver response times?
4. How will driver perception-response time affect standard design guidelines for Stopping Sight Distances?

Main Hypothesis

Driver response time in a Level 3 Automated Vehicle will necessitate updates of the existing design guidelines for Stopping Sight Distances.

1.3 Dissertation Structure

The structure of the research document is as follows:

Chapter 1 – Introduction and Scope of Research

Chapter 2 – Literature Review

Chapter 3 - Research Design and Methodology

Chapter 4 – Data Collection

Chapter 5 – Analysis and Results

Chapter 6 - Discussion and Conclusions

References

CHAPTER 2: LITERATURE REVIEW

The driving process is undertaken in two parts, the driving strategy and the driving tactics (Northwestern University Centre for Public Safety (NUCPS), 2006). The driving strategy is related to the general perception of the vehicle operating in road traffic and includes the analysis of safety risks and the actions to address or reduce such risk (NUCPS, 2006). Thus the driving strategy is the reaction of the driver to a prevailing situation and includes the actions to eliminate or reduce risk (NUCPS, 2006). Driving tactics are the manoeuvers made by the driver to avoid a safety risk (NUCPS, 2006). The safety risk must be recognized and analysed, then the driver decides on the action to be taken followed by the actual implementation of such decision (NUCPS, 2006). If the driving strategy adopted by the driver is not appropriate, the driver might not be able to avoid the hazard (NUCPS, 2006).

The different levels of automation, broadly referred to as automated vehicles (for Levels 1 to 3), automated (for Level 4) and driverless for (Level 5) (Reese, 2016). It is important to differentiate between the levels of automation because each level is more advanced than the previous (Reese, 2016). The different levels effect the level of accident risk of the vehicle where the vehicle becomes safer on the road as the level of automation increases (Reese, 2016).

According to a research carried at RAND Corporation, a non-profit and non-partisan think tank from California, it was concluded that automated vehicles need only be slightly better at the driving task than humans to reduce the amount of fatal accidents (Albrecht, 2017). The research involved comparing three scenarios with driverless vehicles which were 10%, 75% and 90% better than human drivers (Albrecht, 2017). For both the short and long term scenarios modeled, hence for 15 years and 30 years respectively, it resulted that many lives would be saved with driverless cars which are just 10% better than human drivers (Albrecht, 2017). The most common advantage quoted for automated vehicles is the safer and more efficient driving when compared to human drivers. Provided that there are no failures to the technological systems of the automated vehicles, these vehicles have the potential to reduce human error and thus reduce 90% of accidents (Walker & Marchau, 2017; Bouton et al., 2015). This is because human error is considered to be the predominant reason for motor vehicle accidents. According to the United States Department of Transport, 80% of motor vehicle accidents in 2006 were due to human error (Genovario, 2015). Other research has attributed human error to more than 90% of accidents (CUTR, 2013).

2.1 The Driving Process

2.1.1 Vehicle Handover

It has been established that vehicle automation poses both advantages and disadvantages in relation to performance of a human in such vehicle (Bainbridge, 1983). Sometimes there is a failure in the automation technology and such can be due to (Wickens et al, 2010):

a. Failure in the software or hardware, or;
b. Failure in delivering the intended operation because of misuse of a function.

It has also been shown that routine vehicle automation reduces the workload of the human in respect of driving (Wickens et al, 2010). However there are serious problems in the human-machine system performace in the instances when there is a failure in the vehicle automation system because of the reduced situation awareness, the excess trust in the automation technology and because of the reduced monitoring of the automated driving task (Wickens et al, 2010). In this respect, Bainbridge (1983) explained that increased automation reliability results in greater complacency leading to an increased chance of serious consequences which such automation fails. Hence, when there are no problems with automation, this improves the human-system performance and increases dependence on automation which results in serious performance consequences when automation fails (Wickens et al, 2010). However, it is also possible that when automated vehicles are provided with effective in-vehicle displays to address situation awareness and the drivers are trained to have realistic expectations of technology failure, such can reduce, eliminate or reverse the complacency issues (Bahner et al, 2008; Wickens et al, 2010).

De Winter et al (2014) carried out experiments to establish the impact of Adaptive Cruise Control (ACC) and Highly Automated Driving (HAD) on the driving workload of the drivers and the situation awareness using a meta-analysis and explanatory review of on-road and simulator experiments. It resulted that drivers in a highly automated vehicle, and also drivers in ACC vehicles albeit a lower percentage of the latter, potentially engage in secondary tasks other than driving such as watching a DVD or sleeping (de Winter et al, 2014). However, if drivers in HAD and ACC are motivated or instructed to identify objects in the roadside environment, such results in enhances situation awareness in relation to manual driving (de Winter et al, 2014). However, if drivers in an HAD and ACC are engaged in a secondary task other than driving, such as reading or reaching into a rear compartment, their situation awareness decreases in comparison to manual driving (de Winter, 2014).

Similarly, studies by Gold et al. (2014) concluded that driver perception-reaction times depended on the type of roadside scenario and also on the type of distraction. Also, it resulted that if the driver in an HAD or ACC needs to monitor the vehicle automation, this increases the driver workload when compared to manual driving (de Winter, 2014). HAD and ACC could potentially decrease driver workload because the cognitive activity related to driving is reduced and the physical activity required to handle a vehicle is also reduced (de Winter, 2014). The analysis carried out by de Winter et al (2014) also indicated that ACC reduces the mental capacity of the driver and hence ACC drivers respond faster to visual stimuli when compared with manual drivers. In the case of HAD drivers, the drivers respond slower to visual stimuli when compared with manual drivers due to drowsiness (de Winter et al, 2014).

Also, manual drivers gaze at the centre of the road more frequently than HAD drivers which indicates that HAD drivers have lower workload and reduced situation awareness (de Winter et al, 2014). The eye movement difference between manual driving and ACC were also examined by de Winter et al. (2014) but the results were not conclusive. The research by de Winter et al. (2014) also concluded that there is a high risk of a collisions in a critical HAD scenario when drivers are distracted or not alerted. This shows that an alert system reduces the risk related to low workload and low situation awareness in an HAD.

Also, considering the concepts of human factors, HAD is very different to ACC driving because the driver in an HAD can engage in a secondary task other than driving but a driver in an ACC must always be engaged in the driving task (de Winter, 2014). In this respect, researchers involved in Human Factors research probably agree that driver situation awareness and workload are the most important factors which determine driver performance and safety (Stanton & Young, 2000; de Winter et al, 2014; Parasuraman et al, 2008).

Studies which were carried out by Merat & Jameson (2009) showed that drivers in a HAD responded to a red traffic light with a perception-reaction time which was 2.5 seconds more than those for manual driving. Also, drivers in HAD had longer perception-reacton times even for the scenarios of emerging vehicles and oncoming vehicles (Merat & Jameson, 2009).

Flemish et al. (2008) carried out an experiment where an acoustic alert was given upon AV system failure which was 2 seconds before the vehicle entered a curve. In this experiment, none of the five participants managed to keep control of the vehicle (Flemish et al, 2008). Also, further research carried out by Flemish et al. (2011) found that HAD gave lower time-to-collision values with a lead vehicle which braked hard when compared with manual braking. In this experiment the HAD alert was given between 3.0 to 4.1 seconds prior to collision and such advance warning was not sufficiently long (Flemish et al., 2011).

Similarly, Dambock et al. (2013) carried out research which concluded that HAD had longer reaction times than manual driving when a lead vehicle braked hard unexpectedly whilst its rear lights were flashing. The unexpected roadside scenario was an animal running into the road which was not detected by the sensors (Dambock et al., 2013). The reaction time was measured from the first glance at the hazard to the moment that the brake was activated (Damock et al., 2013).

Research carried out by Omae et al. (2005) involved 30 participnats in an actual AV whereby a sudden rotation of the steering was activated whilst the vehicle was proceeding at low speed. The response time of the drivers in such experiment was a median of 1 second however when this unexpected steering activation occurred after one hour of driving, some of the drivers had more than 5 seconds response time (Omae et al., 2005).

On the otherhand, research carried out by Martens et al. (2008) concluded that there was no statistically significant difference between HAD, ACC and manual driving with a critical roadside scenario of a car accessing a parking space. Similarly, research carried out by Merat et al. (2012b) concluded that there was the same percentage of manual and HAD drivers who changed lane before a traffic cone roadside scenario. Young (2000) carried out research whereby there was no difference between the number of drivers in HAD and ACC driving who responded to an unalerted failure in the vehicle automation technology.

It is to be noted that when AVs are tested on-the-road, the drivers participating in the testing are test drivers who are given rigorous formal training to be constantly alert and they are instructed to resume control of the AV as they deem necessary for any reason including comfort of the ride, vehicle safety or the unexected behavior of other road users (Dixit et al., 2016). Hence the perception-reaction results obtained for test drivers might not reflect the results obtained for normal drivers and would thus not necessarily reflect the reality of AV and driver performance.

The above shows that there are a large number of studies which showed that HAD and ACC driving resulted in longer perception-reaction times and a higher risk of near-collisions in critical roadside scenarios when compared to drivers in manual driving mode. However there are also other studies which showed that drivers in HAD and ACC successfully avoided hazards in critical roadside scenarios. It resulted that the type of roadside scenario and whether an advance alert was give actually effects the driver perception-reaction times (de Winter et al., 2014). Basically, it was concluded that if there is an unexpected failure in the vehicle automation technology and the driver is not allowed sufficient time to respond, then almost all cases result in a collision (Flemish et al, 2008).

Similarly Norman (1990) concluded that the absence of feedback regarding the status of automation is a significant causation of accidents related to vehicle automation. This is the same conclusion reached by Dixit et al, (2016) who stated that disengagements pose a risk in AVs which require the driver to be alert and prepared to resume the driving task however it is also imperative that for the safe transition to manual driving, drivers need to react in an appropriate and timely manner. However, none of these studies which were carried out established the perception-reaction time required in a Level 3 AV to enable the driver to resume the driving task safely in relation to different secondary tasks, different alerts and different person specific characteristics as is being examined and researched in this document. This is also confirmed by Dixit et al. (2016) who stated that existing road design and safety manuals need to be revised because such are still based on the PRT values for manually-oparated vehicles and thus do not provide for aequate road infrastructure to ensure the safe operation of AVs.

2.1.2 Driver Perception-Reaction Time

Perception refers to the detecting of a scenario and understanding its meaning (Molnar & Gair, 2013). The first process is Perception which is followed by Reaction. Perception is determined by the sensory stimulus (Molnar & Gair, 2013) and hence it is affected by deficiencies in vision and deficiencies in skills to distinguish shapes and movement (NUCPS, 2006). The time period occurring between the moment that a safety risk is perceived, hence meaning that the risk is seen, heard or felt, to the moment that the risk is actually comprehended is called Perception Delay and it is difficult to measure because (NUCPS, 2006):

1. the delays are affected by personal factors and there are a large amount of variables to be accounted for;
2. this delay generally happens because the attention of the driver is not focused in the direction of the safety risk and hence the time period for the driver to identify the hazard is indefinite, for example, in the case where a driver falls asleep whilst driving, there is no perception and the Perception Delay is indefinite.

The above research is applicable to Level 1 and 2 vehicles. In the case of Level 3 vehicles the risk or hazard is perceived by the vehicle itself and, in cases of particular or strong stimulus, alerts the driver to take control of the driving task. Hence the Perception Delay is part of the alert system on the Level 3 AV itself. This results in that the time period between the vehicle perception and the driver alert is very important and the alert system must be as effective and efficient as possible to enable the driver to react. The type of alert mode will be examined as part of this research document in relation to type of stimulus and other factors which determine Reaction Time as outlined below.

Advances have been made in understanding visual perception however it is still unclear where visual perception is determined in the brain (Amano, 2006). The time for visual perception to occur was studied by investigating simple reaction time (Amano, 2006; Khoury, 2007). Simple Reaction Time is the time period between the start of a stimulus and the start of the immediate motor response (Shelton & Kumar, 2010; Amano, 2006). Thus, for the purposes of this research document, the Reaction Time is the time between perception of a hazard or situation to the start of maneuvering or the start of control of the vehicle (NUCPS, 2006).

The Reaction Time is the start and finish of the process of perception where a sensory organ gives the decision to start a motor response (Amano, 2006). Hence Reaction Time is the total time needed to think and to start taking control of the vehicle and hence it is generally referred to as Perception-Reaction Time (NUCPS, 2006). However, it is not easy to establish the time period required for a decision to be made because the time required for post-perceptual processing (which is the perception-reaction time including the motor response) is generally unknown. An appropriate way to address this limitation is to associate reaction time with human brain activities which are triggered by a visual stimulus and such time period can be measured noninvasively (Amano, 2006). The data collected for the scope of this research document was based on the premise where the web-link survey involved a visual stimulus triggering a motor response.

In normal Level 1 and 2 vehicles, this perception-reaction time period duration is determined by how complex the decision required to be made and by how urgent the circumstance might be (NUCPS, 2006). Driving Strategy would require a small amount of quick decisions of higher complexity however Driving Tactics require quicker but simpler decisions (NUCPS, 2006). In a Level 3 vehicle, the scenario is completely different because the driver is not expected to be engaged in the driving task.

When it comes to Level 3 AVs, the driver can engage in secondary tasks however he will need to assume control of the vehicle in the event of a critical scenario. The task of shifting from automated to manual control is critical because the event which requires driver intervention will probably be an emergency situation necessitating a rapid response (Merat & Lee, 2012). The AV might require the driver to take over manual control in a matter of milliseconds however it will take seconds for the driver to actually assume manual control (Merat & Lee, 2012). It is noted that vehicle automation can address the least challenging driving scenarios, thus encouraging drivers to disengage from driving, however the AV then alerts the driver to manage the most critical driving situations (Bainbridge, 1983; Merat & Lee, 2012).

Muttart (2005) examined previous research and identified the variables that affect the response time of the driver. The aim of the research carried out by Muttart (2005) showed why similar analogous published studies result in different driver response times.

Muttart (2005) found that some of the studies established the response time of the driver from perception to first reaction. This refers to the point in time of taking the foot off the throttle which is the time when the driver reacts. Other studies measured response times up to first response. Hence when the foot activates the brake or when a steering maneuver is carried out. Other studies measured perception-reaction time up to full braking or first vehicle movement. Hence response times are defined as follows:

a. Perception-reaction time: when the foot is removed from the throttle because that is the actual first driver reaction (Muttart, 2005);
b. Perception-response time: from perception of the hazard up to the first vehicle response (Muttart, 2005);
c. Brake-response time: from perception up to brake application (Muttart, 2005).

The Conference Europeenne des Directeurs des Routes (CEDR) report defines Perception-Reaction Time as (Weber et al, 2016):

“the time it takes for a road user to realize that a reaction is needed due to a road condition, decides what maneuver is appropriate (in this case, stopping the vehicle) and start the maneuver (moving the foot from the accelerator to the brake pedal)”.

In the National Cooperative Highway Research Programme (NCHRP) Report, the Perception-Brake Reaction Time (perception-reaction time) is defined as:

“the interval of time between the moment the driver recognizes the existence of an object or hazard on the roadway ahead and the moment the driver applies the brakes or makes an evasive maneuver” (Fambro et al, 1997).

On the otherhand, the Calfornia Department for Motor Vehicles defines PRT as

‘the period of time elapsed from when the autonomous vehicle test driver was alerted of the technology failure and the driver assumed manual control of the vehicle” Dixit et al., 2016).

This definition by the California Department for Motor Vehicles does not include the perception time of the test driver following an alert (Dixit et al., 2016). It is to be note that the drivers being referred to in this definition are specifically referred to as being test drivers and not normal drivers. Such test drivers are given rigorous formal training where they need to show and determine their driving skills both in normal and in difficult roadside conditions and scenarios (Dixit et al., 2016). They are trained to be constantly alert and they are instructed to resume control of the AV as they deem necessary for any reason including comfort of the ride, vehicle safety or the unexected behavior of other road users (Dixit et al., 2016). Thus these drvers are constanty alert and not distracted by a secondary task. For this reason, it is understood that the definition does not include the perception time because the test driver would have already perceived the hazard given that such driver was alert and not distracted.

Based on the review of the above definitions and considerations, for the scope of this research, the definition of perception-reaction time will be taken as defined by the CEDR and the definition defined by Muttart (2005).

The transition phase between levels 3 and levels 4 and 5 of vehicle automation are critical and NHTSA (2013) has drawn up a list of preliminary policy recommendations outlining how testing of such AVs can be carried out safely on the public road network. One such recommendation is directly related to the importance of the driver receiving a timely alert to resume the driving task as follows '*ensure that the process for transitioning from self-driving mode to driver control is safe, simple, and timely.'* This specifically refers to the timely alert for the driver to safely resume the driving task and hence that the driver is alerted in time to allow for safety perception-reaction time periods. Such perception-reaction time period has been the subject of various researchers where different related aspects were considered and evaluated.

Lee et al (2004) examined the effectiveness of graded and single-stage alert systems and different alert types. The scope of the study was to examined on how such collision warning systems actually mitigate driver distraction and focus the attention of the driver on the road in case of unexpected braking. Two experiments were carried out where drivers used an email system in-built in the vehicle and a collision warning system alert when the lead vehicle was braking.

The first experiment had the objective of examining how driver response is affected by graded and single-stage warning systems and is also examined how the modality of the warning display affected the reaction of the driver. It resulted that the type of alert did not affect the number of collisions and nor did it affect the safety risk however the alert strategy did have considerable impact. In the second experiment, the main objective of Lee et al (2004) was to establish how the type of warning and warning mode affected the driver. The participants perceived that the haptic type of alert was more effective than the graded or single stage auditory alert.

From the two experiments carried out, Lee et al (2004) concluded that, when alerted by the collision warning system, the type of alert used had very little affect on the response of the drivers because they responded similarly to both haptic and auditory alerts. However the results also showed that it is important to consider warning strategies to promote the most efficient response times.

Bao et al (2012) and Merat & Lee (2012) focussed on the adaptation of the driver to vehicle automation. Koustanai et al (2012) outline the advantages of forward collision warning (FCW). Their results show that although trust increases with use however the acceptance of such systems does not increase (Merat & Lee, 2012). Xiong et al (2012) and Merat & Lee (2012) assessed how the style of driving and the personality of the individual effect the adaptation to automated cruise control (ACC). The research was based on cluster analysis where three groups of drivers were identified based on their tendency towards adopting risky behaviours. Xiong et al (2012) conclude that education, experience and personal experience in relation to technology of a similar nature determine adaptation to automation.

Research carried out by Neubauer et al (2012) showed that the voluntary control of vehicle automation did not relieve fatigue. Also, fatigued drivers had a greater probability to use the automation which resulted in added distress. Interestingly it resulted that automation could actually distract drivers and that drivers who were fatigued had a slow response time to emergency scenarios.

On the other hand Carsten et al (2012) have concluded that increased automation results in an increase in secondary tasks such as watching a DVD in the vehicle. Merat & Lee (2012) examined a similar concept and focused on the consequences of engaging in secondary tasks in respect of the response time of drivers to critical scenarios both during manual and automated vehicle control. Merat & Lee (2012) noted that drivers who were engaged in secondary tasks had a spike in their workload when a critical scenario was encountered because the effort to regain control of manual driving exceeded their ability to cope. This resulted in increased response time.

The research carried out by Bao et al.a (2012), Neubauer et al. (2012), Carsten et al. (2012) and Merat et al. (2012a) focuses on and compares automated driving with support driving.

The results of these studies suggest that vehicle automation can increase the driver response time to assume manual control (Merat & Lee, 2012). The collective results of these studies show that AV technology is not in a position to seamlessly substitute a human. It also indicates that the driver cannot necessarily make up for the limitations of automation (Merat & Lee, 2012). Hence the actual role of the driver in a highly automated vehicle must be carefully examined and success of such technology will depend primarily on how the new role of the driver will be supported (Merat & Lee, 2012). Similarly to Lee et al (2004), the research carried out by Bao et al (2012), Neubauer et al (2012), Carsten et al (2012) and Merat et al (2012a) concluded that a critical challenge for AV technology is the transfer or the sharing of the control of the vehicle between the system and the driver especially at critical scenarios (Merat & Lee, 2012).

Louw et al (2015) studied the effect of reading as a secondary task in an AV on the capability of the driver to engage in manual control and avoid a collision with a stationary vehicle. The way that the driver reacted to the stationary vehicle during manual control was compared to two different automation scenarios (Louw wt al, 2015). The first scenario involved the driver being engaged and attentive to the roadside situation during automation. The second scenario involved the driver reading on an iPad during automation. The study investigated the difference in behaviour between different levels of driving engagement and how these interact with the driving task. This research by Louw et al (2015) showed that the determining factor effecting response time is whether the driver is actually engaged in vehicle control or not prior to the critical roadside scenario. Following similar conclusions, Merat et al (2014) recommend that, since driver re-engagement at fixed time intervals is not desirable and defeats the scope of AVs, additional research is required to establish a strategy on how drivers are to be informed of their obligations to re-engage into driving mode when necessary. This is because AV technology, which is perceived as assuming the role of the driver, will increase driver distraction and the tendency for carrying out secondary activities will make people vulnerable to roadside scenarios which automation will not be in a position to address (Merat & Lee, 2012).

As concluded in the research of Merat et al (2012a) when comparing manual to automated driving, the response time of the driver was slower following brief intervals of automated driving. Louw et al (2015) have shown that the determining factor affecting response time is if the driver is actually in control of the vehicle or not prior to the critical roadside scenario. The results of Louw et al (2015) suggest that disengaged drivers took longer to perceive potential collisions but, once identified, the manoeuvre to evade the collision was faster and more erratic. Hence, according to Louw et al (2015), this aspect of driver engagement should be the backbone of any strategy to transition the driver back to manual control.

Merat et al (2014) carried out research using a driving simulator intended to assess the ability of the driver to engage in manual control from highly automated driving under two different conditions. The first scenario involved the automated driving mode being switched off and the driver was required to engage in manual driving mode at regular intervals. The second scenario was the engagement of the driver to manual mode from automated mode based on the time period that the driver was distracted. For both experiment scenarios, Merat et al (2014) assessed the time period required by the driver to engage in the manual control of the vehicle from automated control. Also visual focus on the roadside environment and the pattern of eye fixations of the driver during re-engagement were observed using eye tracking systems.

The results of this study showed that when the driver was distracted by a secondary task during automated driving mode, the pattern of eye movement fixations of the driver were still variable even after the driver had re-engaged in manual driving mode. When re-engagement into driving mode was more predictable, the attention of the driver on the road ahead was higher and more stable. When the re-engagement into manual mode was predictable based on fixed time intervals, the lateral driving control and steering corrections of the driver were more stable within 10 seconds. However Merat et al (2014) found that irrespective whether the re-engagement to manual mode was predicted or not, it took drivers 35-40 seconds to fully stabilise their lateral control of the vehicle.

This research, carried out by Merat et al (2014), concluded that if drivers are engaged in secondary tasks during partial automated driving (Level 3) of the vehicle they are in a position to regain control of the vehicle much faster because they expect that the automated control can be switched off (de Winter et al., 2014).

Research was carried out by Shoettle and Sivak (2016) regarding preferred driver intervention notification for partially automated vehicles. A survey was carried out and 59.1% of the respondents preferred to be notified to resume control of the partially automated vehicle through a combination of visual, auditory and haptic alerts (Shoettle & Sivak, 2016). The results showed that 58.0% of females and 60.2% of males preferred the combination of three alert types and also the majority of each age group preferred the same alert combination (Shoettle & Sivak, 2016). It is also to be noted that for all these categories, the second preference of type of alert was a combination of visual and auditory alert.

Triggs & Harris (1982) carried out research on the reactions of drivers in actual driving scenarios without vehicle automation. The reactions were of drivers who were unaware of the experiment being carried out. This unobtrusive method of collecting driver response times was considered essential to obtain realistic estimates of their response.

Triggs & Harris (1982) concluded that the response times depend on the type of scenario, the level of urgency and the vehicle speed when the hazard alert starts. Different traffic scenarios necessitate different types and levels of responses. These comprise simple driver response, responses which are more complex in nature or decisions which require a change in the cognitive mind set. One can assume that the more complex the response required, the greater the increase in the perception-reaction time (Triggs & Harris, 1982).

Following the experiments carried out by Triggs & Harris (1982) for driver response times in a normal vehicle, excluding car following, can frequently be expected to be more than the accepted design value of 2.5 seconds. Hence the revision of the 2.5 seconds design value seems to be required. Also, design values for different types of scenarios might need to be considered. In the experiments carried out by Triggs & Harris (1982) the 85th Percentile reaction time values which were less than 2.5 seconds were for particular scenarios where the driver was pre-alerted on the approach such as for a railway crossing or a broken down vehicle by the roadside. General hazard warning approach signs, speed reduction signs and non emergency signage resulted in 85th Percentile reaction time values above 2.5 seconds even for drivers proceeding at higher speeds and which thus who would have had a greater level of alertness.

The research carried by Triggs & Harris (1982) did not involve reaction and response times of drivers in automated vehicles re-engaging into manual driving. However their results vary considerably from the baseline reaction and response times on which standard guidelines and regulations used in traffic engineering are prepared. Triggs & Harris (1982) noted that driver reaction times are relevant to many areas of road design, traffic engineering, vehicle spacing or headways, driver education and road safety campaigns.

The safety of all roads is based on the driver, the vehicle and the road. One major concern for traffic engineers has always been the response time of the driver in an expected roadside scenario arising out of either design features or events necessitating immediate action (Triggs and Harris, 1982). Additional data is still required even for Levels 0, 1 and 2 vehicle automation (Triggs and Harris, 1982).

The recommendation made by the Australian Expert Group on Road safety in a report to the Commonwealth Minister of Transport recognised the need to prepare a more realistic value for driver reaction time for the scope of road design (Triggs and Harris, 1982). This reaction time is a standard used in the area of geometric road design in order to ensure the forward visibility distances required to ensure the minimum time needed for the driver to take action (Triggs and

Harris, 1982). These visibility distances, known as Stopping Sight Distances (SSD) require the definition and evaluation of seven design parameters namely, perception-reaction time, driver eye height, object height, vehicle operating speed, pavement coefficient of friction, deceleration rates and roadway gradient (Layton & Dixon, 2012).

The potential impacts of AVs on exiting road infrastructures and transport plans has probably not been fully understood and the rapid rate at which this will occur has not been contemplated by most regulatory authorities (ITS International, Nov/Dec 2014). The need to develop transport infrastructure to address this technological change will have a compounded affect as the amount of AVs on the roads will increase and their technology develops further.

The extent to which there will be mixed levels of AVs/CVs/CVAs operating together in the traffic system will depend on the rate of market penetration. Clearly there is the possibility of having sections of the road network shared by vehicles of all levels of automation (Johnson, 2017; Gonzalez-Gonzalez et al, 2019). This situation would necessitate the retention of all safety infrastructure and the possible addition of new infrastructure required by AVs (Johnson, 2017). This would be a critical situation which might result in higher potential accident risks (Thomopoulos & Givoni, 2015). This higher potential risk can be mitigated by implementing measures such as dedicated lanes for AVs and higher levels of road design and maintenance standards (Litman, 2019).

Transport networks need to be restructured and redesigned to meet the needs of AVs (Litman, 2019). Thomas (2014) suggests that the safety systems for a mix of different levels of AVs must include choosing the optimal safety technologies from evidence-based assessment, introducing a smooth and lengthy transition and address the issue of liability in the event of a collision.

Currently extensive testing is being carried out in various countries with AVs on the public roads. However such test vehicles are being driven by a ‘test driver’ and not by a normal vehicle driver. A test driver is a specially trained driver who supervises the testing of the AVs and be constantly in a position to assume control of the vehicle if necessary irrespective if the vehicle is in manual or automated mode. This research proposal intends to obtain results of normal drivers, across different age groups, who would realistically eventually be operating the Level 3 AVs.

2.1.3 Type of Reactions and their Impact

The majority of the time delay between the perception of a hazard and the reaction by the human driver is due to human central processing time and not to delays along neural pathways (Triggs and Harris, 1982; Tang & Yip, 2010). Reaction time tasks vary in complexity and there are four different types of reactions. Also the amount of thinking time required differentiates between the different types, hence:

i. Reflex Reactions arise out of an instinct to react and have the shortest time period because there is no thought or decision making process involved (Nelson & Associates, 2010). When the stimulus is such that it results in a reflex reaction, the type of vehicle control or manoeuvering adopted is usually inappropriate (NUCPS, 2006). The time for such reaction may be as low as one tenth of a second (NUCPS, 2006)
ii. Simple Reactions are generally the type occurring during driving where the stimulus is as expected and the driver has decided the line of action (Nelson & Associates, 2010). These type of reactions are generally a matter of driving habit and usually have a time period of half a second (NUCPS, 2006).
iii. Complex Reactions involving choosing between different actions to identify the most appropriate action where the decision cannot have been taken in advance of the arising situation (Nelson & Associates, 2010). The time duration of a complex reaction is greater than for a Simple Reaction and depends on the complexity of the stimulus, the

number of actions to choose from and driver experience (Nelson & Associates, 2010). The time period is generally from one to three seconds for Level 1 to 2 vehicles (NUCPS, 2006).

iv. Discriminative Reaction occurs when the driver is to choose between a number of actions which he is not familiar with (Nelson & Associates, 2010). This is the slowest type of reaction and the time duration may be up to one minute for complex situations and slight urgency (NUCPS, 2006).

2.1.4 Effect of Person Specific Characteristics

2.1.4.1 Relationship between Country of Origin and Perception-Reaction Time

In the research carried out by Sohn & Stepleman (1998) a meta-analysis was used to examine the parameters which affect total braking time in Levels 1 and 2 automation where such total braking time is the equivalence of perception-reaction time. This research showed that there are many variations in the perception-reaction time which are influenced by country of origin and driver awareness and these are affected by criteria which involve the driver, the vehicle and the roadside scenario (Young & Stanton, 2007). The results of the meta-analysis showed that driver distraction and country of origin were significant factors of the average total braking time (Sohn & Stepleman, 1998). The research showed that United States drivers generally have higher perception-reaction times when compared to non-United States drivers (Sohn & Stepleman, 1998). The research confirmed that the perception-reaction time, which is the perception time added to the brake reaction time, is affected by criteria which also involve the driver and not only the vehicle and the roadside scenario (Young & Stanton, 2007). No research papers were found in relation to comparison between countries of the European Union.

2.1.4.2 Relationship between Gender and Perception-Reaction Time

Jain et al (2015) carried out research whereby they compared the visual and auditory reaction times based on gender and physical activity. The experiment involved the pressing of a space bar when the stimulus was given (Jain et al, 2015). Five readings of each stimulus were taken and the shortest reaction times were recorded (Jain et al, 2015). It resulted that there was significant difference between the reaction times of males and females (Jain et al, 2015). The source of the difference in the reaction time between males and females was not explained.

Warshawsky-Livne & Shinar (2002) analysed various components of braking time including the impact of gender on perception-reaction time and brake-movement time. The experiment was carried out on a simulator with 72 participants (Warshawsky-Livne & Shinar, 2002). The results of the experiment showed that gender did not affect perception-reaction time but it affected brake-movement time (Warshawsky-Livne & Shinar, 2002).

In a paper by Green (2013) he states that ‘it seems likely that females respond slightly slower than males’. Research carried out by Noble et al (1964), Welford (1980) and Adam et al (1999) resulted that males have less reaction times than females in almost every age group. Botwinich and Thompson (1966) carried out research which showed that most of the difference between males and females was due to the time difference between the start of the stimulus and the start of the muscle contraction. However there was no difference between males and females in the muscle contraction time themselves (Jain et al, 2015). Research carried out by Barral and Debu (2004) showed that although men had less reaction times than females however females were more accurate than men.

Research carried out by Kroemer et al (1994) concluded that gender difference relevant to perception-reaction times are minimal to none. Also they concluded that females perform better in fine-finger movements, hence accuracy, and also have better perception of colour but males tend to be faster. In the research carried out by Moir and Jessel (1991) it resulted that reaction times tend to be slightly shorter for males however they concluded that '*this difference is statistically but not practically significant'* and that for the '*purpose of traffic flow analysis, performance difference between men and women may be ignored*'.

2.1.4.3 Relationship between Age and Perception-Reaction Time

Lerner (1993) carried out research to verify if the perception-reaction times used in current practice meet the needs of older drivers. The study involved participants classified into three age groups, namely 20-40 years, 65-69 years and 70+ years, and compared the brake perception-reactions whilst driving on the road (Lerner, 1993). The experiment tested braking at an unexpected incident at a location on the road without any features which might enhance alertness (Lerner, 1993). It resulted that the younger age group had less perception-reaction times however there was no difference in the central tendency or 85th percentile values among the age groups (Lerner, 1993). The mean value was 1.5s and the 85th percentile value was 1.9 seconds (Lerner, 1993). These values did not exceed the current highway design perception-reaction times of 2 seconds for CEDR and DMRB and nor did they exceed the 2.5 seconds for AASHTO.

Different aspects of human performance, such as the time to respond and processing time leading to making a decision, change over the years in relation to driving (Koppa, 2003). However age is a poor indicator of performance (Koppa, 2003). Generally, visual performance decreases with age due to optical and physiological conditions of the aging process and due to changes in the neural processing of the image created on the retina (Koppa, 2003). Also, older drivers have problems to differentiate between irrelevant and important roadside information (McPherson et al, 1988). Older drivers' performance is affected when tasks that involve fine control, steadiness and fast decisions, are present (McPherson et al, 1988). For this reason older drivers compensate by driving at lower speeds (McPherson et al, 1988).

Research carried out by Petegem et al (2014) resulted that the perception-reaction time of elderly drivers did not significantly exceed the average for younger drivers. Similarly the research carried out by Koppa (2003), Petegem et al (2014) concluded that changes in the cognitive and physical abilities of elderly drivers could adversely affect their ability to comprehend roadside situations and react safely. As a result of this, AASHTO recommended that a design perception-reaction time of 3.0 seconds is adopted (Layton & Dixon, 2012).

Research was carried out by Warshawsky-Livne and Shinar (2002) whereby the impact of driver age on perception-reaction times was examined using a driving simulator. It resulted that the younger drivers not exceeding 25 years of age exhibited the fastest perception-reaction times, drivers between 26 and 49 years of age were slower and drivers exceeding 50 years were the slowest (Warshawsky-Livne & Shinar, 2002). Research which was carried out by Warnes et al (1993) showed that elderly drivers were slightly slower than the control group when not given an alert (Petegem et al, 2014).

However older drivers were significantly faster in their perception-reaction time than the control group when they were alerted and when they were tasked with a distraction (Warnes et al, 1993)(Petegem et al, 2014). Similarly, research carried out by Koppa (2003) and Petegem et al (2014) concluded that the average static and dynamic visual acuity of drivers over 65 years of age is reduced and it is more difficult for them to differentiate between critical and irrelevant information. Research carried out by Jevas and Yan (2001) concluded that age reduces the perception-reaction time however there was no difference between men and women in such case.

2.1.4.4 Relationship between Driving Experience and Perception-Reaction Time

The expectancy of a driver is the direct result of the driving experience and the training of the driver himself (AASHTO, 2011). Similar driving situations and how the driver responds successfully, are embedded in the knowledge base of the driver (AASHTO, 2011). Expectancy of driver reaction depends on the chance that the driver will react to a recurring driving scenario in the same way that was successful in the past (AASHTO, 2011). Expectancy determines how drivers are capable of understanding and managing information and how they therefore modify the type of response and the speed of the response (AASHTO, 2011).

Since the perception-reaction time differs between one person and another, it is important to include the driving behaviour to meet the humanized demands of the driver (Li & Chen, 2017). This aspect is considered to be part of the driving experience which is considered to be an element determining safety in comparative studies (Li & Chen, 2017). Research showed that driving experience yielded a positive impact in driver perception-reaction time in relation to static roadside risks (Scialfa, 2012). Borowsky & Oron-Gilad (2013) carried out experiments to establish the performance of new drivers, experienced drivers, very experienced drivers and taxi drivers by observing and obtaining video and eye movement data. The results of their experiment showed that drivers who had more driving experience had greater driving knowledge and skill when encountering hidden hazards (Borowsky & Oron-Gilad, 2013).

Konstantopoulos et al, (2010) showed that experienced and skilled drivers were capable of adapting their driving behaviour according to the dynamic driving scenarios more often than novice drivers. Even though increased driving experience enhances the perception-reaction time of drivers (Rudin-Brown et al, 2104), the impact varies from one driver to another (Li & Chen, 2017). Research carried out by Sagberg and Bjornskau (2006) did not result in a strong relationship between driving experience and perception-reaction time related to a hazard and nor to risk perception.

Green (2013) states that from research carried out from his end it resulted that although older people respond at a slower rate than younger people however the correlation with perception-reaction times is not clear. According to Green (2013), one issue with the different studies which were carried out is that the age group for older drivers varies between different studies. Also some studies which were carried out did not confirm any relationship between slower perception-reaction time and age (Green, 2013). Green (2013) continues to state that such studies conclude that the greater driving experience which comes with older drivers and their tendency to drive at slower speeds actually compensates for the slowing down of motor skills.

2.1.4.5 Psychological Refractory Period and Interference With Sub-Tasks

When a human is processing information and responding to a stimulus, there might be a delay in the reaction time because of the occurrence of a previous stimulus (Triggs anf Harris, 1982). This delay is called Psychological Refractory Period and it may be the result of the processing of information that the human operator would already be involved in (Triggs and Harris, 1982). This Psychological Refractory Period may account for additional delays to Perception-Reaction Times of a driver in a Level 3 automated vehicle when reacting to an alert to shift to manual vehicle control after the occurrence of a previous stimulus being the secondary task other than driving.

2.1.5 Driver Distraction and Vehicle Alerts

Driver distraction is defined as driver diverted attention from the driving task as a result of an activity or event occurring inside or outside the vehicle (Jin et al., 2014). Such activity competes for the attention of the driver and it generally causes delays in the recognition and processing of the information required for safe driving (Jin et al., 2014). Different previous research carried out suggests that the driving standard degrades when drivers engage in secondary behaviours which include the use of mobile phones, navigation systems and even holding a conversation with passengers (Jin et al, 2014; Wang et al., 2013).

Studies have concluded that secondary tasks have a significant adverse impact on driving performance (Jin et al., 2014; McDonald et al, 2019). Chisholm et al. (2008) concluded that the use of the iPod as a secondary task caused larger variation in steering wheel adjustments than when the driver is not engaged in a secondary task. Jin et al. (2014) concluded that the in-vehicle secondary task of using a touch-screen mobile phone reduced the ability of the driver to control the vehicle. Research carried out by Kun et al. (2007) and Jin et al. (2014) concluded that carrying out a secondary task whilst driving has a significant adverse impact on lane position, steering wheel angle, and the velocity of participants' cars.

Research carried out by Young et al. (2012) and Jin et al. (2014) showed that drivers made a large number of short fixations to the in-vehicle devices during the secondary task driving. Hence, carrying out a secondary task whilst driving has significant and multifaceted road safety implications (Jin et al., 2014). Few studies have analyzed the impact on safe driving in relation to performing secondary tasks while driving in Levels 1 and 2 AVs (Jin et al., 2014).

For this reason, Jin et al (2014) examined the impact of performing different secondary tasks on driver distraction and vehicle control (measured by noting driver eye movements) (Jin et al., 2014). The study by Jin et al. (2014) involved the collection of data of forty drivers performing a secondary task in a driving simulation (for a Level 1 and/or 2 AV) to verify the impact on safe driving. The results of the research showed that driving whilst performing a secondary task, the type of the secondary task and driving experience have an impact on safe driving and that a secondary task whilst driving can significantly decrease the safe driving performance (Jin et al., 2014).

The most extensive analysis of driver behaviour carried out is the 100-Car Naturalistic Study in the United States (U.S.) whereby the activities of 241 drivers were recorded over a period of 12 to 13 months with the aim of establishing the behaviour of drivers (Regan et al, 2009; RoSPA, 2017). From the study, about 42,300 hours of driving data was obtained in which the vehicles had covered about 2 million miles (RoSPA, 2017).

On completion of the study, the researchers studied 15 police reported collisions and 67 non-police reported collision and 761 near-collisions and 8.395 incidents (RoSPA, 2017). The results obtained showed that 78% of the collisions and 65% of the near-collisions were a result of distraction (RoSPA, 2017).

Further statistical analysis of US collision data shows that, for the year 2015, 10% of fatal collisions, 15% of injury collisions and 14 % of all police-reported traffic collisions were reported as being distraction collisions (National Center for Statistics and Analysis, 2017). In the same year, there were 3,477 fatalities and about 391,000 injured persons in vehicle collisions involving distraction (National Center for Statistics and Analysis, 2017). The data also shows that 9% of the drivers aged between 15 to 19 years old involved in fatal collisions were distracted at the time of the collision (National Center for Statistics and Analysis, 2017). Also, in 2015, there were a total of 551 non-vehicle-occupant collisions which resulted in fatalities as a result of distraction collisions (National Center for Statistics and Analysis, 2017).

The importance of this study methodology is that the database of driving events can be used for other similar studies to answer additional research questions than those originally addressed (Singh, 2010). Another advantage of this methodology was that the videos taken of the driving task allow for analysis of the pre-event and the during-event criteria and behaviour of drivers including distraction and fatigue (Singh, 2010). Also, the calculation of Perception-Response Time can be precisely calculated (Singh, 2010).

The Naturalistic Study Report had addressed a number of research questions and the most important results were as follows:

i. This study permitted the recoding of collisions that included minor collisions which are an important source of information since they occur more frequently than serious collisions (Singh, 2010). Also, of the 82 collisions reported in the study, only 15 had been reported to the police which shows that the real amount of collisions occurring are probably five time higher than those reported (Wolshon & Pande, 2016).
ii. About 80% of all collisions and 65% of near-collisions showed driver distraction in looking away from the road just before the collision (Anurag & Wolshon, 2016; Singh, 2010).
iii. 93% of the collisions with lead vehicles and for minor collisions were a result of inattention due to secondary task distraction, driver not looking forward, driver drowsiness and non-driver related eye-glances (Singh, 2010).
iv. With regards to collisions with lead vehicles, minor collisions occurred when the lead vehicle was moving (Singh, 2010). However collisions resulted for all cases that the lead-vehicle stopped which shows that drivers can perform evasive driving operation when lead distances are lower and when the expectation of the traffic flow is not altered (Singh, 2010).
v. Results show that collisions or near-collisions due to distraction decreases with age where the rate for the 18-20 year old bracket is four times higher than that for drivers older than 35 years (Singh, 2010).
vi. The highest frequency of secondary in-vehicle task which caused distraction was the use of mobile phones and PDAs and this was true for all types of collisions and near-collision cases together with looking at something else in the vehicle (Singh, 2010).
vii. Driver fatigue and drowsiness was shown to be a cause of distraction and a contributing factor of collisions at 12 % of all collisions and 10% of near-collisions (Singh, 2010). These rates were higher than those usually reported (Eskandarian, 2012).

For Levels 1 and 2 automation, distracted driving is a increasing becoming a road safety problem. Holding a conversation on a mobile phone and sending text messages results in physical and cognitive distraction and reduces driving alertness (WHO, 2011). Text messaging seems to have an adverse impact on driver behavior and this issue is likely to become more problematic because texting is cheaper than conversing on the mobile phone (WHO, 2011).

This use of mobile phone and texting habit poses a serious problem to road safety. Studies have been carried out related to this safety hazard to the driver in a Level 1 and 2 automated vehicle. In the case of a Level 3 automated vehicle, the driver is allowed to perform secondary tasks other than driving while the vehicle operates in automated mode. However, in case of an emergency where the driver needs to resume the driving task quickly, this distraction poses a challenge because it requires that the driver is alerted to take over the driving operations and this alert sets off the driver Perception-Response Time which is a determining factor to reduce the road safety risk.

The cognitive capabilities of humans are limited (Hole, 2007; Shinar, 2007). This means that if a driving task exceeds the capability of the human, the level of driving performance of the human degenerates and can lead to an accident (Hole, 2007; Shinar, 2007). Many mental resources compete together during the driving task and these include those involving the primary driving task itself and also include a number of different secondary tasks (Hurts et al, 2011). The secondary tasks, which constitute the driver distractions, include those related to the driving task itself and those which are not related to the driving task (Hurts et al, 2011). Driver distractions can be visual, auditory, cognitive and biomechanical and these do not present themselves in isolation however all distractions have a cognitive aspect (Ranney et al, 2000).

Considerable research has been carried out related to the use of mobile phones whilst driving (D’Addario, 2014). Sending a text message, typing a text message or dialing the phone presents a visual, biomechanical and cognitive distraction (D’Addario, 2014). Green (2013) suggests that when the driver is distracted with driving and non-driving-related matters, the perception-reaction time is longer. Green (2013) also identified the use of in-car displays and the use of cell phones as being major sources of an additional load on the driver's attention.

Neubauer et al (2012) suggests that the management of vehicle automation creates a distraction in itself. Carsten et al (2012) carried out research whereby they report that increased vehicle automation increases the chance of engaging in a secondary task such as watching a Digital Video Disc (DVD). Merat et al (2012a) considered the impact of secondary task engagements on driver perception-reaction times during a critical scenario in manual and automated vehicles. The research by Merat et al, (2012a) found that when drivers were engaged in a secondary task and an urgent situation arose, they experienced a sudden increase in workload (cognitive) and the demand to resume the driving task exceeded their cognitive capacity thus impairing the perception-reaction time.

2.1.6 Type of Driver Distraction and Their Effects

Transport literature generally makes reference to four different types of driver distraction namely visual, cognitive, biomechanical and auditory (Ranney et al., 2000; RoSPA, 2017). It is to be noted that such driver distraction classifications are not mutually exclusive (Basacik & Stevens, 2008). Whilst a type of distraction might pose a visual distraction however it would probably also include other types of distractions such as biomechanical as in the case of adjusting vehicle controls (Basacik & Stevens, 2008). Distracted drivers do not fully understand the effects of distraction on their driving performance and do not realize their reduced awareness of the roadside environment and their potential to identify safety risks which is a direct result that they are still looking straight ahead and thus they are not scanning the whole roadside environment (RoSPA, 2017).

The four types of driver distraction are described as follows:

i. Visual distraction is when the driver focuses attention on objects or events which impair the focus on the roadside environment (Gursten, 2019). There are three types of visual distraction during the driving task which impede safe driving namely, when the visual field of the driver is blocked (front, sides or rear), when the driver does not look at these critical areas of the visual field because he would be instead focusing for some period of time on another visual target and when the driver is distracted therefore not concentrating on the driving task (Ito et al., 2001; Adolph, 2010). During driving situations which pose no demand on the driver's attention, the driver tends to focus on objects which are not part of the driving task amounting to a time period of 20% and 50% of the total driving time (RoSPA, 2017).
ii. Auditory distraction occurs when sounds impair the hearing capacity of the driver and the attention of the driver is focused on the origin of the sound rather than on the roadside environment (Adolph, 2010). Such type of distraction is mostly impaired when the driver uses a mobile phone or when holding a conversation with passengers or when listening to the radio (Adolph, 2010).
iii. Biomechanical distraction is when a driver is carrying out a secondary task involving a physical action which is not related to the driving task and thus does not focus on the physical tasks required for safe driving (Adolph, 2010; RoSPA, 2017).
iv. Cognitive distraction is when the driver is thinking about matters not related to the driving task (Gursten, 2019). Studies show that during a cognitive task the field of vision of the driver narrows both horizontally and vertically (RoSPA, 2017). The attention of the driver is taken up thus impairing the ability of the driver to drive safely and the perception-reaction time is also reduced (Adolph, 2010). Drivers involved in cognitive distraction are thus less likely to be attentive to risks in the roadside environment and are also less likely to check mirrors (RoSPA, 2017).

Answering calls on the mobile phone and reading and writing a text message are two common potential causes for driver distraction in Levels 1 and 2 AVs however other important sources of distraction include technology-based equipment, traffic information and in-vehicle entertainment systems such as radios, CDs and MP3 players (Adolph, 2010). Future in-vehicle infotainment distraction will be the direct result of the power of the internet and the personal computer in the vehicle itself and also due to the high-speed wireless interfaces, developments in advanced screen technologies and increased processing capacities (Adolph, 2010).

Such in-vehicle distractions will be more pronounced in Level 3 AVs due to the possibility of the driver undertaking secondary tasks whilst the vehicle operates in automated mode. It is to be noted that the cognitive and sensory abilities differ between older and inexperienced drivers from those of experienced and younger drivers (Hammer et al, 2007). Also, the extent that in-vehicle information and technological systems distract from the driving task depends on the user, the task being performed and on the demand placed on the driver but it does not depend on the devices themselves (Hammer et al, 2007).

2.1.7 Driver Distraction and the Driverless Vehicle

The concept of the driverless vehicle has received a large amount of attention due to the publicity given to companies which are currently developing such vehicles and also due to new legislation which allowed for the testing and operation of such vehicles on the public roads (Merat et al, 2014). Interest was further instilled due to statements made by Nissan, General Motors and Mercedes to start the sales of self-driving cars by 2020 (Merat et al, 2014).

However there has been slow development in relation to policy and research activity to comprehend the impact of driverless vehicles on traffic management (Merat et al, 2014). The technology to support driverless vehicles is relatively at an advanced stage (Kyriakidis et al., 2017). However research, in relation to human factors, is lacking which would ensure that drivers operating such vehicles are fully cognizant of the limitations and potential operations of automated vehicles (Kyriakidis et al., 2017).

About 20 years ago research was carried out on human factors in relation to the interaction between the driver and Adaptive Cruise Control (ACC) (Merat et al, 2014). The research argued that driver attention decreased at higher levels of vehicle automation thus adversely affecting the performance of the driver in case of vehicle system failure (Merat et al, 2014). In the past years, research has developed vehicle automation systems beyond ACC by including lane keeping assistance and moving from Level 1 function-specific automation to Level 2 combined-function automation to Level 3 limited self-driving vehicles (Merat et al, 2014). European research projects which have included human factors with vehicle automation technology included CityMobil, InteractiVe and HAVEit (Merat et al, 2014).

However driver behaviour and performance at Level 3 automation is still not sufficiently comprehended (Merat et al, 2014). At this level the driver is expected to take over manual control of the vehicle with sufficient time to enable a smooth transition (Coles, 2016; Kyriakidis et al., 2017). Hence it is important that the driver is in a position to maintain awareness as this would enable the resumption of vehicle control when necessary. The reasons that the driver might be required to assume the manual operation of the vehicle may be related to a specific road occurrence which the automated vehicle would not be in a position to address (Kyriakidis et al., 2017). There is currently very little research on how drivers transition from automation to manual and also on what is expected of sufficient transition time periods (Kyriakidis et al., 2017).

The research conducted as part of the EASY Project (Effects of Automation on SafetY) has analysed the interaction between the driver and Level 3 automation, the appreciation of the roadside environment and the effect of secondary tasks other than driving (Merat et al, 2014). Results showed that driver visual distraction increased as the level of vehicle automation increased (Merat et al, 2014).

With an increase in the levels of automation, drivers increased the performance of secondary tasks such as watching a dvd (Merat et al, 2014). It resulted that this engagement in a secondary tasks did not pose a problem to driving provided that the roadside environment did not pose a driving challenge (Kyriakidis et al., 2017). However it also resulted that when the driver is required to resume manual control in a challenging situation during the performance of a secondary task, the sudden change in work load poses a driving safety risk (Merat et al, 2014).

One of the most important advantages advocated for increased levels of automation is the increase in road safety when eliminating driver error which is a contributory reason for vehicle collisions (Kyriakidis et al., 2017). On the other hand, vehicle automation appeals to drivers by offering the freedom of engaging in secondary tasks during the driving period (Merat et al, 2014). However this engagement in secondary tasks is actually the reason which causes reduced driving performance as a result of driver inattention to the roadside environment (Kyriakidis et al., 2017). For this reason it is imperative that the automated vehicle technology can effectively and efficiently recall the driver to driving mode when necessary due to occurrances in the roadside environment (Merat et al, 2014).

One of the important aims of the study carried out as part of the EASY project was to assess how quickly drivers transitioned to manual driving mode when the necessity arose by observing driving performance and eye tracking metrics (Merat et al, 2014). This means that this study assessed the Perception Time Period. The participants were enrolled using a newspaper advert and the database of the driving simulator (Merat et al, 2014). There were a total of 46 participants, 25 of whom were males and 21 were females. Results from 37 participants were analysed since 12 participants had missing eye tracking data (Merat et al, 2014). All participants had 10 years driving experience and the age group was between 28 to 67 years (Merat et al, 2014).

Fully automated vehicles still cannot guarantee that no collisions will occur and thus it is imperative that the interaction between the driver and the Level 3 automated system is fully understood (Merat et al, 2014). In spite of the technological advancements made, automated vehicles will still have limitations (Merat et al, 2014). During the study, the driver was alerted to resume manual control at time periods of 6 minutes. The driver was also alerted when distracted. The perception time was less when the driver was engaged at fixed time periods and visual attention was erratic for 40 seconds after transfer of vehicle control to driver (Merat et al, 2014). The results are important to appreciate the criteria required for the design of driver alert systems in automated driving scenarios to ensure that alerts are made in a timely and appropriate manner (Merat et al, 2014).

2.1.8 Effect of Type of Alert on Perception-Reaction Time

In-vehicle alerts are imperative in a Level 3 automated vehicle to alert the driver to resume the driving task. This is because the tendency for the driver towards distraction in the form of a secondary task causes a reduction in situation awareness which may cause the possibility of a dangerous driving situation to arise (Merat & Lee, 2012). In the case of automated vehicles, the time period that the driver takes to resume the driving task is crucial because the driver is required to intervene in critical situations where a fast reaction is essential (Merat & Lee, 2012).

A Simple Reaction Time is the time to detect an alert, where the Simple Reaction Time is established when an individual is required to press a button when a light or sound is activated (Shelton & Kumar, 2010). In the case of this research, the survey participant was required to click on the screen when alerted and hence constituted a Simple Reaction Time. This is a physical ability where the level of neuromuscular coordination interprets visual or auditory alerts which reach the brain as sensory stimuli (Shelton & Kumar, 2010). Research carried out by Thompson et al (1992) resulted that the average reaction time to detect a visual alert was approximately 180-200 milliseconds whilst the time to detect an auditory alert was 140-160 milliseconds. Research carried out by Shelton & Kumar (2010) found that the mean reaction time for a visual alert was 331 milliseconds and the mean reaction time for an auditory alert was 284 milliseconds. Hence according to Thompson et al (1992) and Shelton & Kumar (2010) the auditory reaction time was less than the visual reaction time.

Research carried out by Kemp (1973) shows that the auditory reaction time is less than the visual reaction time because an auditory alert takes 8-10 milliseconds to reach the brain but a visual alert takes 20-40 seconds. This means that the faster the alert reaches the motor cortex, the faster is the reaction time to the alert (Kemp, 1973). Since the auditory alert reaches the cortex faster, the auditory reaction time is less than the visual reaction time (Shelton & Kumar, 2010). The research by Shelton & Kumar (2010) also concluded that males have lower reaction times than females for auditory and visual alerts. This confirms the data obtained by this research when the gender differences were evaluated.

The research referred to above compares auditory alerts to visual alerts. However, the environment is multisensory and hence auditory and visual sensory stimuli are generally processed concurrently (Mishra & Gazzaley, 2012). Also, neural integration of multisensory information is related to the allocated focus or distribution of attention which enables the processing of sensory stimuli (Mishra & Gazzaley, 2012). Mishra & Gazzaley (2012) compared the effect of one sensory mode (visual) to attention distributed across different modalities (visual and auditory) (Mishra & Gazzaley, 2012). It resulted that distributed audiovisual attention was beneficial for multisensory behavior relative to focused visual attention (Mishra & Gazzaley, 2012). This is due to reduced sensorineural processing (Mishra & Gazzaley, 2012). These improvements result from the reduction in the processing period within unisensory auditory and visual cortices and polysensory temporal regions (Mishra & Gazzaley, 2012). Hence the sensory neural processing during distributed audiovisual attention relative to focused visual attention is reduced (Mishra & Gazzaley, 2012).

Kemp (1973), Thompson et al (1992) and Shelton & Kumar (2010) examined the difference in reaction time for a visual alert and for an auditory alert and it resulted that the reaction time was less for the auditory alert. Mishra & Gazzaley (2012) examined the difference in reaction time for a visual alert and for a multisensory auditory and visual alert. It resulted that the reaction time was less for the multisensory alert.

Lu et al. (2019) carried out research in a simulator for conditionally automated driving whereby they examined the effectiveness of Monitoring Requests (MR) and possible Take-Over Requests (TOR) on the safe and efficient driver re-engagement in the driving task. The research involved a total of 41 participants where, for the first experiment, the MR was activated 12 seconds in advance of a zebra crossing whilst the TOR was activated 5 seconds before the zebra crossing where the vehicle would collide with a pedestrian if the drver failed to intervene in a timely manner (Lu et al., 2019).

In the second experiment, the TOR condition only was activated at 5 seconds before the critical situation of the zebra crossing (Lu et al., 2019). Particiants were distracted during the experiment with a self-paced visual-motor task as a secondary task other than driving (Lu et al., 2019). The results of the experiment were that when both the MR and TOR were activated, the participants had a shorter perception-reaction time than the TOR only experiment (Lu et al., 2019). A third experiment was carried out where on the MR was activiated and the perception-reaction times of the participants were the longest out of the three experiments showing that a combination of MR and TOR increases safety and AV acceptance (Lu et al., 2019) and that TOR is essential. As part of their research, Lu et al. (2019) defined the following time periods related to MR and TOR which were:

a. Hands-on-Wheel Time defined as the time period between the hazard becoming visible until the driver put one hand on the steering wheel;
b. Brake Initiation Time defined as the time period between the moment the hazard becomes visible until the first braking movement;

c. Steer Initiation Time defined as the time period between the moment a hazard became visible to the first steering movement;
d. Minimum Time to Collision defined as just after the moment the driver pressed the brake where TCC is zero if collision occurs;
e. Maximum Longitudinal Deceleration (Braking Time) and was calculate for the period that the driver pressed the brakes.

The first three definitions above are for the perception-reaction time period measuring the time from the perception of the hazard to the first reaction which could have been the driver putting on hand on the steering or the first braking movement or the first steering movement,.

Similarly, to the research carried out by Lu et al. (2019), the research carried out by Gold et al. (2013) resulted that distracted drivers in a HAD in a simulator successfully avoided a stationary hazard following an auditory warning which was given 5 to 7 seconds in advance where the lower limit of 5 seconds was considered to be challenging but manageable for visually distracted drivers to safely resume the driving task. Lu et al. (2017) stated that, when drivers need to resume the driving task in conditional driving, they need sufficient time to achieve situation awareness and prepare to resume the driving task and established that time period at 7 seconds.

Eriksson & Stanton (2017) and Zhang et al. (2018) stated that many different researches which have been carried out have confirmed the importance of the driver having sufficient advance warning on the approach to a hazard or collision. Zhang et al. (2018) also concluded that athough often the advance warnings are activation from 5 to 7 seconds prior to collision, the actual time which the driver requires to resume the control of the vehicle depends on the drivng task and the context of the roadside scenario. Research carried out by Mok et al. (2017) resulted that almost all the vehicle drivers collided when the advance warning was activated 2 seconds prior to collision. This shows that a 2 second advance warning is not sufficient for the driver to safely re-engage in the driving task.

Lu et al. (2019) stated that in actual road scenarios it is not always possible to have a long TOR. Lu et al. (2019) continues to state that since vehicle automation depends on radars and cameras to detect a hazard or potential collision hence the time of the advance warning for the TOR depends on the predictability of the roadside scenario and on the limitations of the sensors and cameras. This implies that the advance warning period between the TOR and the actual hazard is relatively short (Lu et al., 2019). Although the intention of conditional driving is that the driver does not need to constantly monitor the road however in a review carried out by Carsten & Martens (2018) they concluded that in most cases it is not possible for the automated technology to alert the driver to resume the driving task with sufficient advance warning so constant monitoring is necessary.

Gold et al. (2013) had examined the effects of MR to prepare the driver for a TOR using a driving simulator and it results that the participants has shorter perception-reaction times at TOR and a reduction in non-intervention cases when the participants were ‘hands on’. Although these studies indicate that having an MR improves safety in automated driving however these studies did not compare the impact of MR with a system which provides only a TOR (Lu et al., 2019). Lu et al. (2019) carried out research to examine the effect of have a combined MR and TOR where the MR would not rely on the cameras and sensor of the AV but on vehicle localization in respect to established and known critical locations on the network.

Hence the driver in a Level 3 vehicle would be prepared to resume the driving task but will not necessarity have to take over the control of the vehicle (Lu et al., 2019). However such concept has the disadvantage that continuous MRs would hinder the potential of the driver engaging in secondary tasks other than driving and would also result in the driver ignoring such MRs when they wish to engage in such secondary tasks (Yang et al., 2017). Studies carried out by Tijerina et al., (2017) and Naujoks et al. (2016) showed that such false advance alarms cause the ‘cry-wolf’ effect. Alternatvely, if advance warnings constanty necessitate a response, the driver may become dependent of such warnings resulting in errors of omission or errors of commission, hence complacency in responding to an alert (Skitka et al., 1999).

A number of other researches focused on the idea of having a two-step TOR to get the attention of the driver and this differs from the advance MR because the driver always needs to resume the drving task for an advance TOR but does not need to do so in the case of an advance MR (Lapoehn et al, 2016; Naujoks et al., 2015).

2.1.9 Relationship between Hue and Perception-Reaction Time

The measure of reaction time is used to examine the central information processing speed and coordinated peripheral movement response (Ayaz & Mazen, 2018; Balakrishnan, 2014). The research quoted above referred to Simple Reaction Time. In the case of Visual Choice Reaction Time, such reaction time relates to colour. People visualise colour in terms of hue, saturation and brightness (Gaines Lewis, 2015). Hue is the colour itself such as red, yellow, green or blue (Gaines Lewis, 2015). Saturation is the depth of the colour whilst brightness is how the colour reflects the light (Gaines Lewis, 2015).

Research carried out by Abramov et al (2012) showed that the difference between men and women in relation to hues was that women were more capable of distinguishing between subtle gradation than men especially when it comes to colours located at the middle section of the spectrum, namely yellow, orange and pink (Abramov et al, 2012). According to Abramov et al (2012), the difference in the levels of testosterone in men and women results in differences in the way that the neurons are organized in the visual cortex. The elements of vision are determined by inputs from the neurons in the primary visual cortex (Abramov et al, 2012). This results in the differences in visual perception for the colours located at the middle section of the spectrum (Abramov et al, 2012).

Research carried out by Balakrishnan (2014) showed that, for a sample of 60 female participants, it resulted that red and green had significantly reduced visual choice reaction when compared with yellow because the individual colour (hue) mental processing time for yellow is more than for red and green (Balakrishnan, 2014). According to Abramov et al (2012), the difference in the levels of testosterone in men and women results in differences in the way that the neurons are organized in the visual cortex (Abramov et al, 2012). This results in the differences in visual perception for the colours located at the middle section of the spectrum (Abramov et al, 2012).

Based on the research carried out by Abramov et al (2012), since red and green are not located in the middle part of the colour spectrum, there is no difference between men and women in the way that the red and green hues are perceived. In the case for both colours, the research by Balakrishnan (2014) may be applicable to both men and women. The red hue itself reduces visual choice reaction and thus reduces the processing time (Balakrishnan, 2014). The research carried out by Coley et al (2008) also measured reaction times in relation to an alert which was a red rectangular bar where such measure was used to determine the alterness of a driver. Balakrishnan et al (2014) recommend that yellow is avoided in scenarios where reaction time is important.

2.1.10 Relationship between Perception-Reaction Times and Accidents

Research which was carried out by Treat et al (1979) resulted that 90% of road accidents were due to human factors and this percentage is higher than environmental and vehicle factors where human factors such as inattention and in-vehicle distraction played a vital role. Research carried out by Hendricks et al (1999) resulted that 99% of traffic collisions were due to driver behavioural error either causing or contributing to the collisions. Dingus et al (2006) carried out the 100-car naturalistic driving study and concluded that distraction or inadequate visual orientation contributed to 80% of all traffic collisions and to 65% of near-collisions.

A number of studies were undertaken studying the association between reaction time and patterns and the rate of vehicle accidents of drivers (Triggs and Harris, 1982). Generally these studies select groups of drivers with different accident levels and then the performance characteristics of each group are analysed (Triggs and Harris, 1982). It is to be noted that, although there is a correlation between accident rates and some laboratory-based performance level, it does not mean that a lack of driving performance skill or capability is necessarily a factor in the driver's collision (Triggs and Harris, 1982).

Vehicle collisions arising from driver distraction was also analysed by the National Centre for Statistics and Analysis (NHTSA) by carrying out the National Motor Vehicle Crash Causation Survey (NMVCCS) for the years starting from 2005 to 2007 (Singh, 2010). Information from interviews with the driver and witnesses was collected immediately after the crash (Singh, 2010). This information included data regarding the driver, the vehicle, the environment and the roadway characteristics (Singh, 2010).

The study focused on the non-driving activities namely conversation and inattention in the NMVCCS data which was recorded for the accident (Singh, 2010). Each of these non-driving activities was recorded as being the pre-crash activity irrespective if it was a cause for the accident itself (Singh, 2010). The two types of inattention factors which were assessed were the interaction of the driver with distractions inside the vehicle such as using the phone or adjusting electronic equipment and the cognitive thinking processes of problems not related to the driving task (Singh, 2010). Also other influential factors including the age of driver, gender, traffic flow, speed limit and environmental conditions were assessed since these may have an impact on the driving operation (Singh, 2010).

The weighted analysis of the NMVCCS data resulted that in-vehicle driver distraction was the significant type of distraction amongst the drivers (Singh, 2010). To assess the impact of the age of the driver, the analysis was carried out on four age groups namely, under 16, 16 to 25, 26 to 64 and 65 years and older (Singh, 2010). The drivers who were mostly distracted were males in the 16 to 25 age group and such in-vehicle distraction frequency decreased as the age of the driver increased (Singh, 2010). On the other hand, the amount of drivers distracted by cognitive thinking did not change with age (Singh, 2010).

Holding a conversation with a passenger was the most common in-vehicle non-driving task which caused driver distraction irrespective of age, gender, speeds, traffic flows or environmental conditions (Singh, 2010). However, it is to be reminded that such distraction cannot be considered as being the cause of accidents. The use of the mobile phone as an in-vehicle distraction, hence conversing, dialing, hanging up or texting, was the second most recorded distraction which was mostly common in the young and middle-aged drivers and was also more frequent with female drivers (Singh, 2010).

Similarly this research study will also be evaluating the results obtained by age group and gender. The Response Time results will be compared to establish trends for in-vehicle distraction for Level 3 automation. However it is to be noted that this research did not assess the response of drivers in relation to driving experience and disabilities. Also the experiment was not carried out within a driverless car scenario.

2.1.11 Stopping Sight Distance Estimates

Most important for the scope of this research document is that the research by Lu et al. (2019) concluded that the survey participants had 0.44 seconds lower brake response time when there was a combination of MR (Monitoring Request) and TOR (Take Over Request) alerts when compared to TOR alerts only. Although such value is modest on an absolute scale however it is to be noted that an additional 0.44seconds braking time means a reduction of

13km/h advance speed for a deceleration of $8ms^{-2}$ (Lu et al, 2019). Also this reduced brake response time translates into reduced braking distance which means that it also reduces the SSDs required. This SSD value is extremely important because the cameras and sensors of the AV are constrained by their range of detection (Lu et al., 2019). However, as stated by Lu et al. (2019), the provision of MRs does not ensure that automated driving wll not result in collisions.

Also very important for the scope of this research document, Lu et al. (2019) showed that when the automated vehicle technology (sensors and radars) do not detect an oncoming hazard and thus do not alert the driver to resume the driving task by providing a TOR, a number of drivers still had a collision even if the drivers were monitoring the roadside scenario following an MR. This conclusion of the research by Lu et al. (2019) is pertinent for the scope of this research because it shows the importance that the sensors and radars of an AV must be able to detect a hazard in the time period which is sufficient for the driver to safely resume the driving task. This time period is directly translated into the distance between the AV and its sensors/radars and the potential hazard/collision. This distance must be sufficiently long to allow for the timely alert of the driver where such distance depends on the speed of the vehicle determined by the speed limit of the road and is the SSD.

Due to safety reasons, the human driver is the main component in road design specifications, which design depends on the PRT of the driver, driver eye height and other parameters which are directly related ot the driver (Khoury et al., 2019). Since the 1900s, road design textbooks put forward guidelines for road design for vertical and horizontal curves, lane widths, road intersections and other related criteria for good road design (Khoury et al., 2019). The SSD determines the distance which a human driver requires to safely perceive, react and bring the vehicle to a halt before colliding with an obstacle (Khoury et al., 2019). The PRT of the majority of drivers in a Level 0 to 2 vehicle is accounted for in the existing SSD values (Khoury et al., 2019).

The online training course by Washburn & Washburn (2018) contains a brief overview of AVs and their likely impact on the flow of traffic and on the geometric design of roads. The course concluded that due to the fact that AV have LiDAR and ther senors installed, such AV can identify obstacles better than humans however the line of sight of AVs could still be obstructed at horizontal curves (Khoury et al., 2019). The existing vehicle automation technologies does not address the most important limitation related to human sight, being the line-of-sight (Washburn & Washburn, 2018). It is not possible to assume that the automated vehicle technology will be able to detect a hazard located around a bend on the road before a human could (Washburn & Washburn, 2018).

SSDs are the primary criteria for the design of road aligments and for locating road signage (Khoury et al., 2019). Research carried out by Farah et al (2018) resulted that existing research focusses on the impact of AVs and CVs on digital infrastructure and not on the physical road infrastructure.

Thus, adequate stopping sight distances are required to establish the geometric design criteria of roads. However even the correctness of such existing values for geometric design have been challenged (Triggs and Harris, 1982). Sight distances are also affected by the eye height of the driver, the height of the obstacle and the speed of the vehicle (Triggs and Harris, 1982). Specific scenarios of the roadside environment determine the type of sight distance which is to be used. There are five different types of sight distances (Triggs and Harris, 1982):

i. Stopping sight distance
ii. Overtaking sight distance
iii. Intersection sight distance
iv. Headlight sight distance
v. Intermediate sight distance.

It was concluded that the sight distance standards currently in use are not appropriate where the risk stimulus is difficult to perceive (Triggs and Harris, 1982). Nor are they suitable when the reaction is complex or where sudden braking is not the appropriate evasive action (Triggs and Harris, 1982). Alexander and Limenfeld (1975) proposed that Decision Sight Distance becomes part of the design concept to enable the addition of other criteria to those already included in the SSD criteria. They established the definition for Decision Sight Distance as being the distance where drivers are capable of noting a risk or alert signal in a cluttered roadside environment, of establishing a safe speed and manoeuvering a safe driving strategy in a timely manner. The scope for this Decision Sight Distance is to establish design standards by which all drivers have sufficient distance to manoeuver with a reasonable allowance for errors (Triggs & Harris, 1982; Alexander and Limenfeld, 1975).

This concept was developed further by McGee et al (1978). The Decision Sight Distance was taken as being the time for the detection and recognitions of a risk situation, the establishment of driving strategies, the identification of the best strategy and the start of the implementation of the strategy (Triggs and Harris, 1982). At the beginning of the experiment the times were assumed to be as follows (Triggs and Harris, 1982):

i. Time for detection and recognition: 1.5s for low speeds and 2.0s for higher speeds
ii. Time for decision and response (worst case scenario): 4.2 – 6.6s for lower speeds and 4.7 – 7.1s for higher speeds.

During the trials carried out, the driver in a non-automated vehicle was required to drive along a pre-selected route on the public road network and to respond to specific geometric configurations of the road which required a change in speed or driving path (Triggs and Harris, 1982). The driver sent an alert on the initial sighting of the geometric characteristic, at the moment of change in speed or change in driving path and also at the moment of completion of the driving manoeuver (Triggs and Harris, 1982). The first alert, that of pressing the horn button, corresponded to Perception-Reaction Time (Triggs and Harris, 1982). Nineteen participants took part in the experiment and they covered a wide age range between them (Triggs and Harris, 1982). The time values obtained from this experiment were as follows (Triggs and Harris, 1982):

i. Recognition Time value: mean of 5.7s with standard deviation of 4.6s. hence the original values for detection and recognition were increased to 3.0s
ii. Time for decision and response: mean of 4.8s with standard deviation of 4.7s. These values fell within the range of the original assumed range of times identified namely 4.2s to 7.1s.

The study by Mcgee et al (1978) concludes Decision Sight Distance time periods in a pre-manoeuver stage being between 5.7s and 7.1s. Both these time values and those of Triggs and Harris (1982) are much higher than the 2.5s Perception-Reaction time used in the U.S. and Australia (Triggs and Harris, 1982). They are also higher than the 2.0s used in parts of Europe and the United Kingdom (HMSO, 1978) and also exceed the 3.0s value which is sometimes proposed (Triggs and Harris, 1982).

A Perception-Reaction times value exceeding 2.5s was supported extensively (Glennon, 1970). Gordon (1979) suggested that the existing 2.5s time value is understood as being a minimum value in the U.S. The Texas Transportation Institute (1970) decided on a value of 5.0s. Forbes and Katz (1957) also recommended that in the case where the vehicle driver is faced with a decision of a complex risk scenario, the decision time may increase to 5.0s or more. When there are situations in which there are a number of different response choices available to the driver or where the risk is difficult to identify, there inevitably are long decision times (Triggs and Harris, 1982).

Within the context of the above, the results of the McGee experiment are not necessarily exceedingly high (Triggs and Harris, 1982). However the time values for the detection and recognition phase were more than the values resulting in other similar experiments of

Perception-Reaction time (Triggs and Harris, 1982). This might have been due to the difference between the critical stimuli (Triggs and Harris, 1982). The time period for the decision-response period might not have factored for the processing capacity of the driver which, in turn, might have posed a limitation (Triggs and Harris, 1982). Instead it factored the delay to start a manoeuver (Triggs and Harris, 1982).

The above research has showed that the results of the experiments from trials carried out on rural roads without alerts had greater reaction times than the results of experiments carried out in controlled conditions or when alerts were given (Triggs and Harris, 1982).

The results also showed the importance of quantifying the response times of drivers on the public road network. The response times depended on the road scenario and circumstance, on the level of risk, and approach vehicle speeds (Triggs and Harris, 1982). In urgent road scenarios, with a high level of risk, most drivers responded in less than 2.5s without being previously alerted however this happened in situations where the stimulus or hazard was simple. With more difficult stimuli requiring complex decision making processes, a greater response time is expected (Triggs and Harris, 1982). As a result of these studies driver response times in a Level 1 or 2 automated vehicles are expected to be greater than the design value of 2.5s on a regular basis (Triggs and Harris, 1982). As a result and on the basis of various experiments carried out, it appears that the 2.5s Response Time value for Level 1 and 2 automated vehicles needs to be reviewed (Triggs and Harris, 1982). This is notwithstanding the requirement for further investigation of Response Times (Perception-Reaction Times) for Level 3 automated vehicles.

This research by Triggs and Harris (1982) shows that the driver will have a faster reaction if there is an alert to a stimulus (Triggs and Harris, 1982). This means that the driver has the possibility of planning how to respond before the stimulus happens (Triggs and Harris, 1982). Accordingly the preparedness to respond is imperative for the different types of reaction times being described (Triggs and Harris, 1982). When an unexpected stimulus happens on the road, the driver may need to alter his mental state to the new situation before being in a position to plan for his response (Triggs and Harris, 1982). This constitutes the Perception Delay referred to previously.

The duration and variability between an alerting signal and the signal to respond, known as the foreperiod, have been shown to determine simple reaction time and type of reaction time (Triggs and Harris, 1982).

Also the human's uncertainty of when the alert would be given can be manipulated (Klemmer, 1956). This is because the human is not in a position to estimate time with precision and, the longer the foreperiod, the less the human will be in a position to estimate when the alert will be given (Klemmer, 1956). Also the foreperiod can be varied (Klemmer, 1956). It is not a constant time period and this adds to the uncertainty of the human (Klemmer, 1956). Klemmer concluded that the reaction depended on a combination of these two uncertainties. Consequenty, the level of prepardness to receive and respond to an alert depends on whether the human can determine with certainty the recurrence of the alert and the time period which will elapse (Klemmer, 1956). This is applicable to a driver being alerted in a Level 3 automated vehicle and his Perception-Reaction Time to engage in the driving operation.

Most of the research carried out in relation to the level of preparation to respond to alerts has been carried out for relatively short time periods (Triggs & Harris, 1982). However, Warrick, Kibler and Topmiller (1965) carried out studies whereby the waiting periods amounted to days. This longer interval created a high level of uncertainty regarding when the alert would occur and thus the participants in this experiment were unalerted and their reaction times were between 100 and 140ms longer than for conditions when the participants were on the alert (Triggs & Harris, 1982; Warrick et al, 1965). It is debatable whether this experiment can be adapted to Level 3 vehicles on the road however this experiment clearly shows how human alertness is affected by the frequency of the alerts (Triggs and Harris, 1982).

In the experiment carried out by Blanco et al (2015) the effect of the driver alert systems in the automated vehicles and the behaviour of the operator were examined. Participants had the necessary tools to perform secondary tasks in the vehicle and were presented with a message to resume the driving task (Blanco et al, 2015). The time taken for the participants to respond was examined. The participants were able to differentiate between the different types of alert and reacted accordingly (Blanco et al, 2015). It resulted that resuming control of the driving task was affected by the type of alert (Blanco et al, 2015). The total mean perception-reaction time for the participants to regain control after an immediate alert without an external threat was 3.00 seconds. The total mean perception-reaction time for the participants to regain control after an immediate alert with an external threat was 2.73 seconds. Both these values exceed the maximum perception-reaction time of 2.5 seconds adopted by different countries to establish the Sight-Stopping Distances.

Motor vehicles are operated by drivers who have different levels of driving training, experience, skills (Bassan, 2018; Cao et al, 2014) and conditions. In road design, the ability of the driver to have sufficient forward visibility to enable the identification of conflicts is important for safe driving operations and it is determined by the perception-reaction time. Innamaa et al., (2018) carried out research whereby they suggest that new indicators will need to be measured for AVs, including the moment that the driver is required to intervene, the response to near-collision incident and time-to-collision. A similar indicator to time-to-collision is the perception-reaction time which is the period of time the driver needs to react before a collision (Shawarby ey al, 2008; Lefevre et al, 2014). Perception-reaction time translates into and is reflected in the Stopping Sight Distance for road design purposes.

Sight distance is defined by O'Flaherty (2003) as '*the length of carriageway visible to a driver in both the horizontal and vertical planes'*. This is the most important design consideration to ensure the safe and efficient operation of roads. Sight distance is a basic component of road design policy which affects the road alignment, vertical and horizontal curves to ensure safety for drivers (Bassan, 2018). On the other hand, Stopping Sight Distances (SSD) are the minimum distances within which a driver can stop safety without colliding with an obstacle (Civil Engineering Terms, 2013). SSD is made up of the distance travelled by the vehicle before the driver reacts together with the distance travelled after the driver reacts and the vehicle comes to a halt (Civil Engineering Terms, 2013). Hence it is the amount of distance travelled for the driver for perception-reaction time of an obstruction and for the vehicle to come to a halt (Civil Engineering Terms, 2013). The perception-reaction time is dependent on the physical fitness of the driver and the alertness of the driver (Regan et al, 2009; Civil Engineering Terms, 2013). The braking time depends on the tyre friction with the pavement surface, the tyre and road condition, the speed of the vehicle and the brake conditions (Schoon, 2019; Civil Engineering Terms, 2013).

Stopping Sight Distance = Perception-Reaction Distance + Braking Distance

Such SSDs are important because they ensure that there is sufficient forward visibility for the drivers to enable them to stop before colliding with any object on the road (O'Flaherty, 2003). This SSD is especially important when there will be a mixed traffic scenario. In such a scenario, there needs to be a clear understanding of the considerations of the driver and the vehicle in an AV to define appropriate sight distance criteria. The SSD of AVs needs to be examined and the existing design criteria for road infrastructure might need to be revised to accommodate the SSD pertaining to AVs. Therefore it is important that the SSD criteria for AVs is examined to determine if the results are different to those currently used in road design with Level 1 and Level 2 vehicles.

Research carried out by Harwood et al (1998) examines the current geometric design practices for sight distances in a number of different countries. The scope of the research was to evaluate the design practices of different countries to provide a tool for road designers in countries that may consider it necessary to update their design guidelines for SSD. Sufficient and adequate forward visibility to detect possible hazards on the road is important for road safety.

The response time varies across the different countries which were examined namely Australia, Austria, United Kingdom, Canada, France, Germany, Greece, South Africa, Sweden and the United States (U.S.) (Harwood et al, 1998). The differences in SSD design practices between the different countries was examined with focus on the parameter values assumed in the SSD models (Harwood et al, 1998).

United Kingdom

In the United Kingdom, road design for national highways falls under the responsibility of the Department for Transport and the design of local roads falls under the responsibility of the County Councils which generally use the standards and specifications issued by the Department for Transport (Harwood et al, 1998).

The design speed of the road is based on the geometric data and the observed speed of adjoining roads (DfT, 1984). The total perception-reaction time adopted is 2.0 sec and the braking distance is based on the coefficient of friction of 0.375 in wet conditions and 0.25 in dry condition (DfT, 1984).

SSD is defined in the UK using the following equation and constants (DfT, 1984):

$$SSD = 0.278\, V_o\, t \;+\; (V_o^2 / 254f) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where

- V_o is the design or initial speed (km/h)
- t is the driver perception/reaction time (seconds) taken as 2.0s
- f is the coefficient of braking friction between the tires and the pavement surface taken as 0.25

The SSDs established in the Design Manual for Roads and Bridges, used for road design in the United Kingdom, gives the following SSD values in Table 1 (DMRB, 2002):

Table 1: SSDs established in the Design Manual for Roads and Bridges

DESIGN SPEED (km/h)	120	100	85	70	60	50
STOPPING SIGHT DISTANCE (M)						
Desirable Minimum	295	215	160	120	90	70
One Step Below Desirable Minimum	215	160	120	90	70	50

Source: DMRB (2002)

However, in the United Kingdom, where the built roadside has side friction, (includes side roads, frontage access and pedestrian movement) within the lateral vision of the driver and where the 85th Percentile speed is less than 60km/h, designers adopt a 1.5 second perception-reaction time (Staffordshire County Council, 2000). Hence this perception-reaction time period is used in the SSD calculation and is limited to those roads with side friction and with an 85th percentile speed less than 60km/h (Staffordshire County Council, 2000) and where appropriate speed restraint measures have been implemented (Essex County Council, 2018). These are the design standards outlined in the Manual For Streets (2007). As per table below extracted from the Manual for Streets (2007) the SSD for speeds not exceeding 60km/h at a perception-reaction time of 1.5 seconds are as follows in Table 2 (Essex County Council, 2018):

Table 2: Sight Stopping Distances used in the United Kingdom

DESIGN SPEED (km/h)	16	20	24	25	30	32	40	45	48	50	60
STOPPING SIGHT DISTANCE (M)	11	14	17	18	23	25	33	39	43	45	59

Source: Manual for Streets (2007)

Australia

The National Association of Australian State Road Authorities (NAASRA) has established the definition of sight distance as *'the distance a vehicle will travel before coming to rest under hard braking after first seeing a hazard in the roadway'* (Urban Services, n.d). This sight distance is established using a general minimum reaction time of 2.0 for all types of roads and taking a longitudinal friction factor of 0.36 (Fanning et al, 2016). The longitudinal friction factor for specific road types and situations is taken as 0.46 and for major highways and freeways this value is taken as 0.26 (Fanning et al, 2016).

The calculation for the SSD value in Austroads is also derived from components of the distance travelled during total reaction time and the distance travelled during the braking time from design speed to a stop (Fanning et al, 2016). The equation is described as for the United Kingdom (Fanning et al, 2016):

$$SSD = (R_T\ V) / 3.6 \ + \ (V^2 / 254d) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:

- V is the operating speed (km/h)
- R_T is the driver perception/reaction time (seconds) taken as 2.0s
- d is the coefficient of deceleration (longitudinal friction factor) generally taken as 0.36

Speed prediction procedures are used to calculate the actual vehicle operating speed to establish the SSD (Urban Services, n.d). Given that the SSD equation is affected mostly by the design speed, NAASRA designs for the faster driver to introduce a larger factor of safety (Urban Services, n.d).

Austria

The Sight Distance Design policy adopted in Austria is determined by the operating speed which is the maximum posted speed limit at a specific section along the road (Harwood et al, 1998). Such maximum posted speed limit is 100 km/h on two-lane rural roads and a maximum of 140 km/h for multilane roads and the reaction time I taken as 2.0 sec (Austrian Research Association for Transportation and Road Engineering, 1981).

In Austria, Germany and in Greece, they incorporate the effect of a speed –dependent longitudinal friction factor and the aerodynamic drag on the decelerating vehicle. Thus a slightly different calculation for SSD is used as follows (Harwood et al, 1998):

$$SSD = 0.278\ V_o\ t \ + \ (0.278)^2 / g \int_{V_0}^{0} V / \{ f_r(V) \ + \ G/100 \ + \ F_L/mg \} \quad \ldots\ldots\ldots (3)$$

Where:

- g is the acceleration due to gravity (9.81 m/sec^2)
- V is the speed at any point in the deceleration manoeuvre (km/h)
- $f_r(V)$ is the speed dependent longitudinal friction factor
- F_L is the aerodynamic drag force (N)
- m is the mass of the vehicle (kg).

The aerodynamic drag force is calculated as follows (Harwood et al, 1998):

$$F_L = 0.5\,\gamma\,C_w\,A\,(0.278\,V)^2 \quad \ldots\ldots (4)$$

Where:

- γ is the density of air (1.15 kg/m^2)
- C_w is the aerodynamic drag coefficient
- A is the projected frontal area (m^2).

In Austria, the following assumptions are made to establish the aerodynamic drag force (Austrian Research Association for Transportation and Road Engineering, 1981):

- Drag coefficient (C_w) taken as 0.46
- Projected vehicle frontal area (A) taken as 2.21 m^2 for a passenger car
- Vehicle mass (m) taken as 1175 kg.

The Coefficient of Braking Friction between the tires and the pavement surface, also known as the Longitudinal Friction Factor, is calculated is follows (Austrian Research Association for Transportation and Road Engineering, 1981):

$$f_r(V) = 0.214\,(V/100)^2 - 0.640\,(V/100) + 0.615 \quad \ldots\ldots (5)$$

Germany

Germany formulated its SDD policy based on the 85th Percentile speed of vehicles (Harwood et al, 1998). They adopt a 2.0 sec reaction time on rural roads and 1.5 sec reaction time for urban roads (Durth & Lippold, 1993). Differently from Austria, Germany uses the following equation for the Coefficient of Braking Friction at any speed in the deceleration manoeuvre:

$$f_r(V) = 0.214\,(V/100)^2 - 0.721\,(V/100) + 0.708 \quad \ldots\ldots (6)$$

For the calculation of aerodynamic drag, Germany also uses assumptions which are different from Austria as follows (Durth & Lippold, 1993):

- Drag coefficient (C_w) taken as 0.35
- Projected vehicle frontal area (A) taken as 2.08 m^2 for a passenger car
- Vehicle mass (m) taken as 1304 kg.

Greece

Greece bases the calculation of design speed on the 85th Percentile speed of traffic (Harwood et al, 1998). Greece adopts a brake reaction time of 2.0 sec for rural roads and 1.5 sec for urban roads (Lamm et al., 1994). The Coefficient of Braking Friction at any speed in the deceleration manoeuvre is calculated using the following equation which is different both from that of Austria and from that of Germany (Lamm et al., 1994):

$f_r(V) = 0.151\ (V/100)^2\ -\ 0485\ (V/100)\ +\ 0.590$ ……………………………………………(7)

However the assumptions for Drag Coefficient, Projected Vehicle Frontal Area and Vehicle Mass are the same as for Germany (Lamm et al., 1994).

France

The development and dissemination of design policies in France falls under the responsibility of the Ministry of Transportation, City Planning and Housing, the Division of Roads and the Division of Safety and Road Traffic (Harwood et al, 1998). The standards used are applicable to the national roads however departmental engineers use such standards also for local roads.

Accident analysis carried out in France suggest that collisions with fixed objects are very rare and hence they do not tend to consider SSD as very important for road design (Harwood et al, 1998). The most prevalent type of accident is collision with a pedestrian amounting to 5% of rural collisions and 8% of accidents resulting in a fatality (Harwood et al, 1998). Such accidents generally occur at night when SSD is not the cause of limited visibility (Harwood et al, 1998). The driver reaction time is taken as 2.0 sec (Service d'Etudes Techniques des Routes et Autoroutes, undated).

South Africa

South Africa base their calculation for SSD on a perception-reaction time of 2.5 sec and on an operating speed above 50km/h that is less than the design speed (Ministry of Works, 2011).

Sweden

The Swedish State Road Network falls under the responsibility of the Swedish National Road Administration (SNRA). The braking-reaction time is taken as 2.0 sec (National Swedish Road Administration, 1986). However SSD is not considered as an important design criteria in Sweden because it is difficult to establish the benefits of varying sight distances in a cost benefit analysis (Harwood et al, 1998). Studies carried out in Sweden have shown that there is an increase in accidents related to an increase in the ratio of the number of locations having less than 300m sight distance of the total length of the road (Harwood et al, 1998).

United States and Canada

The design policies for SSD in the United States are established by the American Association of state Highway and Transportation Officials (AASHTO) (Neuman, 1998). Design speeds are determined according to the function of the road and they are not based on vehicle operating speeds as for other countries (Neuman, 1998). The brake reaction time is taken as 2.5 sec and brake friction coefficients are taken from 0.40 for design speed of 30 km/h to 0.28 for design speeds of 120 km/h (Richl & Sayed, 2006; Neuman, 1998).

The SSD policy used in Canada is similar to the policy of the United States however the Canadian policy has been converted to metric scale (Harwood et al, 1998).

This report included the research project ‘European Sight Distances in Perspective – EUSight’ which is of importance to the scope of this research document. The main aim of the Conference Europeenne des Directeurs des Routes (CEDR) project was to carry out an in-depth evaluation of Stopping Sight Distances (SSD) and the impact on road design. The report also evaluates the parameters for the calculation of SSD used by different countries in Europe. This re-examination of the parameters used was deemed necessary because of developments such as in car braking technology and developments in connectivity which is a resource for the driver (Weber et al, 2016).

The SSD was considered from various inter-related aspects which have a direct impact on SSD namely human factors, road and vehicle characteristics and the condition of the roads. The results of the literature study which was carried out enabled the review of the impact which developments and changes in the relevant parameters might have on SSD. Also, the behaviour of drivers was assessed based on a multi-national empirical evaluation (Weber et al, 2016). The analysis of the literature resulted that there is substantial updated information and knowledge for the calculation of SSD (Weber et al, 2016). The literature review also showed that there is no single threshold value for the specific parameters however it was possible to identify appropriate values for each parameter based on the parameter distributions (Weber et al, 2016). The analysis of the current guidelines for road design in these countries exhibits difference in the parameter values and approaches due to variations of driver behavior, vehicle fleets and driver populations, physical geographical characteristics, existing road infrastructure and traffic regulations (Weber et al, 2016). Such parameter values are accommodated within a range which covers the values of each country being analysed (Weber et al, 2016). However the perception-reaction time was the only parameter which was constant at 2 seconds for all the countries under review (Weber et al, 2016). In the case of the coefficient of friction, the lower values were adopted because this parameter deteriorates after time (Weber et al, 2016). Also it is to be noted that the coefficient of friction value of 0.377 is the maximum comfortable deceleration rate used in design (Harwood et al, 1998).

Thus, based on the parameters used in different European countries and on developments of parameter values, a recommended set of parameters was established for the calculation of SSD. The main conclusion of the CEDR report was the establishment of the common parameters, as below in Table 3, for the observation points to the right and left of curves, obstacle height, observed point heights for sag and crest curve, coefficient of friction, driver eye heights for horizontal alignment, crest and sag curves, deceleration rate and, most importantly, the perception-reaction time (Weber et al, 2016).

Table 3: Summary of established parameter and parameter values

SSD Parameter Variables	Recommended Parameter Value
Observation point position left curve (m) with 3.5m lane width	1.3
Observation point position right curve (m)	1.3
Obstacle height (m)	0.5
Observed point height crest curve (m)	0.5
Observed point height sag curve (m)	0.5
Coefficient of friction	0.377
Braking coefficient of friction	0.377
Driver eye height horizontal alignment (m)	1.10
Driver eye height crest curve (m)	1.10
Driver eye height sag curve (m)	1.10 (2.5 for truck)
Perception-reaction time (s)	2.0
Deceleration rate (m/s^2)	4.0

Source: Weber et al (2016)

Based on equations (1), (8) and (9) and the above parameters identified in the CEDR Report design specification the SSD values resulted as below in Table 4:

Table 4: Stopping Sight Distances in CEDR

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2s and Coefficient of Friction of 0.377										
Recommended SSD by CEDR (m)	26	39	54	71	90	111	135	160	188	217

Source: Weber et al. (2016)

National Cooperative Highway Research Programme (NCHRP) Report 400, Determination of Sight Stopping Distances

The American Association of State Highways and Transportation Officials (AASHTO) model for Stopping Sight Distances (SSD) is made up of the perception-reaction component and the braking component. The formulae are based on basic laws of physics (Fambro et al, 1997). Hence, the SSD is the distance a vehicle travels during perception-reaction time together with the distance a vehicle travels to come to a stop (Fambro et al, 1997). The parameter values used in the model are for a below-average driver, the road and the vehicle and for the capability of the driver to detect an obstacle and stop the vehicle (Fambro et al, 1997). Since it is very improbable that all the said parameters are at a critical level all at the same time, the model allows for a wide margin of error (Fambro et al, 1997). In the AASHTO Report, the brake reaction time was identified as being 1 second and the total perception-reaction time varied between 2 to 3 seconds depending on the design speed of the road (Fambro et al, 1997). Subsequently, the Blue Book adopted a policy for perception-reaction time of 2.5 seconds for all design speeds stating that available references did not justify the difference of perception-reaction time based on design speed (Fambro et al, 1997).

The existing AASHTO SSD values are described as follows by Fambro et al (1997):

$$SSD = 0.278V_0\,t + 0.039(V_0^2/a) \text{ or } SSD = 0.278V_0\,t + (V_0^2/254f) \quad \text{………………. (8)}$$

where:

- V_0 = initial speed (km/h)
- t = perception-brake reaction time (s)
- a = driver deceleration (m/s^2)
- f = coefficient of friction

The parameters used for the existing SSD model represent the 90th Percentile values of the probability distributions as follows in Table 5 (Fambro et al, 1997):

Table 5: Parameters used in AASHTO

SSD Parameter Variables	Recommended Parameter Value
Obstacle height (m)	0.6
Driver eye height (m)	1.08

Perception-reaction time (s)	2.5	
Coefficient of friction	Operating speed (km/h)	Coefficient of Friction
	30	0.40
	40	0.38
	50	0.35
	60	0.33
	70	0.31
	80	0.30
	90	0.30
	100	0.29
	110	0.28
	120	0.28
Deceleration rate (m/s^2)	3.4	

Source: Fambro et al (1997)

The resulting existing SSD values in AASHTO are thus the following in Table 6 (Fambro et al, 1997) (Harwood et al, 1998):

Table 6: Sight Stopping Distances used in AASHTO

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
Minimum – Desirable Initial Speed	30-30	40-40	47-50	55-60	63-70	70-80	77-90	85-100	91-110	98-120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2.5s and Coefficient of Friction varies between 0.4 for a speed of 30km/h to 0.28 for a speed of 120km/h										
AASHTO Existing	29.6-29.6	44.4-44.4	57.4-62.8	74.3-84.6	94.1-110.8	112.8-139.4	131.2-168.7	157.0-205.0	179.5-246.4	202.9-285.6

Source: Fambro et al. (1997), Harwood et al. (1998)

Current literature contains criticism of the AASHTO SSD however there is wide-spread agreement that the AASHTO model produces roads of good design (Fambro et al, 1997). The criticism centres around the fact that the parameters used in the current model do not represent the driving environment nor safe driving behaviour because the parameters of such model are difficult to validate (Stanton, 2017; Fambro et al, 1997). The aim of the NCHRP research was to examine stopping sight distance models in literature and the AASHTO model and develop recommended design procedures (Fambro et al, 1997).

The NCHRP research proposed a revision of the SSD model based on the capabilities of the driver and the performance in response to an unexpected object on a level road (Fambro et al, 1997). The revised SSD model is similar to the current AASHTO model however the initial speed is taken as being the same as the design speed and the design deceleration is changed to a coefficient of friction (Fambro et al, 1997). The resulting SSD model is still made up of two parts, namely brake reaction distance and braking distance (Fambro et al, 1997). This is the recommended SSD as based on below average drivers perceiving an unexpected object in the road and stopping the vehicle prior to collision (Fambro et al, 1997). Thus, although the parameters in the model changed to reflect the changes in the driver and vehicle fleet, the basic model remained the same as follows (Fambro et al, 1997):

$SSD = 0.278Vt + 0.039(V^2/a)$ …………………………………………………………...(9)

where:

- V = initial speed (km/h)
- t = perception-brake reaction time taken as 2.5s (s)
- a = driver deceleration taken as $3.4 m/s^2$ (m/s^2)

Thus the revised AASHTO values, recommended by NCHRP, are as follows, Table 7:

Table 7: NCHRP Recommendations for AASHTO Values

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2.5s, Deceleration rate as 3.4m/s^2										
AASHTO Recommended	31.0	45.9	63.1	82.5	104.2	128.2	154.4	182.9	213.7	246.7

Source: Fambro et al. (1997)

A comparison between the existing AASHTO SSD values and the values in the NHTSA report reveals that the recommended values lie midway between the desirable and the initial speed values of the existing AASHTO SSD distances (Fambro et al, 1997).

European Field Operational Test (euroFOT) Project

In 2012 the results of the euroFOT project were presented and this involved the collection of field data to examine the interaction of vehicle drivers with Advance Driver Assistance Systems (ADAS) (Merat & Lee, 2012). The results of the research concluded that European drivers accept ADAS systems and that such systems add value to driving because they reduce traffic collisions, improve safety and fuel efficiency (Merat & Lee, 2012). Research has been carried out in North America in this area of study since the 1990s focussed on dedicated automated highway systems however research carried out in Europe focussed on the development of automated vehicles for use on the existing road infrastructure (Merat & Lee, 2012). Such research includes the Safe Road Trains for the Environment (SARTRE) Project which investigated vehicle automation in relation to platooning and CityMobil (Merat & Lee, 2012). These studies focussed on the hardware and software required in automated vehicles for safe operation but very little attention was given to how drivers, pedestrians, passengers and cyclists would interact with such automated vehicles (Merat & Lee, 2012).

The National Highway Traffic Safety Administration (NHTSA) Report

As automated vehicle technology continues to develop, the role of the driver has changed from that of supervisor to that of vehicle operator (Blanco et al, 2015). To this end, the National Highway Traffic Safety Administration (NHTSA) has carried out research which focussed on the human characteristics which affect the shift from supervisor to operator mode in a Level 3 automated vehicle (Blanco et al, 2015). It is important that the automated vehicle alert systems are such that they alert the driver in an efficient and effective manner (Blanco et al, 2015). Research carried out by Llaneras et al (2013) showed that the existing levels of vehicle automated systems are intended to support rather than replace the driver. Hence automated systems might give the illusion that the vehicle supervisor/operator does not require to give attention to the operation of the vehicle (Blanco et al, 2015).

Thus the NHTSA carried out research with the aim of investigating the user interface with Level 2 and Level 3 automated vehicles (Blanco et al, 2015). These two particular levels of automation were focussed upon because this is where the role of the vehicle driver changes from that of an intermittent operator who transitions from automated driving mode to manual control (Blanco et al, 2015). The study examined the transitions between the role of operator and driver and how this transition is affected by the human-machine interface (Blanco et al, 2015). Three experiments were carried out however the third and final experiment is the most pertinent to the scope of this research document. The scope of the third experiment investigated which human-interface characteristics are the most viable to alert vehicle operators to assume manual control in a Level 3 automated vehicle and to establish the perception-reaction times of the operator in relation to the automated functions (Blanco et al, 2015).

In this experiment, participants in the experiment drove a Level 2 automated vehicle with the prototype autodrive system to simulate a Level 3 automated vehicle (Blanco et al, 2015). They were given a tablet to use as a secondary task in the vehicle and they received two different types of alert to resume manual vehicle control (Blanco et al, 2015). One type of alert was a Staged Alert whilst the other was an Imminent Alert (Blanco et al, 2015). The Imminent alert was a red visual alert with the instruction to 'turn off autodrive now' (Blanco et al, 2015). The result of the experiment was the investigation of the response times to these alerts, namely the reaction time and time to regain control which was the time period up to turning off the autodrive (Blanco et al, 2015).

The reaction time for the imminent alert showed no significant difference between the imminent alert with and without an external threat (Blanco et al, 2015). The mean reaction time of the participants to an immediate alert without an external threat was 0.69 seconds (Blanco et al, 2015). The mean reaction time of the participants to an immediate alert with an external threat was 0.66 seconds (Blanco et al, 2015). Time to react did not change significantly over time (Blanco et al, 2015).

There was a significant difference in the reaction time for Staged Alerts which depended on whether the participants were awaiting the alert or not (Blanco et al, 2015). Participants reaction was slower when they were awaiting the staged alert (Blanco et al, 2015). For the Staged Alerts, participants resumed control after a mean of 17 seconds.

The above review of various studies shows that, besides the difference in the coefficient of friction adopted for the calculation of stopping sight distances by CEDR, DMRB, AASHTO and NCHRP, the perception-reaction times also differ. CEDR and DMRB use a 2 second perception-reaction time whilst AASHTO and NCHRP use a 2.5 second value.

In the NCHRP report, it is stated that the AASHTO perception-reaction times of 2.5 seconds accounts for the stopping sight distances required to cater for the capabilities of most drivers, including elderly drivers. From a review of the data, it results that 2.0 seconds exceeds the 85th Percentile SSD perception-reaction time for all drivers and the 2.5 seconds exceeds the 90th Percentile SSD perception-reaction time for all drivers (Fambro et al, 1997). Such perception-reaction times are in relation to an unexpected hazard on the roadside (Fambro et al, 1997).

These values allow for the capabilities of most vehicle drivers, including elderly drivers (Fambro et al, 1997). Although the 2.5 second perception-reaction time results in longer sight stopping distances and this time value is established in AASHTO, the NCHRP recommends that it should be retained (Fambro et al, 1997). However, in the case of Levels 1 and 2 levels of automation, the NCHRP report also states that where the road geometry requires other design control measures to ensure safety, a longer perception-reaction time is to be adopted (Fambro et al, 1997).

The CEDR recommended values are based on the 85th Percentile value of the various European countries which were assessed (Petegem, 2014). Such 85th percentile values range from 1.4 to 1.9 seconds (Petegem, 2014). The 90th and 99th percentile values range from 1.8 to 2.5 seconds (Petegem, 2014) which reflect the value of 2.5 seconds as adopted by AASHTO. However it is to be noted that according to an analysis carried out by Taoka (1989), the 2.5 seconds perception-reaction time in AASHTO is assumed to be equal to or exceed the 85th percentile value for all drivers (Taoka, 1989).

In classical research involving the human factors, the perception-reaction time is established by observing the behaviour of drivers and by identifying the reaction time of the 85th percentile driver (Petegem, 2014). This signifies that 85% of the drivers are capable of reacting within that time period (Petegem, 2014). In the DMRB, the sight stopping distance calculated is based on a 2 second perception-reaction time and a deceleration rate of 2.45 m/s^2 (Petegem, 2014). The research carried out by Sohn & Stepleman (1998) recommended the use of the 85th or the 99th percentile value for perception-reaction time and they reported the following values:

i. For USA, perception reaction time of 1.92 seconds at the 85th percentile and 2.52 seconds for the 99th percentile
ii. For non-USA, perception-reaction time of 1.40 seconds at the 85h percentile and 1.52 seconds for the 99th percentile.

Green (2000) carried out research into the aspects which have a determining impact on perception-reaction times, these being expectation, urgency, age, gender and cognitive load. The research also included a meta-analysis of forty different research papers where he concluded that the surprise factor is a dominant factor. Green (2000) concluded that the mean perception-reaction time for an expected reaction was 1.25 seconds and that, for an unexpected reaction, the mean was 1.5 seconds. Green (2000) did not make reference to percentile values and nor to standard deviation so it was not possible to establish any reference thereto.

Layton and Dixon (2012) reviewed a number of studies related to perception-reaction times which refer to the 85th and 95th percentile values. The aim of these studies was to verify the validity of the 2.5 seconds perception-reaction time as established by AASHTO. Layton and Dixon (2012) quote four studies which yielded a maximum of 1.9 seconds for the 85th percentile perception-reaction time and about 2.5 seconds for the 95th percentile time. Gazis et al (1960) tested 87 drivers approaching signalized intersections and obtaining 1.48 seconds perception-reaction time for the 85th percentile value and 1.75 seconds for the 95th percentile value. Wortman and Matthias (1983) tested 839 drivers at the onset of the amber light at signalized intersections and obtained 1.80 seconds perception-reaction time for the 85th percentile value and 2.35 seconds for the 95th percentile value.

Chang et al (1985) tested 579 drivers at the onset of the amber light at signalized intersections and obtained 1.90 seconds perception-reaction time for the 85th percentile value and 2.50 seconds for the 95th percentile value. Sivak et al (1960) obtained 1.78 seconds perception-reaction time for the 85th percentile value and 2.40 seconds for the 95th percentile value. Hence, the CEDR and DMRB value of 2 seconds for the perception-reaction time approximates the 85th percentile values quoted above whilst the AASHTO 2.5 seconds perception-reaction time approximate the 95th percentile value. It is also to be noted that the 95th percentile perception-reaction times obtained by Gaziz et al (1960), Wortman and Matthias (1983), Chang et al (1985) and Sivak et al (1960) are not greater than the 2.5 seconds perception-reaction times used by AASHTO to calculate sight stopping distances.

It is to be noted that all four experiments resulted in similar central tendencies (Taoka, 1989). The 85th perception-reaction time obtained by Gaziz et al (1960) caused the range of its distribution to be restricted when compared with the results of the other experiments (Taoka, 1989). This was due to the small size of the sample of drivers in the experiment of Gaziz et al (1960) (Taoka, 1989).

2.2 Disabilities which Affect Driving

There are about three million disabled persons in the European Union who have a driving license which amounts to about 1% of all EU drivers (Burger & Marincek, 2013). Driving involves both personal and public health matters and it is enveloped in regulatory and legal criteria (Drazkowski & Sirven, 2010). Consequently it is important to appreciate the variables which impair safe driving (Drazkowski & Sirven, 2010). Deterioration of vision, hearing, reflexes, movement and coordination can undermine the safe driving ability because one would be unable to see or hear other vehicles, would be unable to stop suddenly or to safely navigate an intersection or to control a vehicle (Harvard Medical School, 2008).

Automated vehicles can potentially change the concept of transportation systems and the supporting infrastructure however, they can also change the accessibility and quality of life for disabled persons (Clerkin, 2017). Disabled and elderly persons will be relieved from the mental and physical constraints brought about by their reliance on other drivers, public transport and modifications to standard vehicles which come at a considerable cost (Clerkin, 2017).

The technology of vehicle automation is not sufficient to provide the necessary assistance to disabled people (Saripalli, 2017). Additional technological development is needed in the areas of machine learning and artificial intelligence so that such vehicle will be in a position to comprehend a verbal instruction and communicate with humans (Saripalli, 2017). These different technologies need to be developed in tandem, specialised for the personal needs of the user, to successfully give disabled people the independence they require (Saripalli, 2017).

Much of this advanced technology has already been developed (Saripalli, 2017). Both Google and Microsoft have recently launched an app which assists visually impaired people to have a better understanding of their surroundings (Saripalli, 2017). This app uses the technology of machine learning, natural language processing and computer vision to give the disabled person a verbal description of the surroundings (Saripalli, 2017).

Statistics from the Census Bureau show that 19% of the population of the United States had a type of disability in 2010 (Clerkin, 2017). These disabilities ranged from blindness to autism (Clerkin, 2017). A survey carried out by the U.S. National Institute of Health found that a total of 68% of these disabled people outlined that access to transportation was a very big problem for them (Clerkin, 2017). This transportation problem led to the problem of disabled people holding a job because of the fixed working times thus leading to a cycle of poverty (Clerkin, 2017).

Research carried out by the Ruderman Family Foundation concluded that if this transportation hurdle faced by disabled people can be resolved, would provide many job opportunities for disabled people (Clerkin, 2017).

2.2.1 Universal Design of Automated Vehicles

The Convention of the United Nations regarding the Rights of Persons with Disabilities defines the term 'Universal Design' as being '*the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialised design*' (Foldesi, 2017). Such design may include technology to support disabled persons when required (Foldesi, 2017).

The European Union and its Member States, except Ireland, are signatories of the United Nations Convention and thus they are obliged to carry out and facilitate research and development of goods, services, facilities and equipment which are of universal design and which thus need the minimum adaptations to address the requirements of disabled persons (Foldesi, 2017).

The disability community is made up of individuals who have different needs, preferences, and requirements in relation to transportation. The challenges elated to accessibility and social inclusion are addressed through the deployment of autonomous vehicles provided that an agreed set of guidelines and policies are in place to enable the maximization of the potential benefits to disabled persons (Claypool et al., 2017).

The Mobility4EU research project includes the Universal Design Information and Research Centre of Persons with Physical Disabilites as one of its consortium partners (Foldesi, 2017). This centre promotes the concept of Universal Design as a means to make all towns and villages universally accessible for all irrespective of religion, gender, age, race, ability or disability without the need for further adaptations (Foldesi, 2017). Mobility4EU is funded by the Horizon 2020 Research Programme of the European Union (Foldesi, 2017). This Horizon 2020 project has the aim and action plan to succeed in establishing a European Transport system in 2030 (Foldesi, 2017). The work of this programme identifies and assesses the requirements of society which will determine the transport demand and supply of the future (Foldesi, 2017). One of the most innovative solutions to the transportation problem is the development of vehicle automation technology because it provides a solution for the transportation problems encountered by disabled persons (Foldesi, 2017).

2.2.2 Musculoskeletal, Neurological Conditions and Cognitive/Sensory Diseases which Affect Driving

The safety of all aspects of the restructuring and redesigning of a road includes intersections and necessitates the consideration of the driver, the vehicle and the road itself (Layton and Dixon, 2012). Hence an important aspect pertaining to the perception-reaction time, in relation to the driving task, are person-specific medical conditions and research has established the relationship between a number of medical conditions and driving performance (Dobbs, 2005). According to the Bureau of Motor Vehicles (BMV) (2015), there are a large number of neurological and musculoskeletal disabilities which have an adverse impact on safe driving. Disabilities may be caused by altered muscular, skeletal, neurologic and/or cognitive body functions (BMV, 2015). Motor, sensory and/or cognitive disabilities may reduce the strength, memory, reaction time, motion, visual perception, processing speed, judgement, problem solving, attention, memory and awareness in respect of the ability of a driver to safely operate a vehicle (BMV, 2015).

The perception-reaction time is the time period between the perception of a hazard and the response and thus it is related to the detection, processing and response to a hazard, stimulus or alert (CogniFit, 2019). The perception-reaction time depends on three factors, namely (CogniFit, 2019):

i. perception where the ability to see, hear or feel a stimulus is important to achieve a good perception-reaction time;
ii. processing where the comprehension on the surrounding information is important to achieve a good perception-reaction time;
iii. response where good perception-reaction time depends on motor agility.

Perception-reaction time is adversely affected if any of the above three criteria are not met (CogniFit, 2019). Perception-reaction time invariably consists of a motor component and is thus related to good reflexes (CogniFit, 2019). Although the processes of perception, processing and response are carried out in a period of milliseconds however the reaction time depends on a number of factors, namely (CogniFit, 2019):

i. complexity of the stimulus where higher levels of complexity involve more information which would need to be processed resulting in a longer process;
ii. familiarity with the stimulus will result in lower perception-reaction times because the stimulus would have been previously already responded to and would have thus been recorded in the driving knowledge of the driver;
iii. state of the driver may negatively affect the detection of a stimulus;
iv. stimulated sensory modality where the auditory alert results in shorter perception-reaction times because it requires less processing than the visual alert. Different sensory modalities have different perception-reaction times.

The particular type of alert also has a determining factor in the perception-reaction time (CogniFit, 2019). Having a good perception-reaction time results in agility and efficiency when responding to an alert during the driving task (CogniFit, 2019).

Disabilities which affect perception, the processing of information and reduced motor capabilities unavoidably adversely affect perception-reaction times (CogniFit, 2019). It is difficult to outline all the potential problems which persons with disabilities encounter in their ability as a driver because the challenges are person specific (Nebraska VR, 2015). Also, persons with physical disabilities have different challenges from persons with disabilities involving intellectual or developmental issues (Nebraska VR, 2015). Reduced vision or auditory problems, which include blindness and reduced hearing, cause problems to perception-reaction time due to reduced perception (CogniFit, 2019).

Diseases like Bradypsychia, Dementia or Alzheimer's may result in reduced processing of information thus increasing the perception-reaction time (CogniFit, 2019). Inhibition control problems and ADHD may also reduce the speed of processing information which increase perception-reaction times (CogniFit, 2019). Reaction times are affected by motor problems caused by paralysis and by diseases such as Akinesia, Bradykinesia and Parkinson's disease (CogniFit, 2019). Startle reflex in persons with cerebral palsy can make driving a big challenge (Nebraska VR, 2015). Neurodegenerative disorders such as Parkingson's, Alzheimer's, Multiple Sclerosis and Huntington's Disease cause increased reaction times (CogniFit, 2019). Problems which affect the brain, such as brain injury or stroke, may have an adverse affect on all these processes (CogniFit, 2019).

Physical disabilities, hence musculoskeletal disabilities, pose problems for the driving operation which are more visible than cognitive disabilities (Nebraska VR, 2015). Such facilitates the identification of the necessary vehicle modifications (Nebraska VR, 2015). Vehicle modifications include wheelchair lifts, hand controls, extension levers, raised floors, repositioning of the accelerator or brake pedals and joysticks to replace the accelerator, brakes or steering wheel (Nebraska VR, 2015).

Due to technological development in vehicle modifications and adaptations, disabled people who drive are increasing although they still represent a small proportion of the population (Koppa, 2003). The vehicle adaptations reduce the strength and movements required from a disabled driver to nil (Koppa, 2003). Performance studies which were carried out show that the driving performance of disabled people is not distinguishable from that of non-disabled persons (Koppa et al, 1980). Also, according to Koppa et al (1980), the amount of disabled people who drive is not sufficiently large to account for them in a traffic flow model.

Disabled persons applying for a driving license to drive a vehicle must satisfy the Driving Examiner that they have the necessary physical and mental ability to operate a motor vehicle with a reasonable level of safety (Nebraska VR, 2015). The vehicle modifications and adaptations are designed to enable the disabled person to operate a vehicle safely with his or her skills whilst following and adhering to the road rules and regulations (Stern, 2019). Existing vehicle adaptations and modifications help to maximize the opportunities for disabled persons to drive comfortably and to safely operate a vehicle (NHTSA, 2015). Not all persons with a disability are able to drive (Stern, 2019). One of the main requirements for a disabled person to obtain a driving license is the passing of a medical examination (Stern, 2019). The applicant must also assume the responsibility of driving and can operate a vehicle safely, abiding by all road regulations and legislation (Stern, 2019).

The body motor system controls the movement of the human body (Gao, 2014). It is made up of skeleton, joints and muscles (Gao, 2014). The skeleton and joints form the lever and pivot whilst the muscles provide the energy for movement to occur by contraction (Gao, 2014). Steering manoeuvering is carried out using the upper limb muscles (Gao, 2014). Steering movements are executed by the upper limb muscles using the shoulder and elbow joints (Gao, 2014). The driving task requires the individual to undertake and coordinate many complex movements of the muscles (Department of State Growth Transport b). The muscles of the driver must permit the required level of sensation, movement, coordination and strength in the limbs (Department of State Growth Transport b).

Such musculoskeletal conditions include any disabilities which effect hands, arms, legs and spine, any loss of limbs and other muscular weakness conditions (Department of State Growth Transport b). Such disabilities affect driving because the individual might not be in a position to safely operate all the foot and hand controls of the vehicle, or might not be in a position to fully rotate the neck and muscle weakness may prohibit movement (Department of State Growth Transport b). Drivers need to possess the required flexibility of movement, feel, coordination and strength in their limbs (Department of State Growth Transport, b). Such physical limitations are generally classified as follows (Department of State Growth Transport, b):

i. any disability in the arms, hands, spine or legs of the driver
ii. limb amputations
iii. chronic muscular weakness and/or pain.

These musculoskeletal disabilities affect the driving task because the driver might not be in a position to successfully reach and operate all the foot and hand controls to ensure the safe operation of the vehicle (Department of State Growth Transport, b). Additionally the driver might not be in a position to rotate or move the neck or the muscular weakness or pain might prohibit movement (Department of State Growth Transport, b).

The Musculoskeletal Diseases/Disabilities being investigated in the web-based survey are as follows:

i. Full/partial paralysis/weakness/amputation of upper limbs
ii. Muscular Dystrophy
iii. Spinal Injuries.

To ensure that a driver is operating the vehicle in a safe manner the neurological functions, which include judgement, memory, coordination and concentration, must not be impaired (Department of State Growth Transport a). Neurological conditions which affect driving include dementia, Parkinson’s disease, multiple sclerosis, cerebral palsy and brain injuries (Department of State Growth Transport a). These neurological conditions impair the ability to drive because they cause a loss of cognitive ability such as memory, attention, visual functions and reaction time (Department of State Growth Transport a). Also they pose the possibility of loss of limb control whilst driving (Department of State Growth Transport a).

Neurological disabilities may be unpredictable, in episodes or be progressive (BMV, 2015). Neurological, medical and psychiatric disabilities adversely reduce the ability to drive safely (Drazkowski & Sirven, 2010). Driving is a complicated task and neurological functions must be working well to drive safely and appropriately (Drazkowski & Sirven, 2010). Such neurological systems include cognitive, coordination and attention aspects which are essential for safe driving (Drazkowski & Sirven, 2010). Safe driving necessitates critical cognitive functions which include (Drazkowski & Sirven, 2010):

i. alertness to a stimulus involving sensory input and the interpretation of roadside conditions;
ii. decision making process based on the specific roadside conditions and on past driving experience;
iii. reaction to a stimulus;
iv. absorbing information regarding an action to serve as experience for future situations.

When the human body has an impairment in the execution of these tasks, the risks involved in driving due to driving error are increased (Drazkowski & Sirven, 2010). Thus diseases and disabilities which impair attention, perception-reaction, movement and cognitive and behavioural awareness may result in vehicle collisions as a result of a higher risk of driving error (Drazkowski & Sirven, 2010).

The Neurological Diseases/Disabilities being investigated in the web-based survey are as follows:

i. Cerebral Palsy
ii. Alzheimer Disease
iii. Multiple Sclerosis Disease
iv. Amyotrophic Lateral Sclerosis (ALS)
v. Parkinson’s Disease
vi. Huntington’s Disease.

The driving task has a strong visual component where 90% of the information used during the driving task is visual (Dobbs, 2005). Further to a study carried out by Diller et al (1998) it resulted that persons with a history of eye conditions have an increased risk of collisions in comparison to controls with matching age, gender and country of residence. However, when the relation between visual acuity and safe driving was examined by Owsley & McGwin (2010) and Hills & Burg (1977) such research did not find any relationship between poor visual acuity and risk of collision. Such latter research was carried out for young and middle-aged drivers.

The difference in research results for a correlation between visual acuity and safe driving may be partly a result of inadequate sample size (Lyman et al, 2001). Also, it is noted that drivers with severe visual impairment are not permitted to drive (Lyman et al, 2001). Also, in a study carried out by Cross et al (2009) which involved 2159 participants, no significant correlation was found between visual acuity and traffic collisions. It has been concluded that such results are due to the fact that visually impaired drivers drive much less and, when they do so, they visit only familiar areas and adhere to a driving pattern (Lyman et al, 2001). Higgins and Wood (2005) carried out further research which suggests that visual impairment adversely affects road sign recognition and road hazard alerts but it does not affect driving a vehicle through a road.

Safe driving necessitates the use of both visual and auditory senses to be in a position to implement quick and appropriate decisions (Wolf, 2018). Loss of hearing adversely affects the capability of a driver to hear important safety alerts such as horns, sirens or other vehicles (Wolf, 2018). Background noise further creates problems for individuals with impaired hearing (Wolf, 2018). Although auditory information during the driving task is important however there are few studies to show that auditory disabilities impair the driving performance (Dobbs, 2005). A study carried out by Coppin and Peck (1963) showed that deaf individuals as a group have lower driving performance than non-deaf individuals (Dobbs, 2005).

Another study carried out by Hickson et al (2010) established that there is a considerable correlation between hearing impairment and safe driving especially if there are distractions. The results of the study showed that older adults with hearing impairment had problems driving safely when surrounded by distractors in comparison to older adults with no hearing problems (Hickson et al, 2010). Distractions include making conversation, traffic signs, radio and mobile phone. Therefore individuals with hearing problems have an even bigger problem when surrounded by such distractions (Hickson et al, 2010). This research concludes that the additional effort required to understand a low-quality sound is a distraction from other cognitive tasks thus increasing the road safety risk whilst driving (Hickson et al, 2010).

The cognitive and sensory diseases/disabilities being investigated in the web-based survey are as follows:

i. Visual impairment
ii. Auditory impairment
iii. Dementia
iv. Attention Deficit Disorder (ADD)/Attention Deficit and Hyperactive Disorder (ADHD)

Further information regarding the different types of disabilities outlined may be found in Appendix 2.

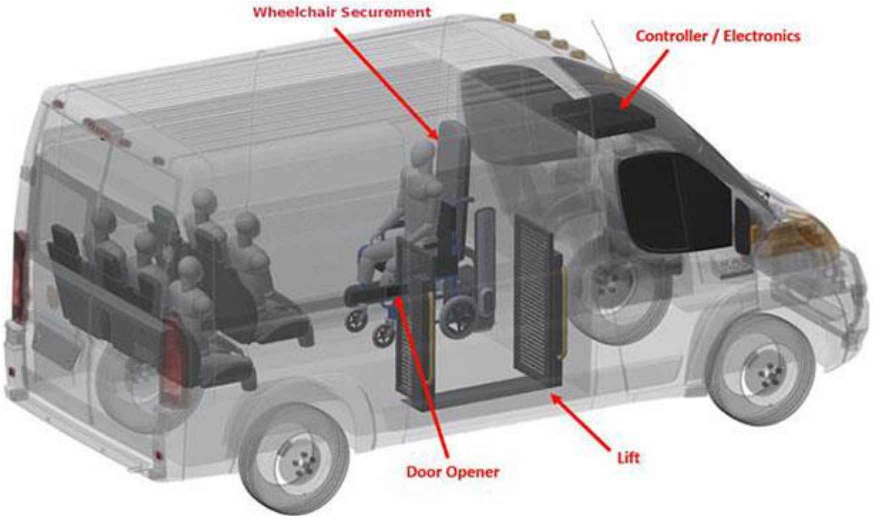
2.2.3 Vehicle Adaptations

Musculoskeletal and neurological disabilities and sensory and cognitive disabilities affect the functional ability of a person to drive safely (Dobbs, 2005). A large number of disabilities may be addressed through non-automated Levels 1 and 2 vehicle modifications to permit such persons to safely operate a vehicle (Dobbs, 2005).

The Universal Design Information and Research Centre of the Budapest Association of Disabled Persons with Physical Disabilities held the first meeting of the focus group on 12 September, 2017 and was attended by persons with different types of disabilities, engineers, representatives of Budapest Technical University, Innovation and Knowledge Centre and car-sharing services (Foldesi, 2017). The aim of the meeting was to discuss the advantages which fully automated vehicles have for disabled persons (Foldesi, 2017). The primary outcome was that automated vehicles are a tool to ensure mobility independence for people who cannot get a driving license (Foldesi, 2017). Participants at the meeting outlined the specific requirements which fully automated vehicles need to be equipped with to ensure that they are accessible for disabled people (Foldesi, 2017).

Due to musculoskeletal and neurological disease, persons with physical disability and wheelchair users outlined that the design would require a ramp or lifting structure as an integral part of the vehicle (Claypool et al., 2017). Car doors should be of adequate width as necessary for wheelchair access (Foldesi, 2017). Also there is to be sufficient maneuvering space inside the vehicle for the wheelchair and also wheelchair anchors are needed so that the wheelchair is secured and does not move when the automated vehicle is in motion (Claypool et al., 2017). The vehicle is also to be capable of maneuvering to alight the disabled person at an appropriate disabled accessible point which does not have infrastructural barriers (Claypool et al., 2017). Figure 6 shows some vehicle adaptations to assist disabled persons.

Figure 6: Vehicle Adaptations for Disabled Persons



The technology firm Robotic Research is developing the system shown in the picture which enables a disabled person to alight/board a vehicle without assistance. Source: Clerkin, 2017.

Persons with visual impairment outlined the key developments which fully automated vehicles need to include (Claypool et al., 2017). There are user interfaces, audible or Braille information regarding the location of the vehicle and where the vehicle is at whilst travelling, alerts regarding the need for maintenance and fuel (Claypool et al., 2017) and the need for contrasting colours and lighting within the vehicle to facilitate the identification of objects (Foldesi, 2017).

Persons with auditory impairment are able to drive however an interface which addresses their needs is still required (Claypool et al., 2017). Audio communication is to be supported by visible alerts and proper illumination is required (Foldesi, 2017).

Persons with cognitive impairment rely more heavily on the vehicle to transport them from origin to destination as required (Foldesi, 2017). Such impairment is a result of a physical, mental, or emotional problem where the individual has difficulty remembering, concentrating, or making decisions (Claypool et al., 2017). The fully automated vehicle can drive them to their destination and they would only require assistance to get into the vehicle itself (Foldesi, 2017). Such disabled persons would require very easy communication systems such as with the use of symbols or pictures and very simple user interface to inform the vehicle occupants at what stage of the journey they would have arrived (Foldesi, 2017). Provision of supervision and tracking of the vehicle during the journey would be beneficial and the vehicle is to generate the least disturbances possible (Foldesi, 2017).

Waymo developed the automated vehicles being tested to incorporate design features to assist the elderly and people with disabilities (Halsey, 2017). An easy-to-use smartphone app was also created and designed to be accessible for disabled people (Halsey, 2017). Waymo is also developing its technology to enable the vehicle to emit an audible alert when it reaches destination and has to alight visually impaired persons (Halsey, 2017). The app would continuously brief the driver on the progress of the journey and key buttons are equipped with braille (Halsey, 2017). Persons with auditory impairment will follow the route of the journey on a screen (Halsey, 2017). Such vehicles are also equipped with a PULL OVER button and a HELP button which activate a two-way communication with the control centre (Halsey, 2017). Wheel-in and wheel-out vehicle body design for wheelchair access has not yet been developed (Halsey, 2017).

2.3 Critical Review

Vehicle automation is classified into different levels where the driver is the operator of the vehicle for Levels 0, 1 and 2, the driver is the supervisor and intervenes when required in Level 3 vehicles and the vehicle operates as driverless for Levels 4 and 5. The levels of automation increase with an increase in the technological development of the vehicles and deployment is estimated to be in the year 2025 for Level 3 and in the year 2030 for Levels 4 and 5.

Vehicle automation technology is adopted in CVs and AVs and these differ in the way the respective technologies operate. CVs operate based on communications of V2V, V2I, V2D, V2X and vice-versa whilst the AVs operate using sensors and auxiliary devices. However, the literature review showed that AVs which are fully connected are the safest because it is difficult to emulate the rationality and perception of humans through technology and thus the AV technology still cannot seamlessly substitute a human and also the driver cannot necessarily make up for the limitations of automation.

The rate of market penetration of AVs will determine the percentages of mixed traffic scenarios between different levels of AV, cyclists and pedestrians and such scenario poses an increased potential accident risk and poses traffic management challenges. The most critical stage of AVs is Level 3 because the driver needs to engage in the driving task when alerted to do so and, for this reason, the PRT is a critical factor to ensure timely re-enagagement in the driving task. Identify why different studies result in different driver-response times and which variables influence PRT.

Different driver response times and PRT were encountered in different research papers and this was due to different definitions used for PRT. The definition for PRT used in this research document is as defined by CEDR. Research also showed that age, alcohol consumption and the surprise factor of the stimulus affected PRT.

Research which examined the effect of graded/single-stage alert and type of alert on driver distraction and attention in case of sudden braking showed that respondents responded similarly to haptic and auditory alerts and that the alert strategy adopted was most important.

In respect of driver adaptation to vehicle automation, it resulted that although trust increases with use of AVs, however the acceptance does not increase. In this respect, driver tendency to adopt risky behavior in an AV was found to depend on driver education, experience and personality. When there is a failure in the vehicle automation system, serious problems are created in the human-machine system performace because the secondary in-vehicle tasks, the excess trust in the automation technology and the reduced monitoring of the automated driving task result in reduced situation awareness which poses serious performance consequences when automation fails. However, when automated vehicles are provided with effective in-vehicle displays to address situation awareness and the drivers are trained to have realistic expectations of technology failure, such can reduce, eliminate or reverse the complacency issues.

Research also concluded that increased vehicle automation causes the driver to increase the chance of engaging in secondary tasks other than driving. This means that vehicle automation increases driver distraction and thus increases the PRT to resume manual control. Disengaged/distracted drivers took longer to resume the driving task and hence had longer PRT. In this respect, the type of secondary task has an impact on driver PRT whereby reading and writing an sms, watching a DVD or sleeping were found to be a highly likely secondary tasks to engage in. Also, it was concluded that the determining factor affecting PRT is if the driver was actually in control of the vehicle or not prior to needing to resume control.

Age factors, musculoskeletal, neurological disabilities and other related disabilities together with a number of person-specific characteristic resulted in having an impact on the perception-reaction time because the driving task is a multi-tasking operation which necessitates the full control of the vehicle. However, no research was encountered where the perception-reaction time of disabled persons was examined in relation to the driver as an operator in a Level 3 automated vehicle.

The aspect of driver engagement should be the basis of any strategy for the driver to re-engage in the driver task because the transfer of the vehicle control from the system to the driver is the most critical. None of the research which was reviewed examined different types of in-vehicle alerts in relation to different types of secondary tasks, in an AV or AV simulator, and none compared the PRT in relation to age, gender, driving experience, disabilities and country of residence.

Studies also suggested that the 2.5 seconds PRT for non-automated driving should be revised because the results showed that such value is higher for unexpected hazards for vehicles proceeding at higher speeds. This revision was suggested for the non-automated vehicle where the driver is engaged in driving and not in a secondary task. Hence, such revision is even more important for the case of automated vehicles where the driver is engaged in a secondary task.

Driver PRT is important to many areas of road design and road safety and new indicators need to be measured for AVs, one of them being the time to collision. Such is a similar indicator of PRT and it translates to and is reflected in the SSD for road design and thus it is a necessity for the redesign of transport networks to address the needs of AVs.

It resulted that the different countries which were reviewed use the same mathematical theory to calculate SSD however the parameters used differ between countries. Also, the PRT used across the countries vary between 2.0 to 2.5 seconds. Table 8 shows that the United States, Canada, South Africa and Australia use perception-reaction time values on the upper end of the range at 2.5 sec whilst Austria, the United Kingdom, France, Germany, Greece and Sweden use values towards the lower end at 2.0 sec. The main assumptions used to determine SSD values are perception-reaction distance and braking deceleration distance based on coefficient of friction values (Harwood et al, 1998). The SSD calculation takes into consideration a safety hazard on the road and that the driver of the vehicle approaching this hazard must detect its existence of such hazard and then must be able to brake to a halt.

Table 8: Minimum Required Sight Stopping Distances for Level Roads adopted in different Countries

Country	Time (sec)	Design Speed (km/h)												
		20	30	40	50	60	70	80	90	100	110	120	130	140
		Stopping Sight Distance (m)												
Australia (all road types)	2.0	-	-	40	55	73	92	114	139	165	193	224	257	-
Austria	2.0	-	-	35	50	70	90	120	-	185	-	275	-	380
United Kingdom	2.0	-	-	-	70	90	120	-	-	215		295	-	-
Canada	2.5	-	-	45	65	85	110	140	170	200	220	240	-	-
France	2.0	15	25	35	50	65	85	105	130	160	-	-	-	-
Germany	2.0	-	-	-	-	65	85	110	140	170	210	255	-	-
Greece	2.0	-	-	-	-	65	85	110	140	170	205	245	-	-
South Africa	2.5	-	-	50	65	80	95	115	135	155	180	210	-	-
Sweden	2.0	-	35	-	70	-	165	-	-	-	-	-	-	-
United States	2.5	-	30	44	63	85	111	139	169	205	246	286	-	-

Source: Harwood et al, 1998; Fanning et al., 2016; National Swedish Road Administration, 1986; Service d'Etudes Techniques des Routes et Autoroutes, undated; Ministry for Works, 2011; Neuman, 1998; Lamm et al., 1994; Durth & Lippold, 1993, Austrian Research Association for Transportation and Road Engineering, 1981.

For most of the cases reviewed, stimuli, alerts and driving conditions were not for Level 3 automated vehicles but are important as they provide background information and understanding of experiments carried out and their methodology. They are also required to verify if conditions, alerts and stimuli in Level 3 vehicles, would yield different reaction times which would in turn have an impact on the design standards for Stopping Sight Distances used in various sectors of road design and engineering which are critical to ensure road safety.

2.4 Limitations of Existing Research

A detailed Literature Review was carried out and this was examined and analysed in relation to the aims and hypothesis of this research document and formed the basis for the aims which the research intends to achieve. The limitations of existing research established the goals for this research and guided the preparation of the questionnaire to be used for the purposes of this research document.

The scope of the research carried out by Lee et al (2004) was to examine how the alert strategy and modality determined the effectiveness of collision warning systems in mitigating driver distraction. The participants of the research included 20 females and 20 males whose ages varied between 22 and 55 years. All were licensed drivers. The relevant gaps in this research were that visual alert warnings were not considered, the group of participants was small and the experiments were carried out using collision warning systems as the only automation in the vehicle.

The scope of the research carried out by Muttart (2005) was to identify variables which influence driver response times. The research was based on a desk study of 130 published studies and 6 non-published studies with the respective databases made up of 10,000 driver responses. The relevant gaps in this research were that neither AVs and nor AV simulators were used to collect the data, the drivers did not have any secondary tasks hence they were not distracted.

The scope of the research carried out by Triggs & Harris (1982) was to establish the time delay between the creation of a stimulus and the response of the driver. The experiment was carried out with response times in reaction to external stimulus such as road signs. The relevant gaps in this research resulted from the fact that the participants were all alert young drivers, the stimuli were coming from the roadside environment, the drivers were not distracted and the experiment was not conducted on an AV.

The scope of the research carried out by Merat & Lee (2012) was to examine the research carried out by others in relation to driver interaction with advanced automated technology and to establish a guide for the design of AVs. The relevant gaps in this research were that different alert systems or a combination of such were not used and only one type of distraction, namely watching a DVD, was considered.

The scope of the research carried out by Shoettle and Sivak (2016) was to determine the type of alert which the driver preferred when in a Level 3 automated vehicle and what was required for the driver to be alerted to resume the driving task. The research concluded that drivers preferred a combination of a visual, auditory and haptic alert and their second preference was a visual and auditory alert only. However this research by Shoettle and Sivak (2016) did not include the investigation of the impact of these types of alerts on the perception-reaction time of the driver.

The scope of the research carried out by Blanco et al (2015) was to evaluate which human-machine interfaces were effective and efficient in alerting the operator in the automated vehicle to resume the driving task of a Level 3 automated vehicle and to identify the perception-reaction times of the operator in relation to the alert systems (Blanco et al, 2015). This research by Blanco et al (2015) showed that staged alerts are not as effective as imminent alerts. The gaps in this research are that the results were not differentiated between different age groups and did not factor any disabilities of the participants nor did they establish how such person-specific characteristics affect the perception-reaction times. Also the research did not differentiate between different secondary tasks being performed and how they influence the effectiveness of the type of alert given.

From the Literature Review carried out as part of this research document, no studies were found whereby the perception-reaction time of disabled persons was examined when an individual is operating a Level 3 automated vehicle.

The scope of the research carried out by Merat et al (2014) was to establish the time period required for drivers to engage in manual based on observable driving performance and eye tracking. The participants were 25 males and 21 females using a simulator after having been trained to use it. The age group varied between 28 to 67 years. The incident alert was external using a Variable Message Sign. The gaps in the research were that in-vehicle different alert types were not used and the group of participants was small so no correlation between sex, age and driving experience was possible.

2.5 Importance of the Research

The results obtained and explained in the previous sections show the importance of timely communication and alerts in Level 3 automated vehicles to ensure safety. With earlier alerts on approach to a critical scenario, the time provided for the perception-reaction time is longer.

For the sensor based automated vehicles, the detection of obstacles and the navigation of the vehicle is managed by the automated system (ERSO, 2018). It is suggested that this system does not ensure 360degree mapping of the roadside environment (Silberg & Wallace, 2012).

Hence, the road side infrastructure needs to be redesigned to address this limitation incurring large expenses which might delay the introduction of AVs (ERSO, 2018).

For the connectivity based automated vehicles, roadside devices would be required along the road network where AVs are not in a position to detect the infrastructural elements or obstacles (ERSO, 2018). Such devices would also be important as a failsafe system to address unexpected roadside scenarios and thus drivers can be alerted in a timely advance period to resume the driving task (ERSO, 2018).

Hence, merging the sensor-based and connectivity-based technologies provides the fail-safes and redundancies needed to produce safer automated vehicles (ERSO, 2018). Connecting vehicles to each other and to the roadside infrastructure enables the enhanced predictability and safety for both manual and automated vehicles (Traffic Technology International, Oct/Nov 2018; Johnson 2017). Connected vehicles, both for vehicle-to-vehicle communication and vehicle-to-infrastructure communication, are part of the vehicle automated system and such connections provide quality data (Dhameja, 2018).

Connected vehicles facilitiate connections between vehicle systems, driver and passenger devices, and the external devices, networks or systems (Martin, 2018). They use internet, Bluetooth and V2V communication technologies which are still evolving (Martin, 2018). Connected vehicles start communication with and react to communications from IoT systems being both internal and external to the vehicle (Martin, 2018). Hence, connected vehicles enable drivers and passengers to be connected beyond the confines of the vehicle whilst travelling (Martin, 2018).

These automated and connected vehicles are made up of high-quality cameras and sensors which collect a large amount of data (Joshi, 2018). The data being collected is not just about the operation of the vehicle itself but also about the road side conditions (Kucharczyk, 2018). Further development of automated vehicles will render them mobile sensor beds which collect data at granular level across the world (Kucharczyk, 2018). These sensors will collect information regarding changes to the road conditions and situations (Kucharczyk, 2018). This data could be used by governments to allow for the best possible data-driven decisions (Kucharczyk, 2018). Hence automated vehicles are not self-contained but are seamlessly connected to roadside infrastructure, to each other and to centralized traffic management systems (Schaub, 2018).

The data must be easy to access to enable sharing of traffic and road data and the system used must be capable of managing large volumes of data (Dhameja, 2018). It must also have a high level of security (Dhameja, 2018). Since the different parts of the process depend on different data sets, the storing and organising of these data sets is a challenge (Sharma, 2018). Also such data needs to be analysed and used immediately and with high precision (Williamson, 2018). This makes automated vehicles part of the Internet of Things (IoT) (Schaub, 2018). Since automated vehicles are connected to the internet, the exploitation of weakness in security could result in serious problems (Ilunin, 2018). It is important that hackers do not compromise the data as this would negatively affect the safety and security of the vehicles and the passengers (Joshi, 2018). The data needs to be robustly anonymised, strongly encrypted and securely protected to ensure that individual privacy is protected and that the system is not vulnerable (Parkinson et al., 2017).

Automated vehicles give control of the driving task to hardware and software and these create an interconnected system of vehicles and traffic management centres (Parkinson et al., 2017). V2I communication mechanisms are the tool for AVs to connect to the electronic devices which control and monitor the physical roadside environment in which such AVs operate (Parkinson et al, 2017). The roadside infrastructure uses this information to maximize traffic flow (Parkinson et al., 2017).

The rate of market penetration of automated vehicles will determine the extent to which the roadside environment is shared by vehicles of different levels of automation (Johnson, 2017).

Also, different levels of automation require that the role of the driver changes from supervisor to operator depending on the specific roadside circumstances (Shen 2016; Shladover & Bishop, 2015). Hence it would be necessary to retain all the existing traffic management and road safety features of the road infrastructure to address the needs of Levels 1 and 2 vehicles whilst possibly creating the need for additional infrastructure to address the requirements of Levels 3, 4 and 5 automation (Johnson, 2017).

The need for additional road infrastructure is confirmed because although artificial intelligence is the core of automated vehicles, they are still not sufficiently precise to be used with confidence (Dhameja, 2018). The lack of road and traffic data makes it challenging to train the artificial intelligence to reach a high level of confidence (Dhameja, 2018). One hundred billion miles of human driving are considered necessary to build sufficient data in the automated vehicle to obtain an adequate level of accuracy and it is not possible to obtain such data from one single source (Dhameja, 2018).

Automated vehicles operate using machine learning algorithms to provide safety for the vehicle and the passengers (Joshi, 2018). These algorithms process large volumes of user driving data to recognize patterns which are the basis for driving decisions (Joshi, 2018). This system is known as Deep Learning and it is the use of algorithms to parse data, learn from such data and then to use such data to make a prediction (Sandt & Ownes, 2017). This is what makes it possible for AVs to be familiar with the roadside environment including people (Sandt & Ownes, 2017).

From research carried out by Dixit et al. (2016) it resulted that road infrastructure is a major reason for AV disengagements due to the improper detection of traffic lights, poor road conditions, signage and markings, potholes and the erratic behavior of other road users including other drivers, emergency vehicle, pedestrians and cyclists. Other critical reasons for disengagements were construction sites and weather conditions (Dixit et al., 2016). AV collisions which occurred where partially and highly automated vehicles were involved indicated that the existing vehicle sensors and driving strategies require additional improvement (Stewart, 2017).

It is difficult to eliminate disengagements and it is also challenging safe human takeover because, notwithstanding the advances in sensor and radar technology, existing AV on-board sensors require a higher level of reliability, increased redundancies and a longer perception range (Orosz et al, 2017). The most critical limitation of the AV on-board sensors is the line of sight because they cannot perceive through an obstruction or round a bend gving the AV a restricted view of the roadside environment thus reducing the safety margin of its driving strategy (Orosz et al, 2017).

Thus it is important that AVs has V2X communication to obtain information about the roadside environment which lies beyond its line of sight to enable more effective decision-making (Orosz et al, 2017) and more timely alerts to the driver in case of a necessary takeover. Through V2X communication, the information within the line of sight of the AV can be further enhanced such as in a traffic jam (Orosz et al, 2017). In this respect, a number of cities in the United States are testing the deployment of roadside V2X units and Japan has already installed such units in a number of zones (Orosz et al, 2017).

The time period required for the driver to resume the driving task may exceed the time available to react to a critical situation from the moment of the alert for takeover based on the line of sight of the AV sensors (Sandt & Ownes, 2017). This matter is of critical importance to the point that some organization, including NACTO, have request restrictions on Level 3 AVs to operate on roads where pedestrians and cyclists are allowed (Sandt & Ownes, 2017). Other areas where Level 3 vehicles could be restricted to manual mode ony include roadside scenarios where unpredictability is expected, around street celebrations, marathon and cycling events, residential zones and sharded use roads and spaces (Sandt & Ownes, 2017).

More research is required in relation to vehicle-driver communication, technology and interface design to establish when a handover needs to be activated to alert the driver and the adequate time required for the driver to safely re-engage in the driving task (Dogan et al., 2017; Walch et al., 2017 Clark & Feng, 2016). This scope of this research document is precisely to establish the time period required for the driver to safely re-engage in the driving task following an in-vehicle alert.

The vehicle sensors and radars need to replace or be better than human vision and human perception to make AV safer than human driving. The capacity of these radars and sensors is challenged in the following roadside scenarios (Shoettle 2017):

a. Bad weather, such as heavy rain, snow or fog, which adversely effect the maximum range and signal quality for the vehicle sensors;
b. Dirt or obstructions on the road finished level;
c. Darkness or glare;
d. Obstructions and dense traffic which limit the line of sight of the AV sensors

Automated vehicles will be able to see beyond the line of sight of a human only through vehicle connectivity and in such scenarios, the AV can surpass the human driving capability. Hence the other information collected from other vehicles and from the road infrastructure is the tool to increase the performance of automated driving (ERTRAC, 2015). This is because this additional information enables the automated vehicle to adapt the driving programme according to the information received regarding the roadside scenario (ERTRAC, 2015), such as advance road works or other roadside hazards, where possibly the driver might need to be alerted in a timely period to resume the driving task.

Other critical scenarios where the driver might need to takeover the operation of the AV and thus needs to be alerted include special on-road events, dense traffic, on-going road works or maintenance, newly installed traffic management easures, road accidents and malfunction of traffic light systems. Such are unexpected roadside scenarios which would not have been previously programmed into the AV on-board units and hence, unless they are perceived by the AV sensors and radars well in advance to allow for timely driver alert, there is the likelihood that the driver does not resume the driving task in advance of the hazard.

Safety hazards related to work zones are of particular concern for automated vehicles to operate safely and, in such critical cases, connected vehicles would allow the effective dissemination of work-zone information upstream to allow the safe passage of automated vehicles (Kockleman et al., 2016). Huggins et al (2017) stated that it is extremely important to forsee temporary traffic management arrangements and warn AV drivers. Also Huggins et al (2017) continue to state that roadworks also pose a problem because the line markings and signage on the road would have been altered to allow for the temporary traffic management arrangements and hence such changes would have made rendered useless the information contained in the digital maps.

Hence the digital road maps need to be updated regularly through the roads authorities and communicated via I2V/V2I communication technology in a timely manner to allow for the safe vehicle take over by the human driver where necessary. This is especially important because during road works and/or maintenance, the roadside scenario can change many times a day thus such interrupt the normal AV service (Huggins et al., 2017). Also, clear and regular communication with AVs is necessary to ensure safe and timely progress through the work zones and any other road disruptions due to special events, traffic management changes or arrangements. For these particular roadside scenarios where temporary traffic mangeent arrangements are in place, the safety of the automated vehicles would depend on the devices and warning systems which must be properly located outside the vehicles (Huggins et al, 2017).

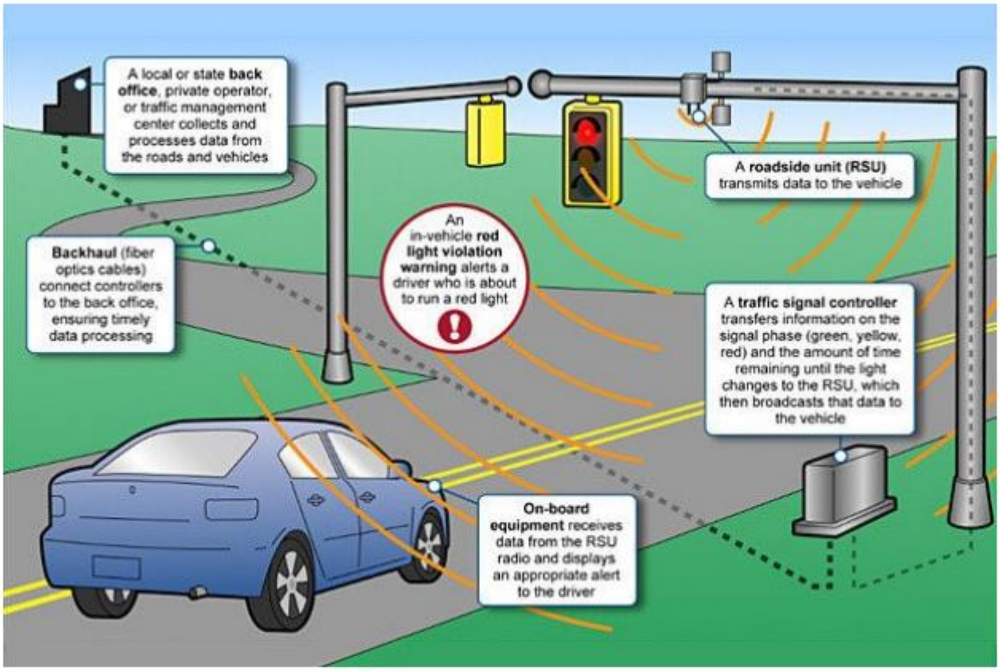
Road works, incidents and special on-street events necessitate the need for V2I/I2V interaction through the Traffc Control Centre in liaison with the police and the emergency services

(Huggins et al., 2017) so that issues may be resolved and communicated to the driver sin a timely manner (Hyatt, 2018). These present complex roadside scenarios where it is likely that the AV would alter the driver to resume the driving task (Huggins et al., 2017). New traffic management arrangements outlining new traffic operational systems will be implemented and these will create a new approach to traffic arrangements on the road network (Huggins et al., 2017).

Hence, the role of the Traffic Control Centres will need to develop to manage such big data being received from connected vehicles and to use this data proactively, to be responsive and to support the dynamic road network (Kockleman et al., 2016) by ensuring timely information being relayed to automated vehicles to alert the driver to safely resume the driving task. The management and access to such traffic data includes all the data needed by an AV to operate effectively and safely (Huggins et al., 2017). Such data includes vehicle positioning, road map attributes, information from sensors, data being shared V2V, updates to the software, security certifications and attributes (Huggins et al, 2017) and also traffic incidents, hazard warnings, environmental conditions, traffic signs, road closures and major events on the road (Hallmark, 2019).

Through vehicle-to-vehicle and vehicle-to-infrastructure communication, critical scenarios may be communicated to approaching vehicles. The most critical V2I/V2V applications which require the sharing of data include curve speed advance warning, red light violation advance warning, stop sign gap assist, weather condtions warning, pedestrian advance warnings and reduce speed warning and work zone warnings (Hallmark 2019). Other unexpected incidents such as traffic accidents or sudden roadside hazards can be communicated to subsequent vehicles in a timely manner (Hallmark, 2019). Figure 7 shows a typical road communication arrangement to enable V2V and V2I communication. However, currently, there is no such infrastructure in place for such communication to operate successfully (Ater, 2018). For automated vehicles, activating an alert through I2V communication is important because the roadside data collected through V2V and V2I communication can provide timely alerts to successive drivers in Level 3 automated vehicles. This improves road safety by increasing the time period which ensures adequate advance alerts to meet perception-reaction times.

Figure 7: Typical road communication arrangement



Source: Cooney (2016)

However the positioning of road signage warning in advance of critical, new or changing roadside scenarios is also important for the timely alert for vehicle take-over. CAV also constantly rely on road signs for the necessary information (Hallmark, 2019). As the technology of CAVs develops further, the system will required enhanced road signage which offer redundancies n the event that a technological component, such as GPS, malfunctions (Veoni, 2017). The road infrastructure must also support both human and AV advance warning by providing sgnage which is visibile in any road condition (Hallmark, 2019). Such road signage, as part of the road infrastructure, has an impact on the AV to 'read' the roadside scenario (Huggins et al, 2017) and especially pertinent to this research is the signage related to incidents or traffic arrangements which fal beyond the line of sight of the AV sensors or beyond the distance required to meet the required SSD following vehicle take-over.

Huggins et al. (2017) outline the criteria which effect the detection and recognition of traffic signs by AVs and these include inconsistencies in road signs, obstructed/obscured signage, differences in illumination, missing signage, legibility of electronic signs and maintenance. Huggins et al. (2017) also mention '*care in locating and orienting signs'* however there is no mention of positioning of such signage at distances in advance of the hazards/dangers/specific roadside scenarios for which these signs are actually required to be on the road in the first place and which are a tool for timely in-vehicle alerts in AVs.

Hence, although all the research described above highlights the importance that an AV perceives a hazard in sufficient time in advance to alert the driver to resume the driving task safely, however none of the research specifies nor examines the value of this minimum time period required to allow for the driver to safely resume the driving task. The scope of this research document is to provide the minimum time required in advace of a hazard to enable the driver to resume the driving task in sufficient time prior to collision.

This minimum time period is translated into the minimum SSD required by the driver to bring the AV to a halt following the in-vehicle alert. This means the minimum distance in advance of the hazard which is required for the perception-reaction distance of the driver and the braking distance of the AV. Hence the AV must perceive and alert the driver within the respective SSD measured form the position of the AV to the the potential point of collision, where the SSD depends on the design speed of the road.

There are various cases where automation is being adopted such as Domino's who use pizza delivery robots, Amazon which makes use of Prime Air Drones and Waymo with automated taxis (Ater, 2018). However these commercial entities use a platform model which is closed and non-inclusive (Ater, 2018).

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Research Strategy

3.1.1 Outline Methodology of the Research

Distraction whilst driving is a safety hazard and it is becoming a concern to road designers and policy makers (WHO, 2011). A considerable amount of studies have been carried out in relation to driver distraction primarily for Levels 1 and 2 vehicle automation. Inspite of various studies carried out, the actual magnitude of the problem related to driver distraction and its impact on accident risk and traffic collisions is not clear (WHO, 2011). Even more so, the risks associated with driver distraction in a Level 3 automated vehicle, where the driver is engaged in a secondary task, are even more unclear especially when the driver is required to engage in driving when the road scenario poses the greatest risk which cannot be managed by the vehicle automation systems.

This research aims to establish the driver Perception-Reaction Time (Response Time) when the driver is performing a secondary task in a Level 3 vehicle and is alerted to engage in driving operations. The Perception-Reaction Times obtained will be compared with the type of distraction, type of alert, age, the driving experience, sex and country of origin of the respondents to verify which parameters are of most significance in relation to response times obtained and the variances which are based on the inter-relation between the parameters.

The research methodology used involved an extensive literature review to establish any existing studies carried out in relation to driver distraction in Level 3 automated vehicles. Research into this area was very limited with various gaps in research which this study aims to address. Based on the literature review carried out, primarily in relation to Level 1 and 2 vehicles, it resulted that the use of mobile phones and electronic devices is one of the primary causes of distraction. Also, research related to driver distraction in a Level 3 automated vehicle in relation to different types of alert systems, different age groups, gender, any disabilities, different years of driving experience and different secondary tasks was not carried out in a holistic manner to establish the various possible correlations between the different criteria.

Primary data was collected through the creation of a computer programme which simulated a driver in a Level 3 vehicle engaged in a secondary task, other than driving, and who is alerted to engage in driving. The first part of the programme explained the scope of the questionnaire, giving a background regarding the different levels of automated vehicles and a guide to the first group of questions. This group of questions in the questionnaire involved the collection of demographic data related to the age of the driver, driving experience, any driver disability, gender and country of origin. These demographic details were important to establish the correlations between the various data groups thus identifying trends, worst case scenarios and inter-dependency in the particular scenario of performing a secondary task in a Level 3 vehicle and responding to an in-vehicle alert.

The impact of mobile use on driver distraction is more pronounced for younger and older drivers (Strayer & Drews, 2004). Also, research carried out by Strayer and Drews (2004) resulted that, when compared with the single task of driving, the reactions of drivers were 18% slower and their following distance was 12% longer when they were using their mobile phones. Younger drivers have less driving experience and so have more difficulty to balance their allotted attention between driving and a secondary task (WHO, 2011). Older drivers have greater levels of visual and cognitive impairment which makes it more challenging to manage a secondary task whilst retaining a level of alertness and this resulted in increased Perception-Reaction Times (Claypool et al., 2017).

Research has concluded that it is more probable that men make use of the mobile phone while driving however the impact of this on driving behavior is not established (WHO, 2011). Other studies resulted that the use of mobile phones has a larger impact on driver behaviour in the case of young females (WHO, 2011). In the case of text messaging, research showed that male drivers were more likely to text whilst driving however the distraction level for texting was higher for female drivers (Llerena et al, 2015).

Generally new drivers on the road are young drivers and hence there is a strong relation between the effects of age and driving experience in the scenario where the driving skills of a young driver are challenged when using a mobile phone whilst driving (Llerena et al., 2015). However, younger drivers are more sensitive to the impact of distraction whilst driving (WHO, 2011). It is important to note that cognitive development occurring during the years of adolescence results in younger drivers being more susceptible to distractions which have a more pronounced impact on their driving performance than on older drivers (WHO, 2011).

Existing research identified the use of the mobile phone and other electronic equipment as significant sources of driver distraction and hence the secondary tasks identified in the methodology simulated the driver using the mobile to text and the driver watching a video. The first scenario was a DO NOTHING scenario where there was no secondary task as a distraction. In the second case, the driver distraction involved watching a video on the screen with sound. In the third scenario, the driver distraction was reading and writing an sms. Thus these scenarios caused the driver to:

i. lose focus from the road ahead resulting in visual distraction during texting and whilst watching a video
ii. lose attention from what is going on in the road resulting in cognitive distraction especially in the case of texting
iii. remove hands from the steering wheel resulting in physical distraction
iv. experience auditory distraction if loud music is played.

The use of the mobile phone and watching a video increases in-vehicle driver distraction and causes:

i. extended Perception-Reaction Times to respond to unexpected in-vehicle alerts to engage in driving mode
ii. reactions to become slower but with more pronounced car braking
iii. increase in the mental processes thus an increase in the stress levels of the driver
iv. impaired awareness of the immediate roadside scenario.

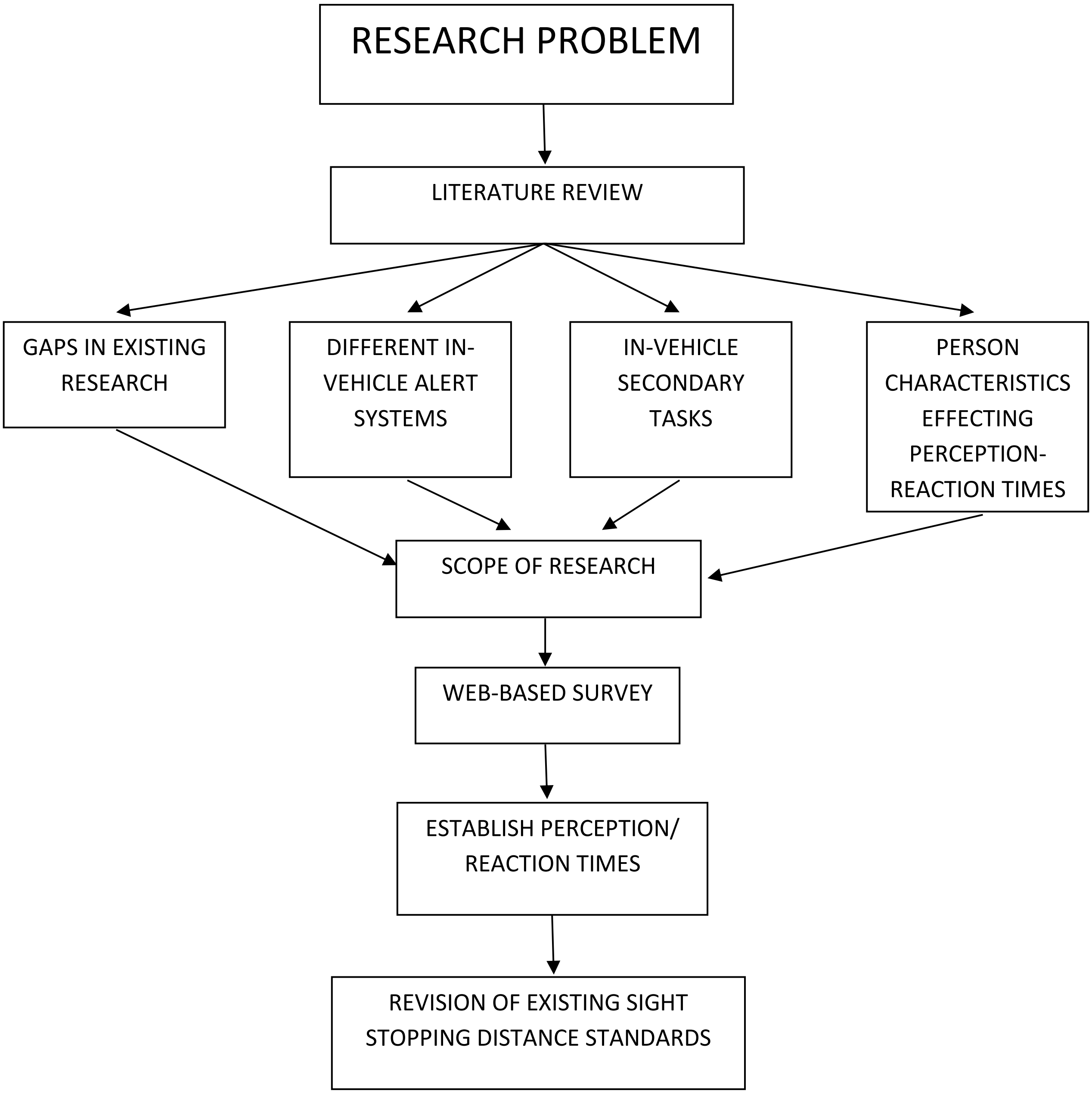
The complexity of the secondary task causing the driver distraction and its demand on the cognitive awareness are important factors to determine the extent of the distraction (WHO, 2011). Specific driver characteristics are also important to establish to which level the driver is affected by the type of distraction (WHO, 2011) and the impact of the different types of alert.

3.1.2 Research Strategy

The strategy used for this research was based on quantitative research into the human problem of driver distraction whilst performing a secondary task in a Level 3 automated vehicle. Such quantitative data provided reliable data which was measurable and countable and in this quantitative approach, the research objectives could be comprehended better because they were based on a theoretical framework established by the literature review (Naoum, 2004).

The approach adopted for conducting the research depended on the objective of the study and the nature of the investigation and the type of data and information required to reach the objective (Naoum, 2004). The Fieldwork Type of data collection, hence the collection of primary data, was the chosen method based on the survey approach. This type of approach is appropriate for collecting primary data from a large number of respondents within a limited time period (Naoum, 2004). This approach deals with a generalized result where data is collected from a specific population which (Naoum, 2004), in this case, has accessibility to internet. A summary of the methodology used is as follows in Figure 8:

Figure 8: Summary of Methodology Used in this Research Document



3.1.3 The Survey Approach

The questionnaire programme was designed to consist of both a descriptive survey and an analytical survey. The first part of the questionnaire dealing with demographic information is designed as a descriptive survey with primary data being collected regarding the characteristics of the number of respondents (Naoum, 2004). This data is collected for analytical purposes to compare and illustrate trends and tendencies.

The second part of the questionnaire is an analytical survey to establish the relationship and association between the attitudes of the respondents and the objective of the questionnaire. In this case, the category of respondents, as established through the descriptive survey, is the independent variable and the attitudes of the respondents, as established through the analytical part of the questionnaire, are the dependent variables. Hence, the attitudes of the respondents to driver distraction in a simulated Level 3 automated vehicle are dependent upon the characteristics of the respondents. However, in turn, the attitudes of the respondents are also dependent on the nature of the distraction in the analytical part of the survey.

The analytical part of the survey was a roadside driving simulation where the respondents were alerted by two different types of alert, namely a visual alert and a combined visual and auditory alert. The respondent was required to react to the alert and the Perception-Reaction Time was measured. The respondent had two different scenarios in which the driver was involved in two different secondary tasks, namely texting and watching and listening to a music video. In the third scenario the driver was involved only in driving without any distractions, and therefore, no secondary task. Given that the scope was to measure unexpected perception-reaction time according to in-vehicle distractions with the intention to simulate the driver being asked to engage in a driving mode from automated driving, the scenario with no distraction was important to compare data.

3.2 The Web Survey

3.2.1 Technique for Data Collection

When the type of data to be collected was established, namely the collection of quantitative data, and the research approach was identified, the most appropriate technique for the collection of data was assessed to ensure that the required data and information would be obtained from respondents within a stipulated time frame. The Web-based questionnaire technique was considered as most appropriate to reach the research goals. Also, in this case, the data required involved a driving simulation and hence a web-based questionnaire was inevitable to enable the respondent to participate in the simulation.

The web-based technique is a refined development of the more conventional postal questionnaire. This technique is probably the technique most frequently resorted to for analytical and descriptive surveys for the collection of data and to establish facts (Naoum, 2004). This technique is most appropriate to surveys whose scope can be explained in a few paragraphs and where the questions are not elaborated.

The questions in the first part of the questionnaire, the descriptive section, were closed-ended questions which required specific responses. Such questions were quick and easy to answer and their analysis was straightforward. Such closed-ended questions had a factual format and were designed to specifically obtain information related to the background of the respondents.

The second part of the questionnaire involved a driving simulation in a Level 3 automated vehicles where the respondents were not required to answer a question but instead were required to react to an alert based on the scenario presented. In the case, the results obtained also required specific perception-reaction responses.

The advantages identified for the web-based questionnaire carried out were the following:

i. the web-based questionnaire offered a high validity of results because it enabled a wide geographical coverage (Naoum, 2004). It was appropriate for collecting a large amount of information at the least expense and the least amount of human resources;
ii. the method adopted was a relatively quick way to collect information which was possible to analyse in a relatively short period of time. A time period of three months was sufficient to ensure a statistically viable sample;
iii. the online surveys enable participants to fill in the survey by imputing their answers while being connected to the internet. Hence, their answers are automatically stored in the assigned database. Thereby data handling is reduced and the risk of errors in data inputting is minimised;

iv. online surveys are also the most convenient method for participants because the latter can answer the survey at their own pace and time (Creative Research Systems, 2018; Andrews et al., 2003);
v. online surveys provide flexibility in their design which is not afforded by other traditional formats. Moreover, pictures and videos can be featured in such surveys;
vi. participants tend to provide more sincere feedback when answering a computer rather than when they give feedback to an interviewer or on paper (Creative Research Systems, 2018; Andrews et al., 2003).

The disadvantages identified were:

i. the descriptive questions needed to be simple and straightforward. The reactions to the driving simulation also needed to be carried through a simple operation which was designed to be applicable to all internet accessible portals such as lap tops, mobile phones and tablets. It was imperative that the questions and reaction responses were free from ambiguity or vagueness (Naoum, 2004);
ii. since the questions did not involve a face-to-face interview, only the results entered in the system were available. No additional in-depth opportunities and open-ended questions were possible. Also, it was not possible to monitor the respondents during the questionnaire itself;
iii. online surveys cannot reach participants who do not have access to the internet such as elderly persons or persons living in areas with no internet connection;
iv. this type of questionnaire strategy adopted did not allow for any control over the respondents and there was the risk of survey fraud (Creative Research Systems, 2018; Andrews et al., 2003).

Given that the second part of the survey consists of a video simulating a driver in a Level 3 automated vehicle, a web-based online survey was the only practical way to have a large number of participants viewing and reacting to the video simulation. Establishing the appropriate survey collection method was very important. This was determined depending on the data which was required to be collected, by the limitations posed by the software and the technology readily available for participants. Given that an online survey was considered to be the only practical method to collect the data required for this research document, the validity of such data collection method was researched to ensure that it was valid and reliable.

Research shows that the most critical disadvantage of online surveys is the low coverage of population. However this disadvantage is gradually being reduced because the global internet penetration rate has gone for 0.4% in 1995 to 38.8% in March 2013 (Gao et al, 2013; Internet World Stats, 2013). According to Gao et al, (2013) and Internet World Stats (2013), in 2012 the internet penetration rate was 79.5% for Japan, 78.1% for the United States, 81.3% for Belgium, 83.0% for Germany and 81.3% for Belgium wholst in 2019, the internet penetration rate was 86.8% for Europe. Between the years 2000 to 2019 the world total internet penetration growth was of 1114% and as a result of increased internet penetration, the population is becoming more familiar with online surveys (Gao e al., 2013).

Some studies indicate that participants of online surveys tend to have a larger percentage of males participants, the contributors tend to be younger and have higher levels of education and income (Lindhjem & Navrud, 2011) (Marta-Pedroso et al., 2007). Other research which was carried out showed that there were no significant differences in the education level of the participants, income, gender and age groups when participating in online and other types of surveys (Windle & Rolfe, 2011; Olsen, 2009). Other recent studies carried out resulted that no significant difference exists in the quantitative and qualitative data between online surveys and other types of surveys and it also resulted that online surveys examining consumer preferences, attitude and behavior have increased in their popularity so the quality of the data of online surveys is very important (Gao et al., 2013).

Schillewaert & Meulemeester (2005) carried out a study comparing the results between traditional survey methods and online surveys as methods of data collection. The study compared the responses and profile of participants who were participating in the survey through postal mail, telephone, online and on internet pop ups. The topics of the survey were related to opinions, attitudes and interests. It resulted that the samples generated similar results. The instances where there were differences turned up in the results were not related to the topic or methodology used.

Similarly, Neubauer et al. (2010) concluded that desktop-based driving simulators yield valid results for subjective stress, fatigue, loss of task engagement and driver response to criticial scenarios. However, Farber (1999) concluded that driving simulators do not accurately represent real automated driving. It is to be noted that in a study carried out on a test track by Bender et al. (2006) it resulted that in 88% of the automatic braking response, the participants inadvertently pressed the gas pedal in reaction to the inertia forces created when the vehicle was decelerating, which motion effects cannot be reproduced in a simulator.

3.2.2 Relationship between Expected and Unexpected Perception-Reaction Time

This methodology for the collection of the necessary PRT data for the scope of this research was possible because of the research carried out by Johansson and Rumar (1971) who undertook a study to evaluate the response time of drivers on the public road whilst driving their own cars.

Johansson and Rumar (1971), carried out a very important research on driver perception-brake reaction time. They measured the perception-brake reaction time of 321 drivers in an EXPECTED alert situation and a much smaller sample of drivers under SURPRISE alert (Hooper & McGee, 1983). This study is very important because it was identified by AASHTO as the basis for the 2.5 second perception-brake reaction time used in the SSD model. In this study the 85th percentile perception-reaction time of the driver was used to establish the Design Perception-Reaction times for the unexpected and expected events. AASHTO considers that ‘‘for approximately 90 percent of the drivers (in the Johansson and Rumar study), a reaction time of 2.5 seconds was found to be adequate’’ (Fambro et al, 1997).

Johansson and Rumar (1971) originated their research from the premise that the usual driver reaction to a likely incident is sudden braking. Thus, driver reaction time is one of the determining factors of whether an accident occurs or not. Johansson and Rumar examined the unexpected surprise and anticipated surprise perception-brake reaction times (PBRT) for drivers proceeding along the rural highways in Sweden. The perception-reaction times were subsequent to an auditory alert signal. One of the challenges in the methodology adopted for their study was to obtain results which reflect the common traffic scenario. It was also important to determine the distribution of brake reaction time across the driver population. The aims of their research were:

i. to establish a correction factor to obtain UNEXPECTED brake reaction time (same as perception-reaction time) from EXPECTED brake reaction time.
ii. to establish the EXPECTED brake reaction time distribution in a representative sample of drivers.

Perception-reaction was always an issue of concern in the areas of physiology and psychology and two surveys which assessed perception time in relation to driving were carried out by Teichner (1954) and Forbes and Katz (1957). The studies carried out by Johansson & Rumar (1971) showed that the reaction time varies according to the tasks being carried out and it also varies between one person and another. Hence, it was also concluded that the surveys for reaction time need to be carried out in situations which are similar to the actual driving scenario.

Johansson and Rumar (1971) adopted two methods of measurement of data. The first method involved obtaining the brake-reaction time on a large group of drivers driving under normal conditions with EXPECTED braking conditions. In this method the scope was to establish the brake reaction times from a representative group of drivers who were expecting an incident. All drivers who were briefed and interviewed were instructed to respond to a signal when driving past the measuring station.

The second method involved obtaining the brake reaction time of a small group of drivers under UNEXPECTED conditions. In this method the scope was to establish how brake-reaction time in an UNEXPECTED situation compares with the response to an EXPECT signal. Brake reaction time was taken for a small group of five drivers both under an unexpected and an expected alert situation. The drivers each had a minimum of seven years driving experience.

It resulted that all participants had a longer reaction time for the unexpected alert and the range of brake reaction time values obtained for the unexpected situation was similar for each participant. This was similar to the range of values obtained by the first method of survey under the surprise alert condition where the range of values was small.

These results obtained by Johansson and Rumar (1971) concluded that a correction factor can be established which can be applied to data collected under expected conditions. The data which was collected was used to establish an empirical correction factor between a surprise perception-brake reaction time and anticipated perception-brake reaction time as follows:

$$\text{Correction Factor} = \text{Surprise PBRT} / \text{Anticipated PBRT} = 1.35$$

The data collected by Johannsson and Rumar suggests that the perception-brake reaction time obtained when the driver anticipates the need to respond can be corrected. This can be done by estimating a surprise perception-brake reaction time by using the correction factor of 1.35 multiplied by the anticipated perception-brake reaction time. It is to be noted that the correction factor established through this research by Johansson and Rumar (1971) is applicable for simple reactions and there is basis to understand that this correction factor would be larger for more complex brake-reaction situations.

The definition of Perception-Reaction Time in the CEDR report clearly shows that this time period was the SURPRISE perception-reaction time as follows (Weber et al, 2016):

''the time it takes for a road user to realize that a reaction is needed due to a road condition, decides what manoeuver is appropriate (in this case, stopping the vehicle) and start the maneuver (moving the foot form the accelerator to the brake pedal)''.

In the NCHRP Report, the Perception-Brake Reaction Time (perception-reaction time) is defined as ''the interval of time between the moment the driver recognizes the existence of an object or hazard on the roadway ahead and the moment the driver applies the brakes or makes an evasive maneuver'' and that the research proposed ''a revised stopping sight distance model based on driver capabilities and performance in response to an unexpected object in the road'' (Fambro et al, 1997). The hazard is assumed to be an unexpected object of sufficient size for the driver to require evasive intervention. Such clearly shows that this time period is considered to be the SURPRISE perception-brake time period. Hence, the AASHTO recommended an SSD to be used in road design which is based on below average drivers detecting an expected object in the road and taking action to stop the vehicle before hitting the object (Fambro et al, 1997).

It is to be noted that for studies carried out under closed-course conditions where the driver anticipated braking during the test, the drivers exhibited a shorter perception-reaction time than the AASHTO 2.5 second period (Fambro et al, 1997). However it is to be noted that braking performance and maximum deceleration results were similar both for the surprise and the anticipated scenarios (Fambro e al, 1997).

The survey carried out as part of this research obtained values for ANTICIPATED perception-reaction times because the participants taking the survey were informed in advance of how the survey was to be completed and so the participants were anticipating that they would need to react to an alert. Thus, the values obtained need to be corrected to obtain the SURPRISE perception-reaction times to enable a like-with-like comparison of surprise perception-reaction times with the 2.0 second value established by CEDR and the 2.5 second value established by AASHTO.

Hence, the Correction Factor established by Johannssen and Rumar (1997), was applied to the survey data for perception-reaction time and such data was used for the analysis of the survey results. Although the experiments carried out by the latter did not involve a driver performing a secondary task in a Level 3 automated vehicle however the results of this experiment are applicable to the data obtained as part of this research for the following reasons:

a) The experiment carried out by Johansson & Rumar (1971) was for a driving situation and the PRTs being measured were directly related ot the driving situation where the driver was required to react. In the case of the survey of this research document, the PRT are related to a simulated driving scenario where the survey participant is required to react to an alert;
b) The experiment conducted is applicable for simple reactions and this is also the case fr the PRT data collected in this research document, which PRT data was collected for a simple reaction;
c) The alert in the experiment was an auditory alert and thus similar to the alert system in the survey designed for this research;
d) The PRT measured was from the moment of the auditory alert to the moment of the first driver reaction, which reaction was to apply the brakes. Similarly, the survey carried out as part of this research involved the measurement of the PRT from the moment of the alert to the first reaction which was the pressing of the alert button on-screen;
e) Although the experiment carried out did not include an in-vehicle distraction, however this does not impair the validity of the use of their results for the survey scenario in this research document. This is because the 1.35 is a factor which reflects the difference between the PRT of the expected and unexpected alert and does not reflect the value of the PRT itself. It is related to the difference between the expected and unexpected alert scenario which the driver was subjected to under the same driving conditions.

3.3 Sampling Method

When the type of questions and feedback required for this research was decided, the potential respondents were identified. Participation of individuals in this research study was through email invitations to access the internet link, adverts in news portals and through social media. The aim was to obtain as many completed questionnaires as possible with a wide range of age groups, gender, driving experience and countries of origin, all of whom with access to the internet to be able to access the web link.

The sampling method used to collect the raw data for this research was Convenience Sampling. This is a type on non-probability methodology of sampling which gathers data from members of the population who are easily available to participate in the survey (Crossman, 2019). The main advantages of Convenience Sampling was that the data collection process was time-efficient which was important to the scope of this research document as it allowed the data to be collected in the course of the research project. Also, this type of sampling technique was low cost because it used the population which was readily available. Although this type of sampling technique does not consider if the survey respondents represent the entire population however, with this technique, habits and trends can be observed in the easiest manner (Bhat, 2020) and thus this was in line with the scope of the survey for this research which was to establish the reaction time to a distraction of a driver.

3.4 Web-Based Survey Design

Characteristics of the best survey questionnaires include a professional appearance, motivated flow and simple to understand questions (Dillman, 2000). The email invitation to participants to encourage them to take the survey should:

i. define the background and credibility of the researchers
ii. give an explanation of the scope of the survey
iii. explain the benefits of the results to the public at large and the importance of participation
iv. ensure respondent privacy
v. Explain the sampling methodology.

Most of the design criteria applicable to paper-questionnaires are also relevant to online surveys (Dillman, 2000; Fink, 1985) as follows:

1. The first question should be straightforward and subsequent questions should follow each other logically;
2. Related questions should be grouped together and bold lettering should be used to emphasise important words should be used. These would attract the attention on the respondent;
3. Although there are many design options available for online surveys, such as bells, whistles, audio and coloured pictures, however it is recommended that such surveys are kept as simple as possible.

These concepts were developed with the objective of consideration enabling the participant to access and answer the survey by using different electronic operating systems. These concepts were examined and the web-based survey was developed. This can be accessed at:

http://survey.horizon2000computers.com/

3.4.1 Welcome and End Screen

The first screen, which introduces the online survey, needs to be motivational and should explain to the respondent the next actions required (Fink, 1985) (Office of Planning and Institutional Assessment, 2006). This screen needs to outline the scope of the survey and to explain the conditions for anonymity and confidentiality.

The last screen at the end of the survey should be a Thank You screen to show appreciation for the respondent taking time to cooperate and answering the. Both the Welcome and Thank You screen were included in the online survey.

3.4.2 Types of Questions

As the respondents gradually proceed through the questions and tasks in the survey, they generally become more interested and thus the risk that they stop half way through answering the survey is less (Fink, 1985). It is more probable that the participant abandons the survey after the first few questions of the survey. So the first few questions should be short, simple and straightforward (Fink, 1985) (Office of Planning and Institutional Assessment, 2006). The first question tends to reflect the tone of the subsequent questions (Fink, 1985). If this question is complicated, respondents may conclude that the subsequent questions are similar increasing the risk that they do not complete the survey.

It is important that the questions in the survey are designed to be similar to questions found on self-administered paper questionnaires because respondent might not be a familiar with online surveys (Dillman & Smyth, 2007). Such a format gives a sense of familiarity to the respondents and will promote the tendency that the respondent will be able to complete the questionnaire quickly and correctly. Conventional formatting needs to be applied to the online survey whereby questions are numbered, left justified text and response options located just below the question.

The language used for the questions is also a challenge. Questions should maintain objectivity to eliminate bias (Andrews et al., 2003). Moreover shorter sentences and simple vocabulary/diction were found to be better than more complex ones for reading on a screen and to ensure understanding of the question (Office of Planning and Institutional Assessment, 2006; Dillman, 2000). Research showed that people do not read web pages but instead they just scan them and focus on key words and phrases (Nielsen, 1997).

The survey welcome screen and the first few questions related to demographics were left simple to simulate the paper-type of survey and general modules which people fill up regularly.

3.4.3 Colour

Online surveys have the possibility of adding colour and interest to the survey without additional costs. According to Zuckerman et al. (1999) this improves the visual impact of the survey, facilitates the flow through the survey and encourages the respondent to continue the survey. Furthermore it is to be noted that the use of colour should not detract or impair readability and consistency throughout the survey and, given that colour tends to look differently on different screens, it is important that the standard 256-colour palette is used.

To ensure optimum readability, there is to be a high level of contrast between the colour of the text and the colour of the background. A light background with dark text gives the best readability whilst light text on a dark background, although easy to read, is tiring to the eyes. Red and green colours should not be overlayed since persons with colour blindness, amounting to 10% of men, would not be able to see the difference (Fink, 1985).

The slides preceding the demographic questions and the simulation part of the survey briefly describe to the participant how to interact with the survey simulation and coloured pictures were added. Also, the simulation shows a coloured video with which the participant needs to engage.

3.4.4 Technological Issues Affecting Visual Output

Different browsers, operating systems, screen configurations and partial screen displays might make the visual output of the survey look different to how it was originally designed and intended to be viewed (Fink, 1985). Participants might not be in a position to participate in the survey because of incompatibilities with software and hardware so the developer must ensure that the survey is checked with different browsers such as Explorer and FireFox, and with different operating systems such as Windows XP, Windows 2000 and Mac OS.

Participants may opt to take the survey on the smartphone or tablet. Many of these types of equipment have high resolution however they have small screens and hence the text of the survey might not be readable unless they zoom in (Creative Research Systems, 2018). Hence it is important to ensure that the software adapts fonts and elements to fit such devices. Also it is useful to use drop down lists which minimise this problem. For the scope of this online survey, the actual on-screen placement and presentation of items was carefully checked and verified.

3.4.5 Instructions

It is important to add instructions on how the survey needs to be completed even if the procedure is simple. Instructions are to be simple, short, comprehensive and straightforward and abbreviations should not be used as they might not be understood by all participants (Waltson et al, 2006). In the case of complex questions, a link to the directions on how to reply should be placed next to the question itself. Questions requiring the same type of directions should be grouped so as not to overwhelm the participant with a large amount of instructions.

In the case of the survey for this research document, the survey consisted of two parts. The first part had simple demographic questions with simple instruction preceding them in the Welcome page. The second part of the survey was the driving simulation which was also preceded by simple instructions on how to complete the survey. Hence the two different types of participant interaction with the survey were grouped in two parts to make it simpler for the participant to complete.

3.4.6 Format for Response Options

During the design phase of the survey, the software developer can choose from a number of options how to present the response options (Waltson et al, 2006). The most adequate response options need to be selected from different options such as radio buttons, check boxes, drop-down menus, random order matrics, scaled responses, constant sum and open-ended text boxes (Waltson et al, 2006; Van-U-Lan, 2007; Office of Planning and Institutional Assessment, 2006). A different number of response options can be selected provided that the font type and size, width of response categories and colour scheme are kept constant throughout the group of questions in the survey (Fink, 1985). If these vary, the respondents might think that some questions are more important than others.

In order to ensure achieving the objective of this survey as part of this research, the response format to the questions in the first part of the survey consisted of Drop-Down Menus and Scaled answers. For the Drop-Down Menu, the question remains visible but the content of the menu becomes visible when the respondent clicks on the text box to enable a choice of reply. The participant selects a reply from the drop-down list. The Drop-Down Menu for the question pertaining to country of origin of the respondent is a long list with all the countries in the world so this question was placed last so that the menu would not obstruct the subsequent questions when it is dropped down. For the Scaled answers, the respondents need to type in free text. In this case, the respondents need to type in numbers because the related questions were related to the age of the respondent and the years of driving experience.

Drop-Down Menus were used for responses related to gender. The same method was used ot certify whether the respondent was a driver with a valid driving license, whether the respondent was disabled and to establish the country of origin. Scaled answers were used for the respondent to enter the age and the number of years of driving experience.

3.4.7 Requiring Answers

It is not recommended that respondents are required to answer the preceding question before progressing to the next as an ethical norm for voluntary participants for the whole survey (Fink, 1985). It is to be noted that in other survey modes such as paper-based surveys and interview questionnaires, respondents can skip any question and still be able to proceed with the completion of the rest of the survey. In the case of the survey for this research document, the questions are neither difficult nor embarrassing and so it is not envisaged that such issues would occur however there is not in-built system in the survey where answering all the questions is made mandatory. Participants are free to leave questions unanswered. Unfortunately, given the nature of the research, an incomplete set of replies would not be beneficial to the analysis.

3.4.8 Font Type and Text Size

The types of fonts fall into two different categories namely serif and sans serif (Fink, 1985). Serif fonts have small wings on the top and bottom of the letters and can be seen in fonts such as Times New Roman and Georgia (Fink, 1985). These wings facilitate the reading of long phrases of lines of text. Sans serif fonts are simple letters which are more adequate for short phrases or titles (Fink, 1985). These include Ariel and Verdana fonts. For the case of online survey design, it is important to choose the most effective font size and font type.

Research carried out in assessing the preferred font type, font size and format and the study results concluded the following (Fink, 1985):

i. the fastest reading of a text was with 12-point Times New Roman;
ii. the most legible text was with 12-point Arial;
iii. 12-point Times New Roman and 12-point Arial had the same sharpness;
iv. the preferred font size and type was the 12-point Arial.

It is recommended that if the survey targets older adults, 12-point Arial font type and font size are used since such font size improves reading efficiency, reading time and legibility for adults aged between 63 and 83 years (Fink, 1985). For the scope of the survey designed for this research document, font size adopted was at least 12-point and Arial font type was used.

3.4.9 Motion and Sound

Online surveys have the benefit of being able to include motion, graphics, links and sound. These help create a more interesting and attractive survey. However an excess of such features might also increase the downloading time of the survey itself or cause the computer of the respondent to crash and negatively affecting the response rate (Zuckerman et al, 1999). Research showed that with a fancy and highly animated survey which requires more memory and download time, the response rate was 82.1% whilst the response rate for a plain version of the survey was 93.1% (Fink, 1985). Hence, to avoid such issues, the survey design should be kept simple and graphics are to be kept to the minimum possible to reach the scope of the survey.

In the case of the survey pertaining to this research document, the pictures which were included were limited to the two screens which gave instructions to the respondents on how to complete the survey. Consequently the participants could appreciate that automated vehicles operate with the help of many sensors. This also enabled them to better cope with the vehicle simulation part of the survey. The second part of the survey is an interactive section showing a vehicle simulation. The video shows a vehicle in motion and bleeping and flashing icons simulating an in-vehicle alert system.

The alert system is a visual alert for the first, third and fifth driving scenarios. The alert system is a visual and auditory (multimodal) alert for the second, fourth and sixth driving scenarios.

This type of alert is the same as the alert signal used in the Google AV for the driver to resume manual control whereby such Google AV gives out an audio and visual alert signal (Vincent, 2016; The Guardian, 2017). These features are compulsory to enable the simulation to be carried out. The final screen also had a picture.

3.4.10 Software used for the Creation of the Online Survey

The online survey was developed using the C# and Java programming languages to create this executable programme which created the online survey. The company Horizon 2000 of Zebbug Malta was commissed to create the online survey.

C# is a programming language which takes the best of C++ language and C language to create a modernized language which is easy to use and more verbose Visual Basic (Davis & Sphar, 2008; Mkhitaryan, 2017). C# programme is flexible and can be executed on the computer itself or it can be transmitted over the web and be executed on a separate computer (Davis & Sphar, 2008). This aspect was very important for the scope of the survey for this research document as such survey programme was distributed as a web link for participants to take part in.

Another advantage for the use of C# is that it has error-proof commands because the code is checked before it is transformed into a command (Mkhitaryan, 2017). Also the .NET code library provides the assistance required to create complicated display frames with drop-down lists, tabbed windows and background images (Davis & Sphar, 2008). Such features were necessary for the design and development of the survey required for this research document. C# is also a secure programming language and is intended for use on the internet as it includes foolproof protection against hackers, thus reducing the hacking risk of the survey (Davis & Sphar, 2008).

Java was also used to develop parts of the web-based survey for this research document. Java is a programming language similar to C and C++ however there are some differences. Java is popular because of its platform independence which enables the Java programme to function on many different types of computers (Lowe & Burd, 2007). It is designed to be used in the distributed world of the internet and it is the most popular programming language for Android smartphone applications, for the development of edge devices and the internet of things (Mckenzie, 2019). This aspect of the programme was essential for the development of the survey for this research document as it was imperative that the online survey would be able to operate on different types of computers which participants would be using.

Another important aspect of Java is that the data is secure because Java does not use pointers and the data is converted to bytecode and is not readable to humans (Mckenzie, 2019). Java runs the programmes in a sandbox to ensure that no changes are made by unknown sources (Mckenzie, 2019). As for the case of C#, this security aspect of Java was also important for the objectives of the online survey for this research document.

3.5 The Questionnaire and Pilot Questionnaire

The questionnaire survey was in the form of a structured online questionnaire which was designed to collect data regarding driver Perception-Reaction times whist performing a secondary task, acting as a distraction, in a simulated Level 3 automated vehicle. Such data was collected for drivers with different characteristics namely age, gender, driving experience and country of origin. Such research was intended to fill the gaps in the research which has been carried out as described in this chapter. The first part of the questionnaire was designed to collect the demographic data whilst the second part was a driver simulation intended to collect Perception-Reaction time data.

On completion of the questionnaire, such was distributed as a Pilot Questionnaire to a closed group of 5 individuals and an initial Pilot Study was conducted on the questionnaire to confirm that the data required was being collected as intended and that it was well understood by participants. Also, the Pilot Study helped to identify any ambiguity, the effectiveness of the wording and the technique used. Feedback from these 5 individuals was assessed and the Pilot Questionnaire was adjusted to ensure that its maximum potential was achieved.

The following adjustments were made to the Final Questionnaire following the receipt of feedback from the Pilot Questionnaire:

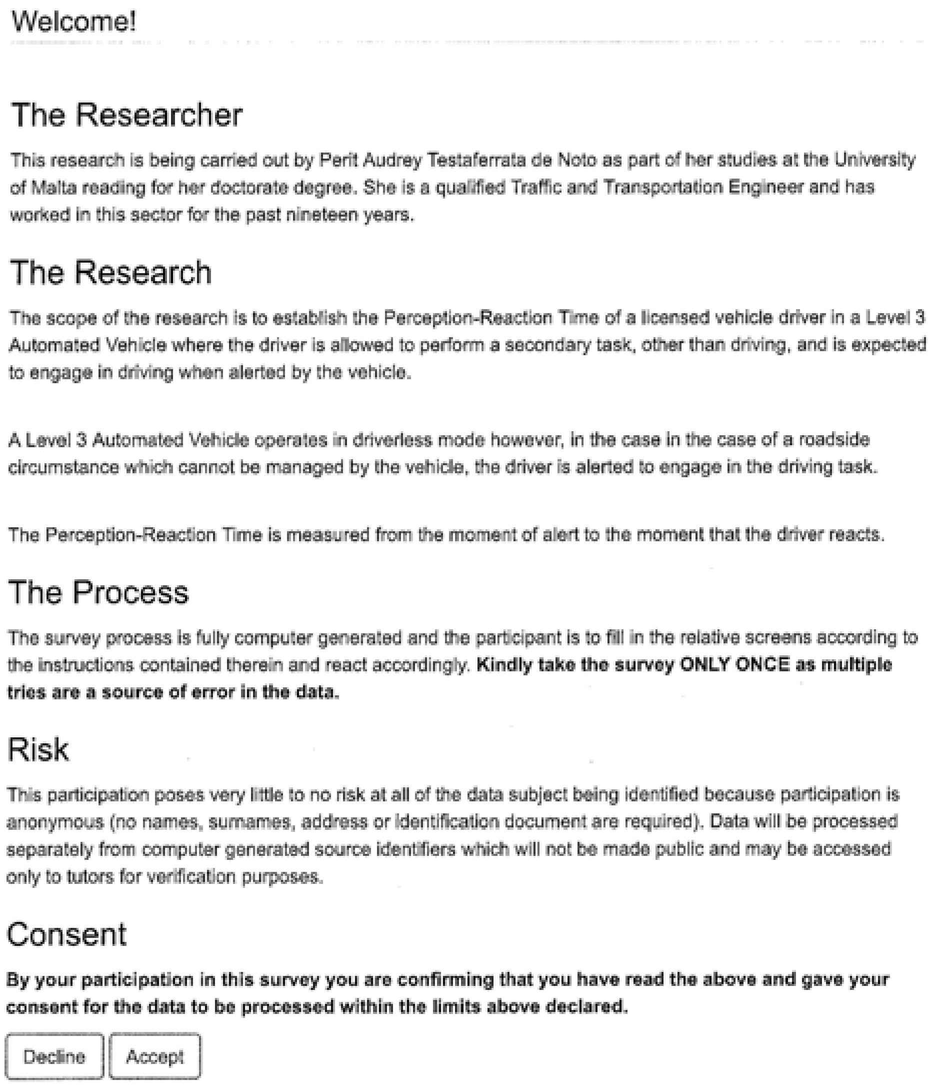
i. the introduction page located before the start of the demographic part of the survey was upgraded to incorporate a better explanation of the scope of the data being collected within a more holistic context. Also pictures were added to increase interest and for the participant to better appreciate what a Level 3 automated vehicle is and what it looks like.
ii. the wording ‘Place of Residence’ in the demographic data collection section was changed to read ‘Country of Origin’ since personal characteristics are generally defined by the culture of the country of origin rather than the place of residence of an individual
iii. the Data entered for gender and country of origin was stored in numeric format for easier subsequent processing of data
iv. a second information page was included before the start of the vehicle simulation part of the questionnaire which was intended to collect Perception-Reaction time data. Such page explained exactly what was expected form the participant to ensure that the survey was carried out as intended and for the participant to appreciate the importance of the research and the role therein.
v. the scenarios in the driving simulation section which did not involve a secondary task were shifted as the first scenarios experienced by the participants.

3.6 Design of the Online Survey

The Welcome screen at Figure 9 included a brief outline of the researcher, some information about the scope and importance of the research and the survey and an anonymity, confidentiality and consent clause. This screen is intended to foster trust in the respondent as an encouragement to proceed with completing the survey. The text was kept simple to replicate the paper-based surveys which are generally more familiar to respondents. The information given about the survey was kept simple and concise to be understood by non-technical people but which still explained the scope and aim of the research being carried out.

The consent was important due to Data Protection legislation even though the participants have very little to no risk of the data subject being identified because participation was anonymous and the data was processed separately from computer generated source identifiers which will not be made public. Given the importance that each participant takes the survey only once, mention of this was also listed in the Welcome page and explained to the participant.

Figure 9: First Welcome Screen of Survey



Welcome!

The Researcher

This research is being carried out by Perit Audrey Testaferrata de Noto as part of her studies at the University of Malta reading for her doctorate degree. She is a qualified Traffic and Transportation Engineer and has worked in this sector for the past nineteen years.

The Research

The scope of the research is to establish the Perception-Reaction Time of a licensed vehicle driver in a Level 3 Automated Vehicle where the driver is allowed to perform a secondary task, other than driving, and is expected to engage in driving when alerted by the vehicle.

A Level 3 Automated Vehicle operates in driverless mode however, in the case in the case of a roadside circumstance which cannot be managed by the vehicle, the driver is alerted to engage in the driving task.

The Perception-Reaction Time is measured from the moment of alert to the moment that the driver reacts.

The Process

The survey process is fully computer generated and the participant is to fill in the relative screens according to the instructions contained therein and react accordingly. **Kindly take the survey ONLY ONCE as multiple tries are a source of error in the data.**

Risk

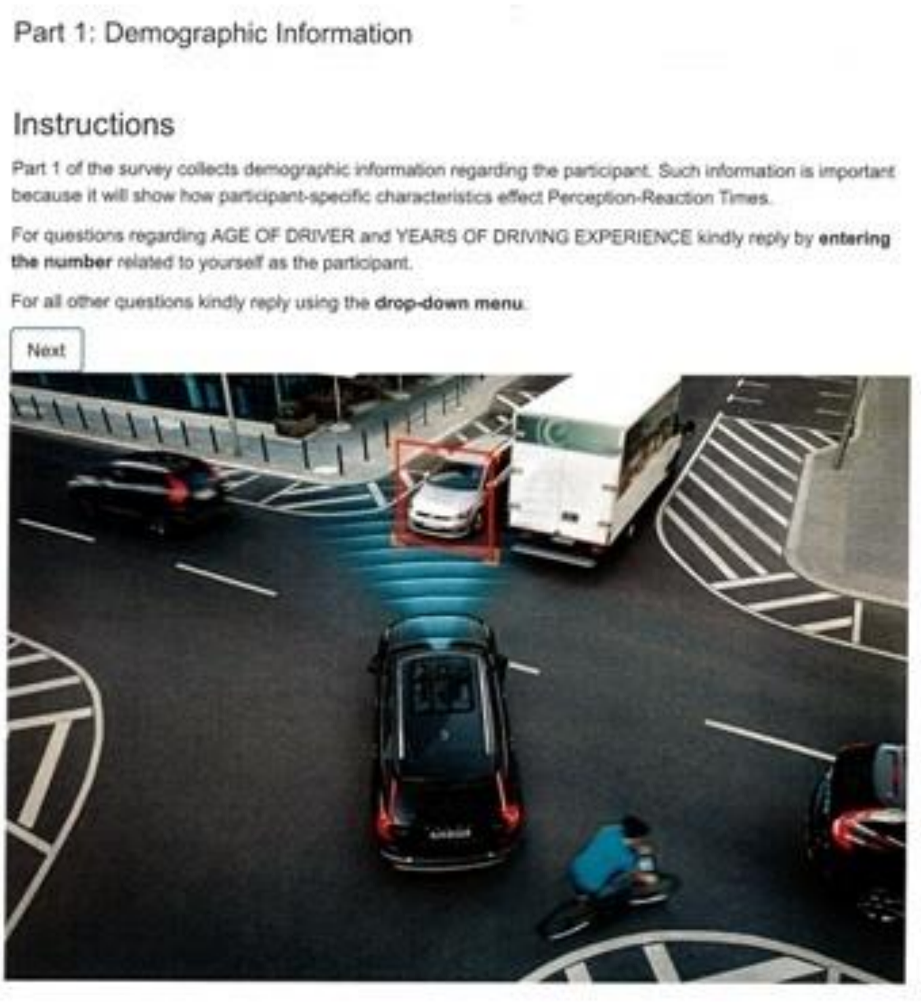
This participation poses very little to no risk at all of the data subject being identified because participation is anonymous (no names, surnames, address or identification document are required). Data will be processed separately from computer generated source identifiers which will not be made public and may be accessed only to tutors for verification purposes.

Consent

By your participation in this survey you are confirming that you have read the above and gave your consent for the data to be processed within the limits above declared.

The second screen of the survey, Figure 10, which complimented the Welcome screen, included coloured pictures of automated vehicles and explained to the respondent the importance of the demographic questions of the survey and how to fill in the first part of the survey which was made up of these questions. Both the scaled questions and the drop-down menu questions were explained to make it easier for the survey particionat to follow through the questionnaire. It was important to explain to the participant what was expected from the survey because the survey was carried out unsupervised and thus it was necessary to ensure that the participant understood what was required.

Figure 10: Second Survey Screen



Part 1: Demographic Information

Instructions

Part 1 of the survey collects demographic information regarding the participant. Such information is important because it will show how participant-specific characteristics effect Perception-Reaction Times.

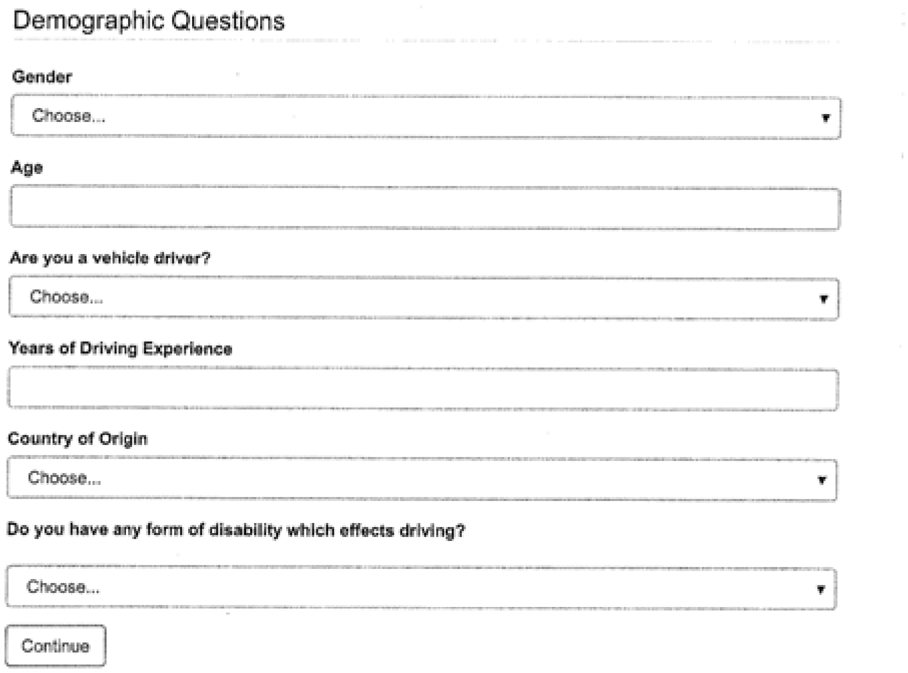
For questions regarding AGE OF DRIVER and YEARS OF DRIVING EXPERIENCE kindly reply by **entering the number** related to yourself as the participant.

For all other questions kindly reply using the **drop-down menu**.

Figure 11 shows the demographic questions and such questions were designed in a simple and straightforward manner to replicate the standard paper-based surveys. All text, throughout the survey, was kept as short as possible using and highlighting key words in bold. The conventional formatting recommendations were applied only to the first part of the survey. The first question was to describe the gender of the participant and the answer was to be selected from a drop-down menu. The second question was to provide the age of the participant. The answer was scaled and the participant was to type in the age as numbers. The third question was to establish if the participant was a driver and the reply was to be selected as a YES/NO answer from a drop-down menu.

The fourth question was for the participant to give the years of driving experience. There the answer was scaled and the participant was to type in the years as numbers. The fifth question was for the participant to outline the country of origin and the answer was to be selected from a drop-down menu. The sixth and final demographic question was regarding any disabilities of the participant. If the answer selected for the final question was NO, the participant proceeded through the survey. If the answer was YES, the participant was requested to select the type of disability from a drop-down menu before proceeding further. This demographic data was very important for the scope of this research as it was the basis that was used to establish which person-specific characteristics have a significant impact on perception-reaction time in relation to in-vehicle distractions and type of in-vehicle alert.

Figure 11: Third Screen of Survey with Demographic Questions



Demographic Questions

Gender

Choose... ▾

Age

Are you a vehicle driver?

Choose... ▾

Years of Driving Experience

Country of Origin

Choose... ▾

Do you have any form of disability which effects driving?

Choose... ▾

The fourth screen, shown in Figure 12, is an instruction screen on how the participant was required to complete the second part of the survey where the participant needed to interact with the survey itself. Each different scenario was explained. The participant was presented with a total of six simulated driving scenarios. The participant was informed that the first scenario did not involve a secondary task and that the second and third scenarios involved a secondary task being watching a video and sending an sms respectively as the distractions. The participant was informed that when the red box could be seen on the screen, it had to be clicked in order to proceed with the survey.

Each part of the interactive survey was explained and the participant was made aware of what to expect and how to react. The coloured picture of automated vehicles would operate and communication was intended to foster interest in the participant and to give information about the advantages of automated vehicles. It was necessary that the participant was informed on how the second part of the survey would operate and what was expected from the participant because the survey was carried out unsupervised. This fact resulted in that the data collected was for an expected alert scenario whereas, in a real life situation, the alert would be unexpected.

The first two driving simulation scenarios which did not include a distraction were important because the participant could familiarize with the design of the web-based survey and understand better what was expected following the instructions which were given. This was important because the nature itself of the web-based survey did not allow for supervision during the actual implementation of the survey by the participant.

Research carried out by Young (2000) established that there is a learning and familiarization effect in a critical roadside scenario which required a braking response where 16 of the total of 44 experiment participants responded in Trial 1 and the amount of participants increased to 36 for Trial 2. Similarly, Nirschl & Kopf (1997) measure the perception-reaction time of 12 survey participants to a light on the dashboard of a real vehicle. It resulted that the perception-reaction time for time-on task in the first driver was 2.90 seconds and this time period was reduced to 2.54 seconds for the second drive (Nirschl & Kopf, 1997).

Also, this type of web-based survey for data collection is relatively innovative and thus such possibility for familiarization was necessary to be in-built as part of the survey itself. Hence, similarly to the research of Young (2000) and Nirschl & Kopf (1997), the sequence of the first two driving scenarios themselves provided a learning effect for the appropriate completion of the subsequent four driving scenarios of the survey and thus provided a mitigation measure for any possible lack of experience or understanding by the participant for the completion of the survey.

Figure 12: Fourth Screen with Instructions to Complete the Interactive Survey

Part 2: DRIVING SIMULATION

Instructions

Part 2 of this survey is a **simulation** of a driver in a Level 3 Automated Vehicle.

The first scenario is a case where the **driver is not engaged** in a secondary task.

The second scenario is a case where the **driver is watching a video** as a secondary task in the vehicle.

The third scenario is a case where the **driver is replying to an SMS** as a secondary task. The participant is kindly requested to interact with the survey by replying to the SMS. Replies to the SMS are to be **typed the text box** found at the bottom of the SMS pop-up box.

For each of these scenarios the participant is to click on the **RED BOX** which appears on the screen and which simulates an alert in a Level 3 Automated Vehicle for the driver to engage in the driving task.

The fifth and sixth screens, shown in Figure 13, were the two first interactive screens where the participant was shown a video emulating a driver looking through the windscreen. There was no secondary task involved in the first driving scenario. The driver was alerted by a visual alert through the flickering red box for the first run and by a visual and auditory alert for the second run. These two screens were the Do-Nothing scenario where the participant was watching a filmed driving video similar to when sitting in an automated vehicle as a supervisor with the automation activated. The participant had no secondary distraction and thus attention was expected to be focused on the driving video.

The survey medium itself limited the types of alerts possible. It was only possible to have a visual only and a combined visual and auditory alert. An auditory alert on its own was not possible because the red box would still need to appear on the screen where the participant would react. Also, a haptic alert, hence a form of vibration, was not possible. Given that these were the first two screens with this special type of simulation, these two runs were also an introduction of the subsequent scenarios which would follow.

Figure 13: Typical Fifth and Sixth Screens of the Survey

Part 2

Follow instruction when alert is given.

The seventh and eighth screens of the survey involved a driving scenario of a road and an adjacent screen showing the secondary task of watching a video. The seventh screen had a comical video including music from Laurel & Hardy soundtrack (Figure 14). There also was a visual alert with a flickering red box. The eighth screen had the music video of the song ‘Despacito’ (Figure 15) and there was a visual and auditory alert with a flickering red box and a bleeping sound. The participant was to click on the red box when the alert was given. The secondary alerts were both a video with sound effects however they were different so that the participant would not lose interest. As explained above, the alert was not unexpected because the participant had been informed to expect such an alert and how to react to it.

Figure 14: Comical Video with Visual Alert

Part 2

Follow instruction when alert is given.

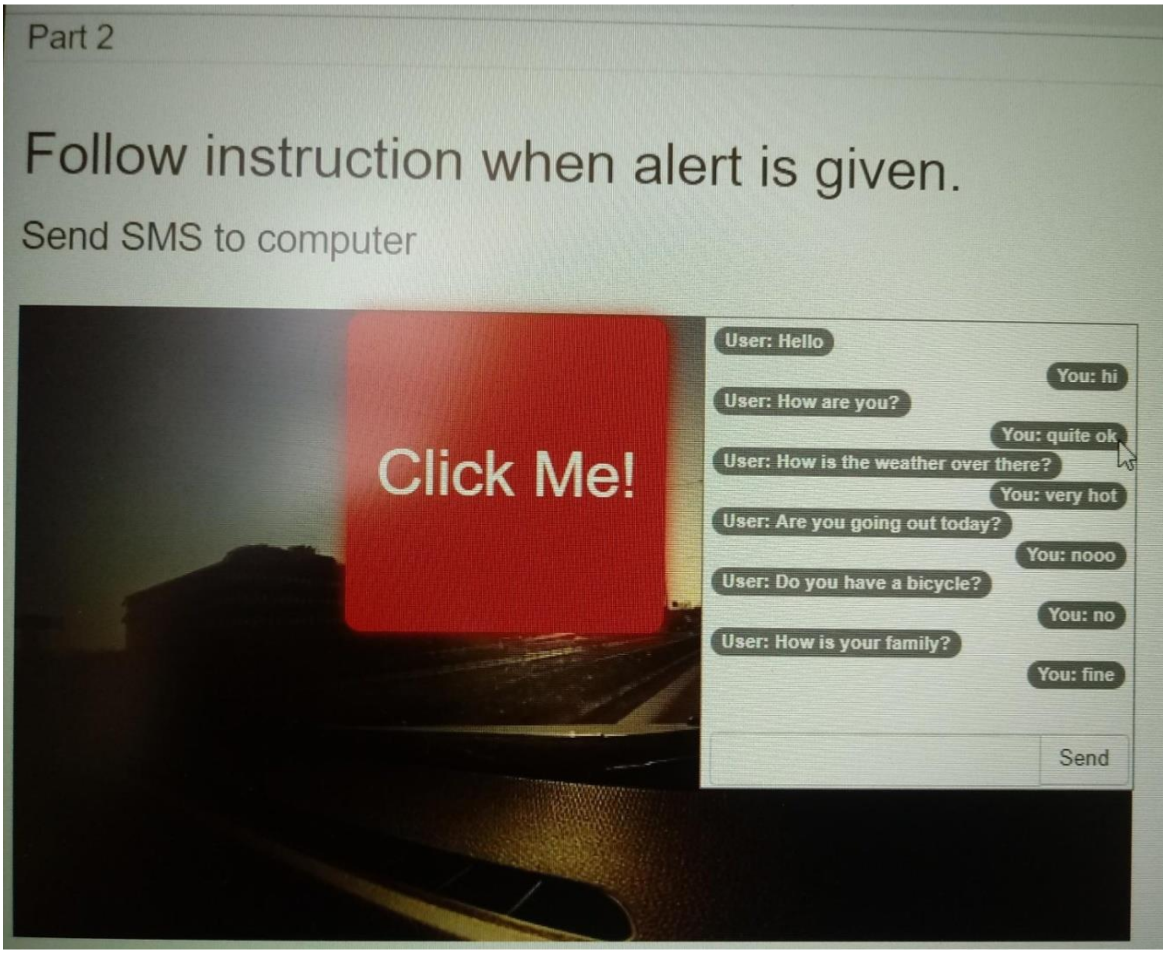
Figure 15: Music Video with Multimodal Alert

Part 2

Follow instruction when alert is given.

The ninth and tenth screens of the survey involved a driving scenario of a road and an adjacent secondary task sms screen simulating the sending of an sms and thus involved the reading and typing of the message. The ninth screen had a simulated sms screen (Figure 16) where the participant was prompted to type in a reply and there was a visual alert with a flickering red box. The tenth screen also had a simulated sms screen (Figure 17) where the participant was prompted to type in a reply. There was a visual and auditory alert with a flickering red box and a bleeping sound. The participant was to click on the red box when the alert was given. The participant was to react to different text messages which varied between the ninth and tenth screens to keep the participant engaged and thus minimize the risk that the participant would stop the survey. Similarly to the previous scenario, only two different types of alerts were possible and the participant was expecting the alert and was informed on what action to take.

Figure 16: SMS Screen with Visual Alert



Part 2

Follow instruction when alert is given.

Send SMS to computer

User: Hello

You: hi

User: How are you?

You: quite ok

User: How is the weather over there?

You: very hot

User: Are you going out today?

You: nooo

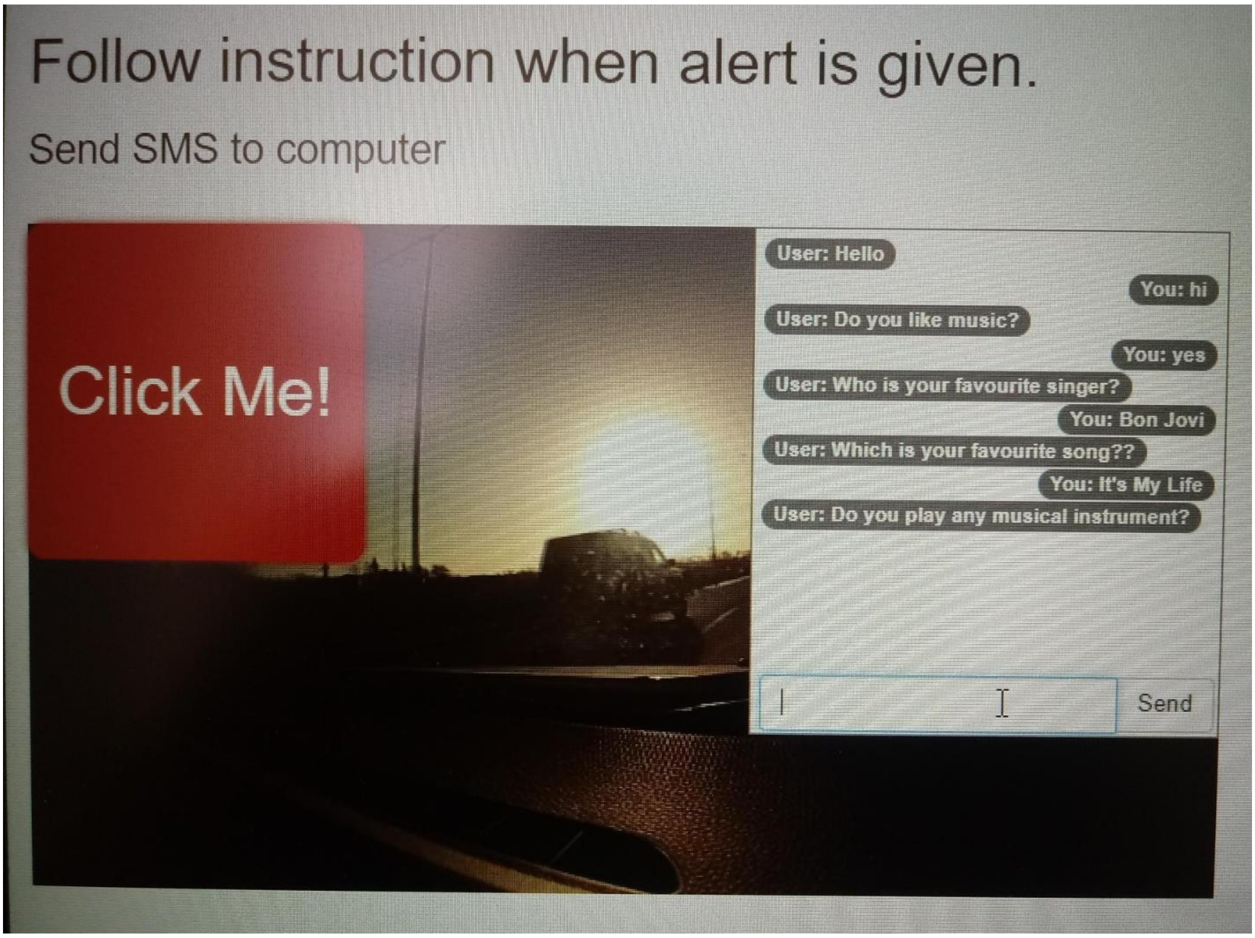
User: Do you have a bicycle?

You: no

User: How is your family?

You: fine

Figure 17: SMS Screen with Multimodal Alert


Follow instruction when alert is given.

Send SMS to computer

User: Hello

You: hi

User: Do you like music?

You: yes

User: Who is your favourite singer?

You: Bon Jovi

User: Which is your favourite song??

You: It's My Life

User: Do you play any musical instrument?

The eleventh and final screen, Figure 18, is a Thank You Screen showing the appreciation that the participant had completed the survey. The picture chosen for the final screen is of a series of automated vehicles on a road and how they connect between themselves and with the road infrastructure. This picture was intended to further explain the concept of automated vehicles.

Figure 18: End Screen

Thank you for your participation!

3.7 Survey Distribution Methods

The amount of online surveys has increased and the types of populations targeted have also increased but they have become less cohesive and less interested in such surveys (Andrews, 2003). This is because of the increase in the large amount of unsolicited emails which internet users receive (Andrews, 2003). A number of different types of respondents have been identified, these being namely complete responders, unit responders who do not reply to surveys, answering drop-outs who do not complete the survey, lurkers who view the survey without answering the questions, lurking drop-outs who only view part of the survey, item non-responders who reply only to some of the questions and item non-responding drop-outs who answer a few questions but stop before completing the survey (Andrews, 2003).

Frequently web-based online surveys do not reach the levels of postal surveys. Email surveys have 20% response rates or lower and where response rates exceeded 70% this was due to respondent cohesiveness (Walsh et al., 1992). Also, the characteristics of online, postal and email surveys are different but without any particular impact on the results (Yun & Trumbo, 2000). According to the University of Wisconsin Survey Centre, the rate of response for mailed surveys is 60-70% whilst the response rate for online surveys is 30-50% even amongst the younger generation (Thayer-Hart, 2010). Yun & Trumbo (2000) recommend the use of all the three different methods but they concluded that, in the case that only one type of survey method can be adopted, the web-based survey together with pre-notification is the recommended method.

Response rates may be lowered due to a number of factors namely technical difficulties, lack of survey robustness and value (Sheehan and McMillan, 1999). Additionally the decreasing rate rate of answering drop-outs can be an indicator of possible judgements of a sector of the population (Sheehan and McMillan, 1999). .

The design of the survey and the method of its distribution have an impact on the response rate (Sheehan, 2006). Studies carried out to assess how response rates differ between long and short email questionnaires showed that there is no significant difference in response rates (Sheehan, 2001). This is being interpreted in this research document as applicable also to online surveys. The location of the request for personal details also affects the response rates and studies showed that such rates were significantly lower when the questions related to personal data were at the start of the online survey (Frick et al., 1999). Placing the questions regarding personal data at the start of the survey can be perceived as honesty by the researcher and is a way to establish greater trust and a relationship (Andrews et al., 2003).

The way that participants are invited to take the survey and the perceived burden of responding to the survey affects response rates. Where the invitation informed the respondent that the survey would not take much time, the rate of response was higher (Andrews et al., 2003). With web-based surveys, when the survey is preceded by an email inviting participants to the URL link to complete the questionnaire, an increase in response rates in observed (Andrews et al., 2003). However other ways to ensure that participants open the email received need to be studied because participants generally receive many unsolicited and SPAM mail. Hence the email address of the sender, the name of the sender and the subject title influence the response rate (Sheehan, 2006).

Another tactic to potentially increase the rate of response is to include a deadline which helps to give the survey a level of priority (Thayer-Hart, 2010). A time period of 7 to 10 days is recommended with an email reminder which is sent a few days before the deadline (Thayer-Hart, 2010). Having a duplicate copy of the survey link in the reminder email yielded the best result (Thayer-Hart, 2010).

CHAPTER 4: DATA COLLECTION

Web-based questionnaires, intended to carry to carry out quantitative research, involve challenges which do not occur in conventional research methods (Andrews et al, 2003). To a certain extent, some of the knowledge obtained during the preparation of paper-based surveys is also applicable for electronic surveys (Andrews et al, 2003). However, electronic surveys have particular characteristics based on technology, demography and responses (Andrews et al, 2003) (Office of Planning and Institutional Assessment, 2006). The latter determine how surveys should be prepared and formatted, whilst keeping in mind both for which type of data collection they can be applicable and also the method of application (Andrews et al, 2003) (Office of Planning and Institutional Assessment, 2006).

The most critical components in carrying out an electronic survey are design, privacy, sampling, distribution methods, response rates and the implementation of a pilot run (Andrews et al, 2003). Web-based surveys are considered to be better than email surveys (Andrews et al, 2003). Moreover, a combination of email with offline media is the ideal when inviting individuals to participate in the web-based survey (Andrews et al, 2003).

Two problems, which can be encountered by persons participating in web-based surveys, are lack of computer knowledge and poor questionnaire design (Fink, 1985). These problems may lead to the questionnaire not being completed. Therefore the need for good design of web-based surveys is required.

4.1 Distribution of the Survey

Following the results of research carried out in the previous chapter, the following best practice actions were adopted in the online survey as part of this research to promote the highest possible amount of respondents:

i. participants were invited to take the online survey by email, through an advert in a local news portal and through facebook;
ii. on the first screen, an ‘opt-in’ informed consent was included before the demographic and personal questions;
iii. official email addresses were used to send the email with the URL connection to the online survey;
iv. the subject of the email, newsfeed and facebook was simple to understand and enticing, hence ‘Driverless Cars: An Interactive Survey’;
v. in the email invitation the participants were informed that the survey would take only 5 to 10 minutes of their time, hence informing them that such survey would not constitute a time burden;
vi. the questions related to demographics and personal data were placed at the start of the questionnaire;
vii. a fifteen day deadline for responses was established and a reminder was sent. In spite of this the response was low. The deadline was extended and a reminder, with a copy of the URL link to the survey, was sent again after 4 weeks followed by further action through facebook and other groups.

The online survey was disseminated to government departments and parastatal agencies in Malta, fora at European Level and on a news portal through the following official channels:

1. Mr Steve Phillips, Conference of European Directors of Roads (CEDR)
2. Mr Oliver Lenz, International Transport Forum (FIA)
3. Ms Laura Sue Mallia, Malta Lands Authority
4. Ms Marie Denninghaus, European Disability Forum
5. Chairman, Enemalta

6. Chairman and CEO, Infrastructure Malta
7. Ms Roberta Cilia, Transport Malta
8. Mr Oliver Scicluna, Kummissjoni Nazzjonali Persuni b'Disabbilta'
9. The Registry, Ministry for Transport, Infrastructure and Capital Projects Malta
10. Mr Gerald Fenech, Editorial Team Maltawinds.

4.2 Survey Respondents

The survey link and invitation email were sent on 10 January 2019 and the chronology of events related to the dissemination of the web-based survey are shown in Figure 19. The web-link to the survey was distributed by the following entities immediately after they were contacted to distribute the survey:

i. International Transport Forum (FIA)
ii. Conference of European Directors of Roads (CEDR)
iii. Malta Lands Authority
iv. Enemalta
v. Infrastructure Malta
vi. Ministry for Transport, Infrastructure and Capital Projects Malta
vii. Editorial Team Maltawinds.

The Chief Executive Officer of the Malta Planning Authority, Mr Johann Buttigieg was contacted concurrently and he agreed to disseminate the survey. Maltawinds uploaded the survey link on their web-page and a Eur100 boost was given. A first reminder email with the link to the websurvey was sent on 24 January 2019.

After 29 days of the survey having been disseminated across the above entities and web-page, there were 231 survey respondents. On 21 February 2019 an email, with a second reminder, was sent to the above entities for dissemination again to their contacts. It also resulted that Transport Malta and the Kummissjoni Nazzjonali Persuni b'Disabbilta' had not disseminated the survey. The latter was due to a change in the email address. Hence Transport Malta (TM) and Kummissjoni Nazzjonali Persuni b'Disabbilta' (KNPD) distributed the email link and invitation letter at the same time that the other entities had sent out the reminder. The invitation letter was also sent to Red Cross Malta for dissemination. With the aim of increasing survey respondents, the researcher launched the survey link on the facebook page and sent it to all contacts on messenger on 21 February 2019. On 22 February 2019 the survey respondents increased to 404 respondents.

Subsequently on the 23 February 2019 the researcher joined the following facebook groups, namely:

i. Dissertation Survey Exchange
ii. Survey Sharing 2018
iii. Survey Tandem.

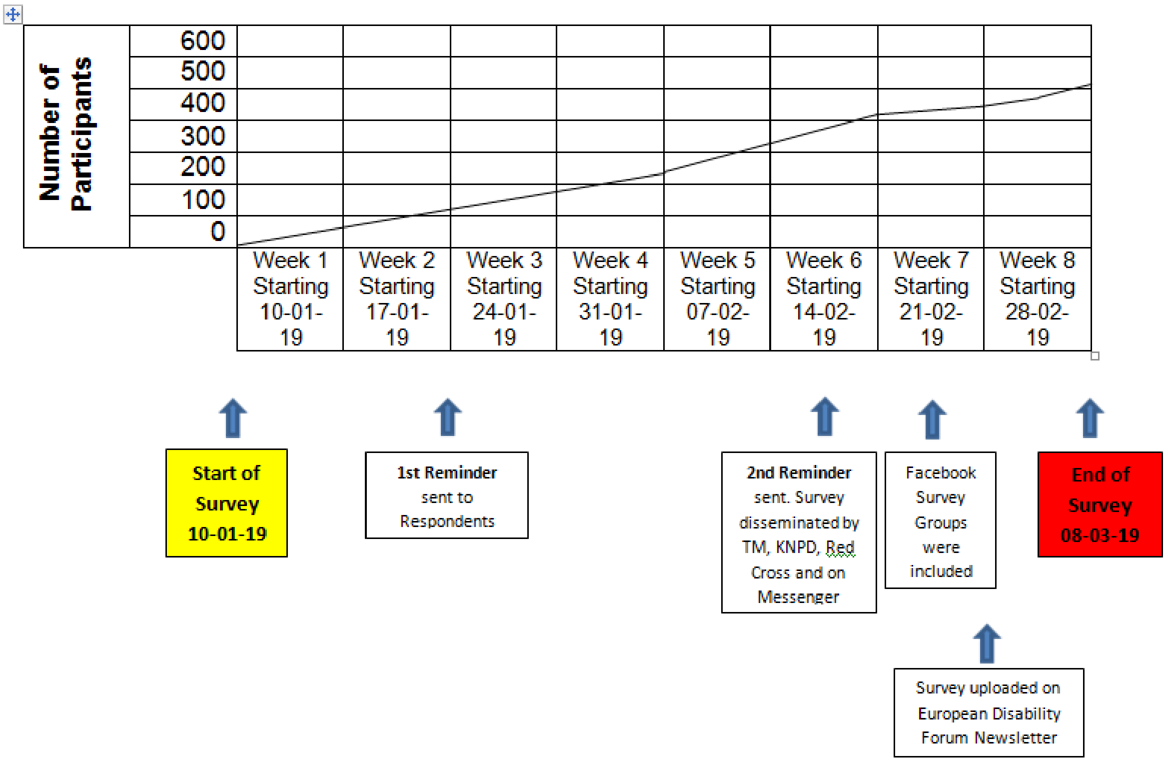
The survey link was pasted on the web page of these groups, which groups consist of persons who participate in such surveys. The Dissertation Survey Exchange group has 6600 members, the Survey Sharing 2018 group has 10,000 members and the Survey Tandem group has 3900 members.

The European Disability Forum sent a notification that the survey link would be uploaded on their official newsletter on 28 February 2019 and asked to extend the deadline for the survey. Given that the participation of the members of this forum was considered to be very important for the research, the deadline was extended to the 8 March 2019.

On the 28 February 2019, the survey respondents increased to 443 respondents.

On 1 March 2019 the survey was shared on the facebook group ‘Ommijiet nghidu kelma flimkien’ which has 26,601 members. It was also shared on the facebook group ‘Il-Kotra’ which has 7,169 members. The chronograph related to the web-based survey is shown in Figure 19.

Figure 19: Number of Survey Respondents against Time



4.3 Corrections to the Survey Data for the Purposes of Analysis

The raw data collected through the web-based survey, found in the Appendix 3,4 and 5, was used to establish the perception-reaction time for a vehicle driver performing a secondary task in a Level 3 automated vehicle. This data was inputted into the SPSS programme for the analysis to be carried out.

There were some anomalous data points which were considerably large when compared with the rest of the data and hence these outliers were removed from the data set. Also, for the purposes of analysis, the perception-reaction times in the data set which were greater than 5 seconds were processed as missing data. Such outliers were not included in the analysis of the results as they would have prejudiced the One-way ANOVA Test.

One entry by a male participant listed his age as 15 years. This was corrected to 18 years. Another male participant listed his age as 612 years and this was corrected to 61 years.

The 85th Percentile with SPSS only got whole numbers because the raw data comprised of discrete values. To resolve this problem, the z-score method was used to calculate the 85th Percentile perception-reaction time.

For the purposes of the analysis, the different driving scenarios in the survey were denoted as follows:

i. P2: Driving scenario without secondary task and with visual alert
ii. P3: Driving scenario without secondary task and with visual and auditory alert
iii. P4: Driving scenario with secondary task of watching a video and with visual alert
iv. P5: Driving scenario with secondary task of watching a video and with visual and auditory alert
v. P6: Driving scenario with secondary task of sending and reading sms messages and with visual alert
vi. P7: Driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert

CHAPTER 5: ANALYSIS AND RESULTS

5.1 Analysis Methodology

5.1.1 Analysis of the Results

When the data was collected the results were analysed to determine the outcome of the research. Given the large amount of data collected, it was not possible to present every bit of the data and thus a summary of the data was represented to emphasise the trends and differences in the most understandable manner.

The Descriptive Statistics Method was used for the demographic and Perception-Response Time data to give a general overview of the results obtained from the questionnaire. This method analyses the results both as percentages and as numbers.

Frequency Distribution was used because a large amount of data needed to be distributed into categories and also because the number of participants for each category needed to be shown. Such Category Frequency was presented in the form of tables and charts. Tables were a simple method to show the frequency of the results of the responses. In this case, the frequency distribution categories of the variables were listed and the number of responses were counted. The Frequency Distribution Table was supported by pie charts and bar charts which give a more pictoral representation of the data obtained. In the case of bar charts, the height of the bars shows the level of the frequency. In the case of pie charts, the area showed the percentages of the frequencies. Data pertaining to gender, country of origin and possession of driving license was interpreted using this method.

The data collected from the questionnaire was directed to a server and was accessed as an Excel file. This format enabled more convenient analysis of the data and also enabled easier transfer of data into the Statistical Package for the Social Science (SPSS) programme which was used to analyse the data.

SPSS was used to analyse the data because it is a data management and a statistical analysis tool which has versatile data processing capabilities. Also, it is a valid tool recognized by researchers who wish to carry out their own statistical analysis. SPSS is ideal for the type of data which needed to be analysed since it:

i. can manage large amounts of data;
ii. can generate descriptive statistical data for the response to the questions in the first part of the questionnaire;
iii. creates graphical outputs;
iv. is capable of exploring the relationship between responses to the profile questions of the questionnaire survey and response times.

A number of statistical theories and methods were used to analyse the data using SPSS and these are the Binomial Test, Null Hypothesis, p-Value, Alternative Hypothesis and the One-Way Analysis of Variance, Shapiro Wilk Test, Kolmogorov Smirnov Test, Kruskal Wallis Test, Gamma Regression Model and Backward Procedure, Ordinal Regression Model and Cluster Analysis.

5.1.1.1 The Binomial Test

In concept, the Binomial Test is the simplest of all the statistical tests because there is only one parameter and the distribution is easy to understand (Tutorvista, 2019). The Binomial Test is defined as '*an exact test for the statistical significance which measures the deviations from the expected distribution of observation which are in the form of two categories'*

(Tutorvista, 2019). This is a probability test based on various rules of probability (Statistics Solutions, 2019). The test was used for the analysis of the data in this research document because it tests whether a proportion from a single dichotomous (binary) variable is equal to a presumed population value (Geert van den Berg, 2018). Thus it tests the difference between a sample proportion and a given proportion (Statistics Solutions, 2019). Hence the binomial test is useful to determine if the sample proportion in one of two categories is different from a specified amount (Elvers, (1)). The Binomial Test of Significance is done using SPSS and a dichotomous type of distribution is assumed where the variable of interest is considered to be dichotomous where the two variables are mutually exclusive and mutually exhaustive in all cases (Statistics Solutions, 2019).

Whilst carrying out the Binomial Test, the formula for Binomial Distribution is used as below where the probability of a binomial random variable X is given by (Tutorvista, 2019):

$$P(X) = C^{n}_{k}\ p^{k}\ (1 - p)^{n-k} \qquad \text{……} \qquad (10)$$

where:

- n is the total number of trials
- k is the number of successes
- (x-k) is the number of failures
- p is the probability of success
- (1-p) is the probability of failure

For the scope of this research, the Binomial Test was used to test whether the 85% Percentile of driver perception-reaction time is 2 seconds, as established by CEDR, or larger than 2 seconds.

5.1.1.2 The Null and Alternative Hypothesis

Statistics are used to establish conclusions about corresponding values in the population being investigated and such values are called parameters (Cuttler, 2017). The Null Hypothesis establishes if a statistical relationship in a sample is just due to chance or whether it actually reflects a real relationship in the population (Price et al, 2013). Hence, Null Hypothesis Testing is a method which enables the decision between two interpretations of a statistical relationship in a sample (Cuttler, 2017). The Null Hypothesis is a statement where there is no relationship between two variables (Surbhi, 2016).

The reasoning supporting null hypothesis testing deals with the assumption that the null hypothesis is true, it deals with establishing how probable the sample result would be if the assumption made were correct and then enabling a decision to be made (Price et al, 2013). In the event that the sample result would result to be unlikely if the null hypothesis was true, then it is rejected and if it would not be unlikely, the null hypothesis is retained (Price et al, 2013).

The method used for the Null Hypothesis Testing is as follows (Cuttler, 2017):

i. the Null Hypothesis was assumed to be true and that there is no relationship between the variables in the population;
ii. provided that the Null Hypothesis was true, the likelihood of the sample relationship had to be determined;
iii. If the sample relationship resulted as being extremely unlikely, the Null Hypothesis would have been rejected in favour of the Alternative Hypothesis. In the event that the sample relationship was not extremely unlikely, the Null Hypothesis would have been retained.

In the case where the Null Hypothesis testing were true, it was critical to find the likelihood of the sample result (Price et al, 2013). Relationship strength of the sample and sample size determine the probability of obtaining the sample result in the event that the null hypothesis were true (Price et al, 2013). Such probability is the p value. If the p value obtained is low, this means that the sample result would be unlikely if the null hypothesis were true (Cuttler, 2017). This rejects the Null Hypothesis (Cuttler, 2017). If the p value is not low, it shows that the sample result would be likely if the null hypothesis were true and the null hypothesis is retained (Price et al, 2013).

For the purposes of this analysis, the p value will be set at 0.05 which means that there is a 5% chance or less to obtain a result as extreme as the sample result if the null hypothesis were true and thus the hypothesis is rejected (Cuttler, 2017). Hence the result would be statistically significant. If the result is more than 5%, which means that there is more than 5% chance of a result as extreme as the sample result, then the null hypothesis is true and it is retained (Price et al, 2013).

For the scope of this research, the Null Hypothesis was used to specify that the 85th Percentile perception-reaction time is 2 seconds and is accepted if the p-value exceeds the 0.05 level of significance. This is because statistical significance is when the p-value is smaller than 0.05 level of significance.

The Null Hypothesis is the hypothesis itself which is actually tested hence it is what the research wants to prove. The Alternative Hypothesis provides an alternative to the Null Hypothesis (Surbhi, 2016). Whilst the Null Hypothesis is a statement that expects no difference or effect however the Alternative Hypothesis expects some difference or effect (Surbhi, 2016). The Alternative Hypothesis is a statement where there is significant difference between a set of variables (Surbhi, 2016). This hypothesis is accepted if the Null Hypothesis is rejected (Surbhi, 2016).

The Alternative Hypothesis was used to specify that the 85th Percentile perception-reaction time is greater than 2 seconds and is accepted if the p-values are less than the 0.05 criterion.

The statistical tests described above will follow the procedure as below (Tutorvista, 2019):

i. the primary data is collected through the web survey
ii. a Null Hypothesis and Alternative Hypothesis is set
iii. a test statistic is determined and it finds the degree of deviation of the observed data from expectation in the null hypothesis
iv. the probability of obtaining the test statistic is found assuming that the null hypothesis was true. The probability is the p-value.
v. on the basis of the p-value, the null hypothesis is rejected or accepted
vi. the significance is concluded.

5.1.1.3 The p-Value

The p value is about the likelihood that the difference observed in the sample is due to chance and the value varies from zero to one (Wilson, 2019). Hung (2016) defines the p value as '*the probability that the data would be at least as extreme as those observed, if the null hypothesis were true*'. If the p-value is greater than 0.05 hence there is no substantial evidence against the null hypothesis and thus it is not rejected (Hung, 2016). If the p-value is less than 0.05, the evidence against the null hypothesis is strong and the null hypothesis is rejected (Hung, 2016). In such case, the alternative hypothesis is accepted (Hung, 2016). If the p-value is close to 0.05, the results are considered to be marginal (Rumsey, 2016).

5.1.1.4 Kruskal Wallis Test

The non-parametric alternative to the One-Way ANOVA Test is the Kruskal Wallis test and such test does not assume that the data has a normal distribution (Glen, 2016a). This Kruskal Wallis Test explains if there is a significant difference between the groups being investigated (Glen, 2016a). This test can be used for data which does not have a normal distribution because it uses the rank of the data values and does not use the actual data values for the analysis (Ghoodjani, 2016). For the scope of this research, this test was used to establish the p-values because the data set is not normal but skewed to the right. Two possible hypothesis are possible with this test as follows (Mackenzie, 2018):

1. *'The null hypothesis that there is no difference between the groups and equality between means*
2. *The alternative hypothesis is that there is a difference between the means and groups.'*

5.1.1.5 Tests of Normality

The principal tests to assess normality are Kolmogorov-Smirnov (K-S) Test, Lilliefors corrected K-S Test, Shapiro-Wilk Test, Anderson-Darling Test, Cramer-von Mises Test, D'Agostino Skewness Test, Anscombe-Glynn Kurtosis Test, D'Agoistino-Pearson Omnibus Test and the Jacques-Bera Test (Ghasemi & Zahediasi, 2012). However the K-S is the most used by researchers and both the K-S Test and the Shapiro-Wilk Test can be carried out using SPSS (Ghasemi & Zahediasi, 2012). These two tests were used for the analysis of the data in this research docuent because they are adequate to test for normality and because SPSS was available for use for this research.

The Shapiro-Wilk Test establishes if a random sample has a normal distribution. The test gives a W value where small values indicate that the sample does not have a normal distribution (Glen ,2014). In the case of this research, the W value was small and the data was skewed to the right. The limitation of this test is that it has a bias by sample size and a larger sample size is more likely to give a statistically significant result (Glen, 2014). However some researchers prefer and recommend the Shapiro-Wilk Test as the most adequate for testing the normality of data (Ghasemi & Zahediasi, 2012).

The Kolmogorov-Smirnov Goodness of Fit Test is important to compare the data of this research with a known distribution, in this case comparing with a normal distribution (Glen, 2016b). This is a non-parametric test and compares a known hypothetical probability distribution (in this case the normal distribution) to the distribution obtained in the data of this research (Gen, 2016b).

Traditional Regression Models assume that the dependent variable is continuous and satisfies the normality assumption. However, for skewed data, these modes are not appropriate . The seminal paper by Nelder and Wedderburn (1972) introduces the concept of Generalised Linear Models (GLMs). These models accommodate both continuous and categorical dependent variables and accommodate any distribution which is a member of the exponential family. This family includes some of the most widely used distributions in statistics such as the Normal, Gamma, Binomial, Poisson, Inverse Gaussian, Exponential, amongst others. Since the dependent variables of this research were continuous and right skewed it was deemed appropriate to use GLMs assuming a Gamma Distrbution and an identity link function for ease of interpretation of the regression corefficients (parameter estimates).

5.1.1.6 The Gamma Regression Model and Backward Procedure

Generalised Linear Models (GLMs) are a synthesis and extension of the Linear Regression Models and are based on identifying the most appropriate mathematical model (Matsuzaki, 2017). For the scope of this research, the Gamma distribution is used because the results are not a normal distribution. Other models exist to accommodate data which is not normal distributed. The Gamma Distribution is appropriate to use in this research since the distribution of the PRT is right skewed. Such GLMs are similar to regression models but they accept also non-normal distribution.

The backward variable selection algorithm was applied to the Gamma Regression Model whereby all the variables were inputted into the model equation and then were sequentially removed. The variable which had the least significant effect (P-value) on the dependent variable was removed and after the first variable was removed, the variables remaining in the model equation with the smallest significance were next removed (IBM Knowledge Centre, no date). The backward procedure was stopped when there were no other variables that met the removal criteria (IBM Knowledge Centre, no date) and thus there was no further improvement in the model (MacEwan University, no date).

5.1.1.7 Ordinal Regression Model

Ordinal Regression Analysis is considered to be a further development of Binomial Logistics Regression (Agarwal, 2016). Ordinal Regression Models describe the data and are capable of explaining the relationship between one dependent variable and two or more independent variables (Agarwal, 2016). In such model, the dependent variable is ordinal and the independent variables are ordinal or continuous-level (Williams, 2008). Ordinal regression can be used to establish the influence that the independent variables have on a dependent variable.

5.1.1.8 Cluster Analysis

Cluster Analysis is a set of techniques which assigns different variables into relative groups called clusters (Aldenderfer & Blashfield, 1984) based on the observed values of different variables (Sinharay, 2010). Cluster analysis can also be referred to as classification analysis or numerical taxonomy (Everitt et al., 2001). For this type of analysis, no information is provided about the composition of the cluster for any of its elements (Everitt et al., 2001). Thus, Cluster analysis is an analysis tool which examines data and it organises such observed data into two or more groups (Kunal et al., 2015). The importance of Cluster Analysis is because it defines the similarity of elements within each cluster and also defines the differences between clusters (Kunal et al., 2015).

5.1.2 Establishing Stopping Sight Distances

The perception-reaction time varies from one driver to another because it is person specific (Petegem, 2014). For this reason the perception-reaction time is defined by a distribution and not by a fixed value (Petegem, 2014). Hence the standard approach to address such variations is to use a percentile of the perception-reaction time distribution (Petegem, 2014).

The literature review which was carried out confirmed that the percentile to be used does not follow from such review (Petegem, 2014). The percentile to be used is a decision which balances safety and comfort with cost, travel time and the existing roadside environment (Petegem, 2014). As a result of the above and to ensure a comparison of like-with-like, for the scope of this research document, the perception-reaction time was established as the 85th percentile values of the data sets for the following reasons:

i. In classical research involving human factors, the perception-reaction time is established by identifying the reaction time of the 85th percentile driver (Petegem, 2014). In the experiments carried out by Gaziz et al (1960), Wortman and Matthias (1983), Chang et al (1985) and Sivak et al (1960), the perception–reaction times were all established based on the 85th percentile value. This is consistent with the design perception-reaction time value adopted by the Institute of Transportation Engineers which was established at the 85th percentile point of the perception-reaction distribution (Taoka, 1989);
ii. For the DMRB and CEDR values (based on values of European countries) the perception-reaction time was based on the 85h percentile value (Petegem, 2014);
iii. The ‘Unexpectedness’ factor established by Johansson and Rumar (1971) was based on the 85th percentile perception-reaction time of the drivers for the unexpected and expected events (Layton & Dixon, 2012). This factor was used to obtain the Unexpected perception-reaction times from the Expected perception-reaction time data collected by the web-based survey of this research.

5.1.3 Theoretical Basis for the Sight Stopping Distance Model

The procedure used to determine SSD, based on the formulae outlined earlier, allows for a normally alerted vehicle driver, in Levels 1 and 2 automated vehicles, who is travelling at or near the design speed on a wet pavement and reacts and stops the vehicle before colliding with a stationery object in the road (Fambro et al, 1997).

This is the basic difference between the SSD values currently being adopted and those being proposed in this research to meet the safety demands for a mix of Level 3 vehicles with Levels 1 and 2 in the vehicle fleet. Therefore SSD is intended to cover the time period from the moment that the driver is alerted by the Level 3 vehicle and the moment that the driver reacts plus the braking distance which is taken to be the same as for a Level 1 and 2 vehicles.

Both the AASHTO and CEDR Report models for SSD consist of two components, namely the distance travelled during perception-reaction time and during braking time for the vehicle to come to a stop (Weber et al, 2016), (Fambro et al, 1997). The models are based on equations (1), (8) and (9) and the models differ only in specific assumptions regarding parameter values.

The CEDR report concludes the following parameter values to be used for the calculation of SSD, hence (Weber et al, 2016):

i. Perception-reaction time = 2 seconds
ii. Deceleration rate = 4.0m/s
iii. Coefficient of friction = 0.377.

The AASHTO parameter values used for the calculation of SSD, are as follows (Bassan, 2018):

i. Perception-reaction time = 2.5 seconds
ii. Deceleration rate = 3.4m/s^2
iii. Coefficient of friction = varies between 0.438 for a speed of 30km/h to a value of 0.377 for speeds greater than 120km/h.

If the model were more sensitive to human behaviour, such parameter would not be constant but would vary as a function of the speed of the vehicle and the type of road (Fambro et al, 1997). However no data nor research was found to verify and confirm this variation (Fambro et al, 1997). However it is to be noted that any such differences would likely be minor and thus there would be an insignificant impact of SSD values (Fambro et al, 1997).

It is to be noted that the current SSD calculation model is simple as it models the scenario of a vehicle driving along a straight section (Cheng et al, 2011) and on a level terrain (Bassan, 2018). Also the model assumes that the friction between the tyre and the pavement meets or exceeds the braking demand of the driver (Fambro et al, 1997). When a comparison was made between the current AASHTO SSD model and those of other countries it resulted that the majority of the countries use measured or estimated 85th Percentile operating speeds as the design speed (Fambro et al, 1997).

Also, the perception-reaction times of 2.0 seconds for CEDR and 2.5 seconds for AASHTO were based on observed behaviour for the 85th Percentile and 90th Percentile driver respectively, hence where 85% or 90% of drivers could react in that time period or less (Layton & Dixon, 2012)(Fambro et al, 1997). Given that there are obvious difference between drivers due to different levels of driver alertness, physical conditions, age and experience, the perception-reaction time is characterized by a distribution rather than by a constant value (Weber et al, 2016). For the purposes of this research document the methodology used will adopt the 85th Percentile of the Perception–Reaction distribution and comparison will be made with the 2 second perception-reaction time established by CEDR since the participants of the survey were all from European Union countries.

The Perception-Reaction times currently used for road design were based on the observed behavior for the 85th percentile driver, hence the longest time period at which 85% of drivers could react (Layton & Dixon, 2012). Similarly, the data obtained from the results of the online survey were collected and the 85th percentile Perception-Reaction times were calculated for the different sub-groups being examined. Such values were compared with the existing values being used to calculate stopping sight distances (SSD) for each subgroup. The above equations were used to determine the SSDs for different design speeds which are recommended to be used in road design and traffic management when the roads will be shared between Levels 1, 2 & 3 automated vehicles all operating in the same road space.

For the scope of this research, the values for the perception-reaction time obtained were used in the following equation for level roads, hence with no gradient, as follows:

$$SSD = 0.278\, V_0\, t + \{ V_0^{2} / 254\, f \} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

5.2 Demographic analysis of the survey data set

The actual raw data collected from the online survey, through the servers where it was stored in EXCEL format, can be viewed in Appendices 2,3 and 4. This format made it easy to process the data and to import the data into the SPSS programme.

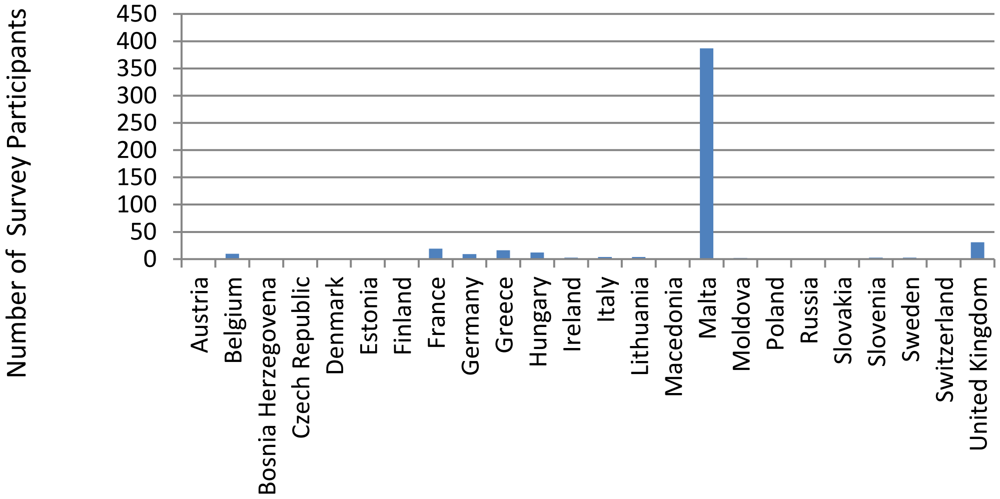
5.2.1 Country of Origin

Only 24.65% of the respondents of the web-based survey were non-Maltese citizens and these came from a total of 23 different European countries. There were a total of 127 non-Maltese respondents out of a total of 514 respondents. The respondents were distributed as follows in Table 9 and Figure 20:

Table 9: Data collected according to Country of Origin from the Web-Based Survey

Country	Amount of Respondents	Percentage of Total
Austria	1	0.19%
Belgium	10	1.95%
Bosnia Herzegovena	1	0.19%
Czech Republic	1	0.19%
Denmark	1	0.19%
Estonia	1	0.19%
Finland	1	0.19%
France	19	3.70%
Germany	9	1.75%
Greece	16	3.11%
Hungary	12	2.33%
Ireland	3	0.58%
Italy	4	0.78%
Lithuania	4	0.78%
Macedonia	1	0.19%
Malta	387	75.35%
Moldova	2	0.39%
Poland	1	0.19%
Russia	1	0.19%
Slovakia	1	0.19%
Slovenia	3	0.58%
Sweden	3	0.58%
Switzerland	1	0.19%
United Kingdom	31	6.03%

Figure 20: Number of Survey Participants by Country

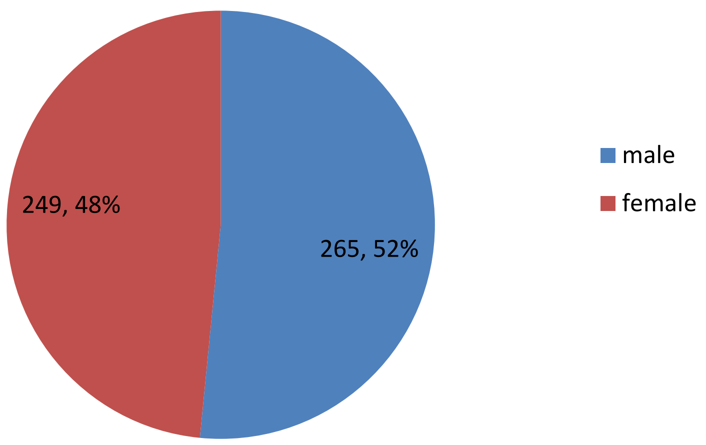


The highest amount of non-Maltese residents was from the United Kingdom at 6.03% followed by France and Greece at 3.70% and 3.11% respectively.

5.2.2 Gender

The data from the web-based survey showed, in Figure 21, that out of a total of 514 respondents, 265 were male and 249 were female. Hence, 51.6% were male whilst 48.4% were female with a 1.06 male/female ratio. In Malta, 49.8% of the population are males whilst 50.2% are females with a 0.99 male/female ratio (CIA World Factbook, 2018). In the European Union the population is 0.96 male/female ratio (CIA World Factbook, 2018).

Figure 21: Male and Female Survey Participants



5.2.3 Age

The respondents of the web-based survey were classified into 5 age groups and the percentage of participants per group was as follows in Table 10 and Figure 22:

Table 10: Data collected according to Age Groups from the Web-Based Survey

Age Group	Percentage of Total
18-30 years	27.4%
31-40 years	21.7%
41-50 years	26.9%
51-60 years	17.3%
61+ years	6.7%

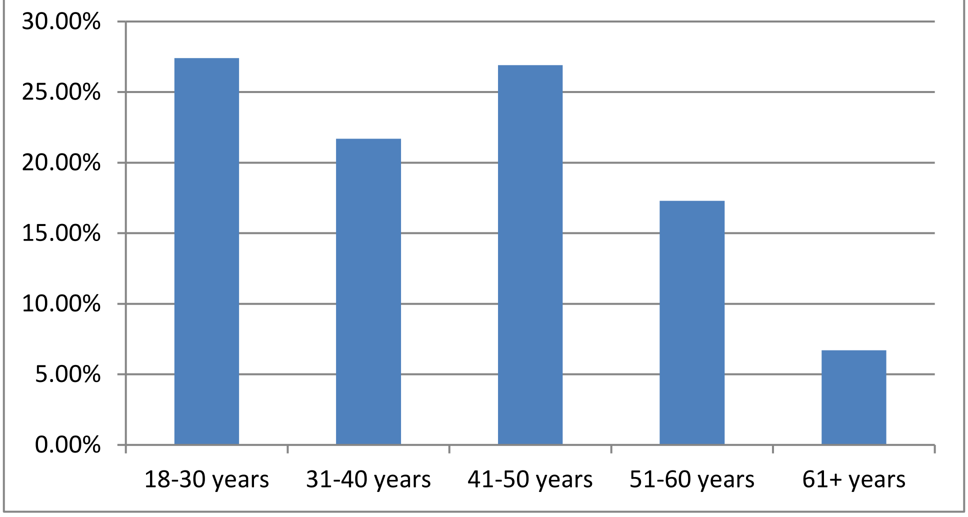


Figure 22: Survey Participants by Age Group

The highest amount of respondents were in the 18-30 year age group followed by the 41-50 year age group.

5.2.4 Driving Experience

The respondents of the web-based survey were classified according to their driving experience. The respondents were split into five groups, 1-10 years driving experience, 11-20 years, 21-30 years, 31-40 years and 41+ years.

The percentage of participants per group was as follows in Table 11 and Figure 23:

Table 11: Data collected according to Driving Experience from the Web-Based Survey

Driving Experience	Percentage of Total
0-10 years	28.5%
11-20 years	23.2%
21-30 years	25.3%
31-40 years	15.0%
41+ years	8.0%

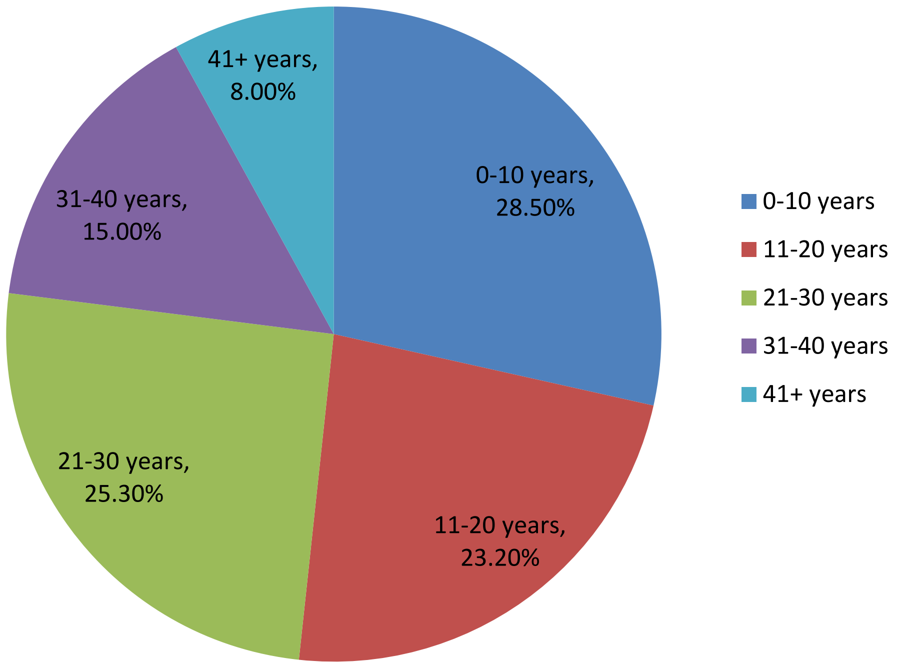


Figure 23: Survey Participants by Years of Driving Experience

As expected, the percentages for driving experience correspond and reflect the percentages of the age groups. The largest group was for the 0-10 years driving experience followed by the 21-30 years group.

5.2.5 Disability

Only six participants of the web-based survey, as part of this research document, had a disability. Hence, only 1.24% of the participants had a disability. It is to be noted that the survey was actually disseminated in entities and groups intended to support disabled persons, both in Malta and in Europe, with the aim of having as many respondents possible with a disability. According to the Malta Census of 2011, 8.55% of the population in Malta have a disability (Parliamentary Secretary for Rights of Persons with Disability and Active Ageing, 2015). In the year 2011, there were 26% of persons in Europe, aged 16 years and older, who stated that they have an activity limitation (Grammenos, 2013). It is to be noted that this 8.55% includes all disabled persons from birth and includes also the disabled persons who do not drive. However, the survey carried out as part of this research, only includes disabled persons who are eighteen years old or more and who possess a driving license.

Of the six respondents, two suffer from full/partial paralysis/weakness/amputation of upper limbs, one suffers from Muscular Dystrophy Disease, one suffers from Spinal Injuries and the remaining two suffer from a disability which was not listed in the drop-down menu of the web-based survey.

5.3 Results and Statistical Analysis using SPSS

5.3.1 Binomial Test

The Binomial Test was used to test whether the 85% Percentile of driver perception-reaction time is 2 seconds or larger than 2 seconds. The Null Hypothesis specifies that the 85th Percentile perception-reaction time is 2 seconds and it is accepted if the p-value exceeds the 0.05 level of significance. This is because statistical significance is when the p-value is smaller than 0.05 level of significance. The Binomial Test was considered the most adequate test for the purposes of this research because the gives the option to change the test proportion from 0.5 to 0.85 to test the 85thPercentile. Other tests, such as the One-Sample T-Test, do not allow to change the test proportion and compares only the mean values. For the purposes of this study it was essential to compare the 85th Percentile value for PRT because this 85th Percentile value was used to establish SSDs of existing standard specifications.

5.3.2 Alternative Hypothesis

The Alternative Hypothesis specifies that the 85th Percentile perception-reaction time is greater than 2 seconds and it is accepted if the p-values are less than the 0.05 criterion. For all the six driving scenarios, the p-values yielded by the Binomial Test (approximately 0), shown in Table 12, are less than the 85th Percentile perception-reaction times and thus differ significantly from the CEDR value of 2 seconds.

Table 12: Results of the Binomial Test

Binomial Test

		Category	Sample Size	Observed Prop.	Test Prop.	P-value (1-tailed)
P2Duration	Group 1	≤ 2	36	0.08	0.85	0.000
	Group 2	> 2	414	0.92		
P3Duration	Group 1	≤ 2	89	0.18	0.85	0.000
	Group 2	> 2	396	0.82		
P4Duration	Group 1	≤ 2	100	0.21	0.85	0.000
	Group 2	> 2	380	0.79		
P5Duration	Group 1	≤ 2	152	0.31	0.85	0.000
	Group 2	> 2	341	0.69		
P6Duration	Group 1	≤ 2	97	0.21	0.85	0.000
	Group 2	> 2	362	0.79		
P7Duration	Group 1	≤ 2	58	0.12	0.85	0.000
	Group 2	> 2	415	0.88		

5.3.3 Tests of Normality and the Kruskal Wallis Test

The tests of Normality were carried out and since the p-values of Shapiro Wilk tests and of the Kolmogoriv Smirnov Test are less than the 0.05 level of significance, this implies that the PRT distribution do not satisfy the normality assumption so a non-parametric test was used, this being the Kruskal Wallis Test. The Tests of Normality show that the PRT distributions are skewed to the right as per Table 13.

Table 13: Results of the Tests of Normality

Tests of Normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	P-value	Statistic	df	P-value
P2Duration	.411	363	.000	.678	363	.000
P3Duration	.344	363	.000	.723	363	.000
P4Duration	.338	363	.000	.717	363	.000
P5Duration	.277	363	.000	.771	363	.000
P6Duration	.326	363	.000	.785	363	.000
P7Duration	.353	363	.000	.785	363	.000

The One-Way ANOVA Test was used to compare mean perception-reaction times between several groups of participants. The groups were clustered by gender, age group, years of driving experience, country of origin and disabilities. However the p-values obtained for the One-Way ANOVA Test cannot be used for the purposes of this research because this test assumes that the data has a normal distribution.

The Kruskal Wallis Test does not give the descriptive tables which are required for the purposes of this research but it assumes that the data distribution is not normal. Thus, the descriptive tables were obtained using the One-Way ANOVA tests and the p-values obtained were replaced by the p-values of the Kruskal Wallis Test.

It is to be noted that the results of the p-values obtained for the One-Way ANOVA Test and for the Kruskal Wallis Test, although some are different, however the vast majority of these p-values vary marginally and thus the two tests complement each other and give the same conclusions. This very slight variation of the p-values for these two different tests shows that the data obtained and the model are very robust because the p-values vary very little with changes.

5.3.4 Analysis of Gender Data

The results obtained show that females are scoring significantly higher perception-reaction times in P3 and P4 driving scenarios than males since the p-values are less than 0.05 level of significance. As shown in Table 14, there was no significant difference in mean perception-reaction times and hence there was no gender discrepancy, for the P2, P5, P6 and P7 perception-reaction times since the p-values exceeded the 0.05 criterion.

Table 14: Results of Gender Data

	Gender	Sample size	Mean	Std. Dev.	P-value
P2Duration	Male	234	3.04	1.105	0.985
	Female	216	3.06	1.097	
P3Duration	Male	248	2.61	0.872	0.032
	Female	237	2.78	0.935	
P4Duration	Male	243	2.57	1.000	0.004
	Female	237	2.80	0.946	
P5Duration	Male	255	2.41	0.915	0.102
	Female	238	2.55	0.957	
P6Duration	Male	240	2.81	1.153	0.769
	Female	219	2.87	1.198	
P7Duration	Male	247	3.11	1.156	0.779
	Female	226	3.12	1.319	

5.3.5 Analysis of Data regarding Country of Origin

In Table 15, the results of the research carried out in this document show that Maltese participants are scoring significantly higher perception-reaction times than foreign counterparts in the European Union in P2 and P3 since the p-values are less than 0.05. For P7 scenario, foreigners are scoring significantly higher perception-reaction times than the Maltese. There was no significant difference in mean reaction times between the two groups of participants in the driving scenarios for P4, P5 and P6 since the p-values exceed the 0.05 criterion.

Table 15: Results of Data for Country of Origin

	Country	Sample size	Mean	Std. Dev.	P-value
P2Duration	Maltese	349	3.12	1.146	0.018
	Other EU resident	101	2.81	.889	
P3Duration	Maltese	365	2.74	.911	0.025
	Other EU resident	120	2.54	.878	
P4Duration	Maltese	362	2.72	.989	0.170
	Other EU resident	118	2.56	.940	
P5Duration	Maltese	371	2.50	.910	0.174
	Other EU resident	122	2.41	1.015	
P6Duration	Maltese	344	2.83	1.180	0.736
	Other EU resident	115	2.86	1.161	
P7Duration	Maltese	351	3.05	1.138	0.162
	Other EU resident	122	3.32	1.464	

5.3.6 Analysis of Data regarding Driving License

The results obtained show that, since the p-values are less than 0.05, participants who do not have a driving license are scoring significantly higher perception-reaction times than those who possess a driving license in P2 and P4 scenarios. With regards to the P7 scenario, participants who do not have a driving license are scoring significantly lower perception-reaction times than those who possess a driving license. As shown in Table 16, there was no significant difference in mean reaction times between the two groups of participants in the driving scenarios for P3, P5 and P6 since the p-values exceed the 0.05 criterion.

Table 16: Results of Data regarding Driving License

	Driving licence	Sample size	Mean	Std. Dev.	P-value
P2Duration	Yes	436	3.03	1.075	0.025
	No	14	3.76	1.604	
P3Duration	Yes	463	2.70	.917	0.966
	No	22	2.64	.656	
P4Duration	Yes	458	2.65	.969	0.000
	No	22	3.31	.997	
P5Duration	Yes	470	2.48	.943	0.513
	No	23	2.58	.805	
P6Duration	Yes	444	2.84	1.178	0.954
	No	15	2.79	1.078	
P7Duration	Yes	450	3.14	1.247	0.038
	No	23	2.58	.805	

5.3.7 Analysis of Data regarding Disabilities

As shown in Table 17, in relation to the P2, P3, P4, P5, P6 and P7 scenarios there was no significant difference in mean reaction times between the two groups of participants since the p-values exceed the 0.05 criterion.

Table 17: Results of Data regarding Disabilities

	Disability	Sample size	Mean	Std. Dev.	P-value
P2Duration	Yes	5	4.05	1.909	0.167
	No	445	3.04	1.086	
P3Duration	Yes	6	2.93	1.016	0.410
	No	479	2.69	.905	
P4Duration	Yes	5	3.51	1.207	0.074
	No	475	2.67	.974	
P5Duration	Yes	6	2.93	1.016	0.205
	No	487	2.48	.936	
P6Duration	Yes	6	2.70	.854	0.930
	No	453	2.84	1.178	
P7Duration	Yes	6	3.60	1.635	0.457
	No	467	3.11	1.230	

5.3.8 Analysis of data regarding Driving Experience

The results obtained in Table 18 show that participants with different driving experience scored significantly different perception-reaction times in all driving scenarios, except for the P7 scenario, since the p-values are all less than 0.05. The results obtained show that participants who have 41 years or more driving experience scored the highest mean perception-reaction times than the other groups of driving experience in the P2, P3, P4 and P6 scenarios. The results for these scenarios, except for the P5 scenario, show that greater amount of driving experience resulted in the greater mean perception-reaction time. Regarding the P5 scenario, the results show that the mean perception-reaction time for the 31-40 years driving experience scenario is the highest value. The results for the P7 scenario, the results show that there is no significant difference between the different groups of driving experience.

Table 18: Results of Driving Experience Data

	Driving experience	Sample size	Mean	Std. Dev.	P-value
P2Duration	0-10 years	126	2.76	.917	0.000
	11-20 years	102	2.87	.944	
	21-30 years	112	3.00	.901	
	31-40 years	63	3.30	1.231	
	41 years or more	36	3.98	1.441	
P3Duration	0-10 years	135	2.51	1.019	0.000
	11-20 years	110	2.66	.867	
	21-30 years	119	2.67	.713	
	31-40 years	71	2.89	1.002	
	41 years or more	38	3.20	.795	
P4Duration	0-10 years	132	2.50	1.008	0.006
	11-20 years	110	2.61	1.006	
	21-30 years	122	2.80	.953	
	31-40 years	65	2.82	.884	
	41 years or more	38	2.91	.916	
P5Duration	0-10 years	136	2.29	1.004	0.002
	11-20 years	108	2.46	.956	
	21-30 years	125	2.57	.864	
	31-40 years	75	2.74	.914	
	41 years or more	36	2.40	.919	
P6Duration	0-10 years	129	2.53	.955	0.001
	11-20 years	107	2.78	1.079	
	21-30 years	114	3.01	1.2450	
	31-40 years	65	3.01	1.302	
	41 years or more	33	3.44	1.475	
P7Duration	0-10 years	132	3.23	1.471	0.074
	11-20 years	106	2.85	1.059	
	21-30 years	115	3.08	1.020	
	31-40 years	74	3.25	1.243	
	41 years or more	33	3.48	1.393	

5.3.9 Analysis of Data regarding Different Age Groups

The results obtained in Table 19 show that participants of different age groups scored significantly different perception-reaction times in all driving scenarios, except for the P7 scenario, since the p-values are all less than 0.05. The results obtained show that participants who are aged 61 years or more scored the highest mean perception-reaction times. The results for these scenarios, except for the P7 scenario, show that the higher the age group bracket, the greater mean perception-reaction time. There was no significant difference in mean reaction times between the different age groups of the participants during the P7 scenario since the p-value exceeds the 0.05 criterion.

Table 19: Results of Data by Age Groups

	Age	Sample size	Mean	Std. Dev.	P-value
P2Duration	18-30 years	123	2.75	.953	0.000
	31-40 years	102	2.82	.852	
	41-50 years	116	3.08	1.020	
	51-60 years	76	3.41	1.237	
	61 years or more	33	3.89	1.538	
P3Duration	18-30 years	133	2.51	.985	0.000
	31-40 years	106	2.55	.860	
	41-50 years	128	2.71	.748	
	51-60 years	84	2.94	.893	
	61 years or more	34	3.22	.998	
P4Duration	18-30 years	131	2.40	.937	0.000
	31-40 years	109	2.69	1.047	
	41-50 years	130	2.88	1.041	
	51-60 years	81	2.75	.811	
	61 years or more	29	2.89	.784	
P5Duration	18-30 years	135	2.28	.996	0.001
	31-40 years	107	2.40	.914	
	41-50 years	133	2.60	.889	
	51-60 years	85	2.64	.881	
	61 years or more	33	2.70	.955	
P6Duration	18-30 years	130	2.51	1.046	0.000
	31-40 years	105	2.74	.963	
	41-50 years	120	2.95	1.212	
	51-60 years	73	3.00	1.258	
	61 years or more	31	3.75	1.425	
P7Duration	18-30 years	131	3.16	1.399	0.268
	31-40 years	107	2.96	1.194	
	41-50 years	124	3.04	1.013	
	51-60 years	80	3.39	1.425	
	61 years or more	31	3.05	.777	

5.3.10 The Gamma Regression Model

The major limitation of the One-Way ANOVA and Kruskal Wallis Tests is that these investigate solely the relationship between the perception-reaction time (dependent variable) to one categorical predictor (Camilleri, 2017). However, the goal of many research studies is to estimate the impact of the predictors collectively on the dependent variable (Camilleri, 2017). It is well known that a single predictor could be rendered a very important contributor in explaining variations in the perception-reaction times but would be rendered unimportant in the presence of other predictors (Camilleri, 2017). For this reason, the Generalized Linear Model assuming a Gamma Distribution, which assumes a skewed distribution, will be fitted to each perception-reaction time where the predictors include age, gender, driving license, driving experience, nationality and presence of disability. .

5.3.10.1 The Gamma Regression Model for driving scenario without secondary task and with visual alert (P2)

Table 20 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P2 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies two significant predictors where driving experience is the best predictor of perception-reaction time. This is because it has the lowest p-value which is followed by the country-of-residence of respondents.

The parameter estimates provide the difference in the mean perception-reaction time between a particular category and the last category. The parameter estimate for Maltese participants (0.219) indicates that the average perception-reaction time of Maltese participants was 0.219 seconds higher than participants from other EU countries, given that other effects are kept constant. Similarly the parameter estimates for participants with driving experience less than 10 years (-1.163) indicates that the average perception-reaction time of participants with, at most, 10 years driving experience, is 1.163 seconds lower than their older counterparts with at least 41 years of driving experience.

Table 20: Generalized Linear Model assuming a Gamma Distribution for the P2 Scenario

Tests of Model Effects

Source	Wald Chi-Square	Type III df	P-value
(Intercept)	106.057	1	.000
Gender	2.056	1	.152
Age	5.038	4	.283
Are you a driver?	1.119	1	.290
Driving experience	5.498	4	.240
Country	4.017	1	.045
Do you have any disability?	.651	1	.420

Dependent Variable: P2Duration

Tests of Model Effects

Source	Wald Chi-Square	Type III df	P-value
(Intercept)	2423.879	1	.000
Driving experience	34.983	4	.000
Country	4.316	1	.038

Dependent Variable: P2Duration

Parameter Estimates

Parameter	B	Std. Error	95% Wald Conf. Int. Lower	Upper	Hypothesis Test Wald Chi-Square	Df	P-value
(Intercept)	3.796	.2202	3.364	4.227	297.216	1	.000
Driving Experience [1-10]	-1.163	.2185	-1.591	-.735	28.326	1	.000
Driving Experience [11-20]	-1.096	.2215	-1.530	-.662	24.476	1	.000
Driving Experience [21-30]	-.994	.2216	-1.428	-.559	20.111	1	.000
Driving Experience [31-40]	-.692	.2404	-1.163	-.220	8.277	1	.004
Driving Experience [>40]	0	.	.	.	.	.	.
Country [Maltese]	.219	.1055	.012	.426	4.316	1	.038
Country=[Other]	0	.	.	.	.	.	.
(Scale)	.095^b	.0063	.083	.108			

5.3.10.2 The Gamma Regression Model for driving scenario without secondary task and with visual and auditory alert (P3)

Table 21 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P3 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies two significant predictors where age is the best predictor of perception-reaction time because it has the lowest p-value. This is followed by the gender of respondents.

The parameter estimates provide the difference in the mean perception-reaction time between a particular category and the last category. The parameter estimate for Male participants (-0.303) indicates that the average perception-reaction time of Maltese participants was 0.303 seconds less than Female participants, given that other effects are kept constant. Similarly the parameter estimates for participants with age not exceeding 30 years (-0.830) indicates that the average perception-reaction time of participants not exceeding 30 years of age is 0.830 seconds lower than their older counterparts with an age exceeding 61 years.

Table 21: Generalized Linear Model assuming a Gamma Distribution for the P3 Scenario

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	147.021	1	.000
Gender	13.799	1	.000
Age	9.630	4	.047
Are you a driver?	.908	1	.341
Driving experience	5.724	4	.221
Country	3.245	1	.072
Do you have any disability?	.837	1	.360

Dependent Variable: P3Duration

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	3208.562	1	.000
Gender	14.109	1	.000
Age	33.196	4	.000

Dependent Variable: P3Duration

Parameter Estimates

Parameter	B	Std. Error	95% Wald Conf. Int.		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	P-value
(Intercept)	3.451	.1889	3.080	3.821	333.815	1	.000
Gender [Male]	-.303	.0806	-.461	-.145	14.109	1	.000
Gender [Female]	0	.	.	.	.	.	.
Age [18-30]	-.830	.1928	-1.208	-.452	18.540	1	.000
Age [31-40]	-.766	.1957	-1.149	-.382	15.309	1	.000
Age [41-50]	-.592	.1945	-.973	-.211	9.262	1	.002
Age [51-60]	-.287	.2052	-.689	.115	1.953	1	.162
Age [More than 60]	0	.	.	.	.	.	.
(Scale)	.104	.0066	.092	.117			

5.3.10.3 The Gamma Regression Model for driving scenario with secondary task of watching a video and with visual alert (P4)

Table 22 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P4 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies three significant predictors where the age is the best predictor of perception-reaction time because it has the lowest p-value and the highest F value. This is followed by the possession of a driving license of respondents and by the gender of the respondents.

The parameter estimates provide the difference in the mean perception-reaction time between a particular category and the last category. The parameter estimate for participants having a driving license (-1.281) indicates that the average perception-reaction time of participants having a driving license was 1.281 seconds less than that of participants who do not have a driving license, given that other effects are kept constant. Similarly the parameter estimates for participants with an age not exceeding 30 years (-0.693) indicates that the average perception-reaction time of participants not exceeding 30 years of age is 0.693 seconds lower than that of their older counterparts with an age exceeding 61 years. The parameter estimates for Male participants (-0.257) indicates that the average perception-reaction time of male participants is 0.257 seconds less than female participants.

Table 22: Generalized Linear Model assuming a Gamma Distribution for the P4 Scenario

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	P-value
(Intercept)	119.198	1	.000
Gender	9.292	1	.002
Age	7.042	4	.134
Are you a driver?	13.030	1	.000
Driving experience	3.718	4	.446
Country	2.082	1	.149
Do you have any disability?	.251	1	.616

Dependent Variable: P4Duration

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	P-value
(Intercept)	317.374	1	.000
Gender	8.864	1	.003
Age	36.232	4	.000
Driving licence	12.001	1	.001

Dependent Variable: P4Duration

Parameter Estimates

Parameter	B	Std. Error	95% Wald Conf. Int.		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	P-value
(Intercept)	4.378	.4131	3.568	5.187	112.312	1	.000
Gender [Male]	-.257	.0864	-.427	-.088	8.864	1	.003
Gender [Female]	0	.	.	.	.	.	.
Age [18-30]	-.693	.1982	-1.082	-.305	12.237	1	.000
Age [31-40]	-.304	.2045	-.705	.097	2.210	1	.137
Age [41-50]	-.137	.2029	-.535	.261	.456	1	.500
Age [51-60]	-.133	.2110	-.546	.281	.397	1	.529
Age [More than 60]	0	.	.	.	.	.	.
Driving licence [Yes]	-1.281	.3698	-2.006	-.556	12.001	1	.001
Driving licence [No]	0	.	.	.	.	.	.
(Scale)	.115	.0074	.102	.131			

5.3.10.4 The Gamma Regression Model for driving scenario with secondary task of watching a video and with visual and auditory alert (P5)

Table 23 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P5 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies two significant predictors where driving experience is the best predictor of perception-reaction time. This is because it has the lowest p-value which is followed by the gender of respondents.

The parameter estimates provide the difference in the mean perception-reaction time between a particular category and the last category. The parameter estimate for participants with less than 10 years (-0.208) driving experience indicates that the average perception-reaction time of participants with, at most, 10 years driving experience is 0.208 seconds lower than their older counterparts with at least 41 years of driving experience, given that other effects are kept constant. Similarly the parameter estimates for male participants (-0.239) indicates that the average perception-reaction time of male participants is 0.239 seconds lower than that of their female counterparts.

Table 23: Generalized Linear Model assuming a Gamma Distribution for the P5 Scenario

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	104.410	1	.000
Gender	6.002	1	.014
Age	5.060	4	.281
Are you a driver?	2.162	1	.141
Driving Experience	5.904	4	.206
Country	.202	1	.653
Do you have any disability?	.433	1	.510

Dependent Variable: P5Duration

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	2651.219	1	.000
Gender	7.413	1	.006
Driving Experience	16.808	4	.002

Dependent Variable: P5Duration

Parameter Estimates

Parameter	B	Std. Error	95% Wald Conf. Int. Lower	Upper	Hypothesis Test Wald Chi-Square	df	P-value
(Intercept)	2.586	.1656	2.262	2.911	243.798	1	.000
Gender [Male]	-.239	.0878	-.411	-.067	7.413	1	.006
Gender [Female]	0	.	.	.	.	.	.
Driving Experience [1-10]	-.208	.1701	-.542	.125	1.500	1	.221
Driving Experience [11-20]	-.012	.1754	-.356	.332	.005	1	.946
Driving Experience [21-30]	.116	.1733	-.224	.456	.447	1	.504
Driving Experience [31-40]	.328	.1903	-.045	.701	2.977	1	.084
Driving Experience [>40]	0	.	.	.	.	.	.
(Scale)	.139	.0088	.123	.158			

5.3.10.5 The Gamma Regression Model for driving scenario with secondary task of sending and reading sms messages and with visual alert (P6)

Table 24 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P6 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies one significant predictor which is the age of the driver.

The parameter estimates provide the difference in the mean perception-reaction time between a particular category and the last category. The parameter estimate for drivers not exceeding 30 years of age (-1.230) indicates that the average perception-reaction time of participants, not exceeding 30 years of age, is 1.230 seconds lower than their older counterparts exceeding 61 years of age, given that other effects are kept constant.

Table 24: Generalized Linear Model assuming a Gamma Distribution for the P6 Scenario

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	97.458	1	.000
Gender	2.604	1	.107
Age	12.687	4	.013
Are you a driver?	2.103	1	.147
Driving experience	4.381	4	.357
Country	1.087	1	.297
Do you have any disability?	.016	1	.899

Dependent Variable: P6Duration

Tests of Model Effects

Source	Type III Wald Chi-Square	df	P-value
(Intercept)	1921.554	1	.000
Age	28.768	4	.000

Dependent Variable: P6Duration

Parameter Estimates

Parameter	B	Std. Error	95% Wald Conf. Int.		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	P-value
(Intercept)	3.745	.2603	3.235	4.255	206.951	1	.000
Age [18-30]	-1.230	.2746	-1.768	-.692	20.069	1	.000
Age [31-40]	-1.007	.2801	-1.556	-.458	12.911	1	.000
Age [41-50]	-.782	.2809	-1.333	-.231	7.749	1	.005
Age [51-60]	-.737	.2952	-1.315	-.158	6.226	1	.013
Age [More than 60]	0	.	.	.	.	.	.
(Scale)	.150	.0098	.132	.170			

5.3.10.6 The Gamma Regression Model for driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert (P7)

Table 25 shows how the six Predictor Model explains the total variation in the perception-reaction time for the P7 scenario. However most of the predictors are not significant since their p-values exceed 0.05 level of significance.

By using a Backward Procedure, the Gamma Regression Model identifies three significant predictors where having a driving license is the best predictor of perception-reaction time because it has the lowest p-value. This is followed by the driving experience of respondents and by the country of residence of the respondents.

The parameter estimates provide the difference in the mean reaction time between a particular category and the last category. The parameter estimate for having a driving license (0.910) indicates that the average perception-reaction time of respondents having a driving license is 0.910 seconds more than those of their counterparts, given that other effects are kept constant. The parameter estimate for participants with driving experience of less than 10 years (-0.187) indicates that the average perception-reaction time of participants with, at most, 10 years driving experience is 0.187 seconds lower than their older counterparts with at least 41 years of driving experience. Also, the parameter estimate for participants with driving experience of between 11 to 20 years (-0.572) indicates that the average perception-reaction time of participants with 11 to 20 years driving experience is significantly lower than that of their older and younger counterparts. The parameter estimate for Maltese residents (-0.285) indicates that the average perception-reaction time of Maltese participants is 0.285 seconds lower than those of other EU residents.

Table 25: Generalized Linear Model assuming a Gamma Distribution for the P7 Scenario

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	P-value
(Intercept)	77.970	1	.000
Gender	.371	1	.542
Age	3.735	4	.443
Are you a driver?	10.086	1	.001
Driving experience	7.077	4	.132
Country	4.565	1	.033
Do you have any disability?	.920	1	.337

Dependent Variable: P7Duration

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	P-value
(Intercept)	366.767	1	.000
Are you a driver?	10.326	1	.001
Driving experience	10.456	4	.033
Country	4.140	1	.042

Dependent Variable: P7Duration

Parameter Estimates

			95% Wald Conf. Int.		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	Df	P-value
(Intercept)	2.744	.3614	2.036	3.452	57.637	1	.000
Are you a driver? [Yes]	.910	.2833	.355	1.466	10.326	1	.001
Are you a driver?[No]	0	.	.	.	.	.	.
Driving Experience [1-10]	-.187	.2505	-.678	.304	.559	1	.455
Driving Experience [11-20]	-.572	.2475	-1.057	-.087	5.342	1	.021
Driving Experience [21-30]	-.318	.2507	-.809	.174	1.603	1	.205
Driving Experience [31-40]	-.163	.2658	-.684	.358	.376	1	.540
Driving Experience [>40]	0	.	.	.	.	.	.
Country [Maltese]	-.285	.1402	-.560	-.010	4.140	1	.042
Country [Other]	0	.	.	.	.	.	.
(Scale)	.139	.0089	.122	.157			

5.3.11 The Ordinal Regression Model

In the Gamma Regression Model, the Perception-Reaction Time was taken as a continuous parameter. Hence an Ordinal regression Analysis was carried out where the PRT was taken as an ordinal variable.

5.3.11.1 The Ordinal Regression Model for driving scenario without secondary task and with visual alert (P2)

Results for the P2 Scenario, as shown in Table 26, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.75 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.11 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.16 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.28 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 0.51 than the 60 years or more age group.

Table 26: Ordinal Regression Model for the P2 Scenario

Parameter Estimates		Scenario P2		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-4.183	0	0.015253
	PRT 3 sec	-0.21	0.562	0.810584
	PRT 4 sec	0.947	0.011	2.577964
	PRT 5 sec	1.899	0	6.679212
Location	Male	-0.294	0.164	0.745276
	Female	0a	.	
	18-30years	-2.156	0	0.115787
	31-40years	-1.847	0	0.15771
	41-50years	-1.264	0.001	0.282522
	51-60years	-0.673	0.091	0.510176
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.11.2 The Ordinal Regression Model for driving scenario without secondary task and with visual and auditory alert (P3)

Results for the P3 Scenario, as shown in Table 27, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.50 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.13 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.17 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.27 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 0.56 than the 60 years or more age group.

Table 27: Ordinal Regression Model for the P3 Scenario

Parameter Estimates		Scenario P3		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-3.353	0	0.034979
	PRT 3 sec	0.207	0.581	1.229983
	PRT 4 sec	1.908	0	6.739596
	PRT 5 sec	3.556	0	35.02283
Location	Male	-0.698	0	0.497579
	Female	0a	.	
	18-30years	-2.011	0	0.133855
	31-40years	-1.773	0	0.169823
	41-50years	-1.304	0.001	0.271444
	51-60years	-0.571	0.169	0.56496
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.11.3 The Ordinal Regression Model for driving scenario with secondary task of watching a video and with visual alert (P4)

Results for the P4 Scenario, as shown in Table 28, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.51 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.23 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.44 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.71 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 0.71 than the 60 years or more age group.

Table 28: Ordinal Regression Model for the P4 Scenario

Parameter Estimates		Scenario P4		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-2.481	0	0.08366
	PRT 3 sec	0.798	0.052	2.221094
	PRT 4 sec	2.361	0	10.60155
	PRT 5 sec	3.427	0	30.78415
Location	Male	-0.679	0.001	0.507124
	Female	0a	.	
	18-30years	-1.449	0.001	0.234805
	31-40years	-0.817	0.062	0.441755
	41-50years	-0.344	0.42	0.708929
	51-60years	-0.348	0.437	0.706099
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.11.4 The Ordinal Regression Model for driving scenario with secondary task of watching a video and with visual and auditory alert (P5)

Results for the P5 Scenario, as shown in Table 29, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.61 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.31 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.44 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.72 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 0.88 than the 60 years or more age group.

Table 29: Ordinal Regression Model for the P5 Scenario

Parameter Estimates		Scenario P5		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-1.684	0	0.18563
	PRT 3 sec	1.213	0.001	3.36356
	PRT 4 sec	3.033	0	20.75942
	PRT 5 sec	5.451	0	232.991
Location	Male	-0.452	0.014	0.636354
	Female	0a	.	
	18-30years	-1.175	0.003	0.308819
	31-40years	-0.808	0.044	0.445749
	41-50years	-0.328	0.402	0.720363
	51-60years	-0.131	0.749	0.877218
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.11.5 The Ordinal Regression Model for driving scenario with secondary task of sending and reading sms messages and with visual alert (P6)

Results for the P6 Scenario, as shown in Table 30, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.78 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.13 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.21 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.28 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 0.34 than the 60 years or more age group.

Table 30: Ordinal Regression Model for the P6 Scenario

Parameter Estimates		Scenario P6		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-2.968	0	0.051406
	PRT 3 sec	-0.246	0.496	0.781922
	PRT 4 sec	1.174	0.002	3.234906
	PRT 5 sec	2.189	0	8.926282
Location	Male	-0.248	0.184	0.78036
	Female	0a	.	
	18-30years	-2.069	0	0.126312
	31-40years	-1.559	0	0.210346
	41-50years	-1.263	0.001	0.282804
	51-60years	-1.084	0.007	0.33824
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.11.6 The Ordinal Regression Model for driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert (P7)

Results for the P7 Scenario, as shown in Table 31, indicate that:

i. Being a male increases the odds of having a longer PRT by a factor of 0.97 than being a female;
ii. Belonging in the 18-30 year age group increases the odds of having a bigger PRT by a factor of 0.94 than the 60 years or more age group;
iii. Belonging in the 31-40 year age group increases the odds of having a bigger PRT by a factor of 0.74 than the 60 years or more age group;
iv. Belonging in the 41-50 year age group increases the odds of having a bigger PRT by a factor of 0.99 than the 60 years or more age group;
v. Belonging in the 51-60 year age group increases the odds of having a bigger PRT by a factor of 1.46 than the 60 years or more age group.

Table 31: Ordinal Regression Model for the P7 Scenario

Parameter Estimates		Scenario P7		
		Estimate	Sig.	
				Exp_B
Threshold	PRT 1 sec	-2.024	0	0.132126
	PRT 3 sec	0.897	0.019	2.452235
	PRT 4 sec	2.089	0	8.076834
	PRT 5 sec	3.153	0	23.40618
Location	Male	-0.032	0.865	0.968507
	Female	0a	.	
	18-30years	-0.062	0.875	0.939883
	31-40years	-0.297	0.465	0.743044
	41-50years	-0.012	0.976	0.988072
	51-60years	0.381	0.356	1.463748
	61 years or more	0a	.	
Link function: Logit.				
a This parameter is set to zero because it is redundant.				

5.3.12 The Cluster Analysis

The most significant variables, as established by using the backward procedure and eliminating the non-significant variables, were used and such remaining significant variables were the gender and age. The clusters show that the predictors with similar characteristics can be grouped together to establish the most significant variables determining the Perception-Reaction Time. Hence, the variables are informative on how the sample can be split into meaningful and distinct clusters.

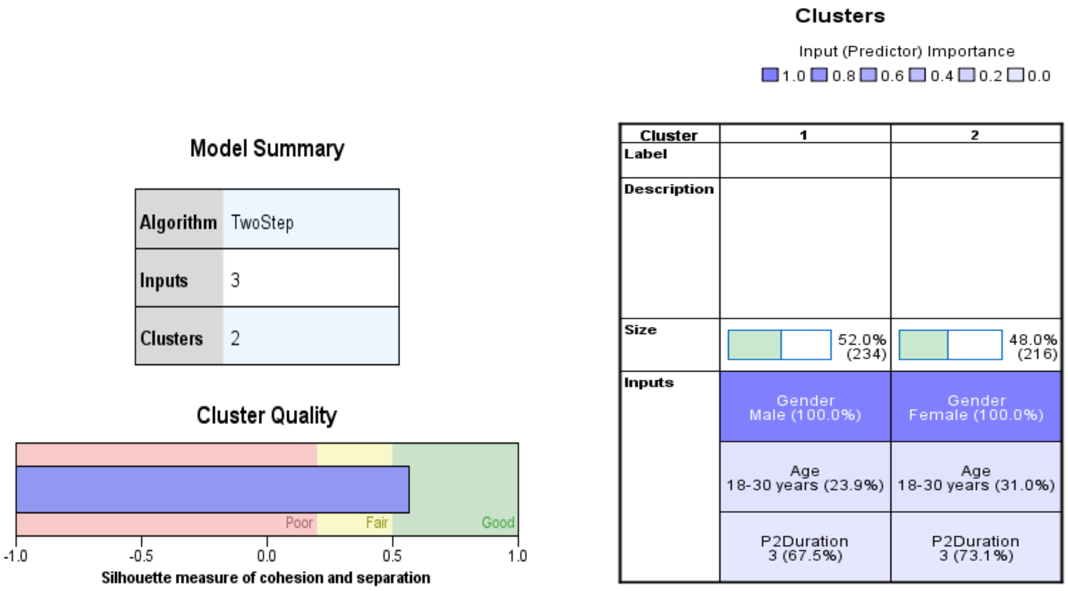
5.3.12.1 The Cluster Analysis for driving scenario without secondary task and with visual alert (P2)

Table 32 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, two clusters were produced in the P2 Scenario. These clusters show that:

i. The first cluster involves 234 participants whilst the second cluster involves 216 participants;
ii. Cluster 1 consists of only male participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (23.9%) with a PRT of 3 seconds;
iii. Cluster 2 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (31%) with a PRT of 3 seconds.

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, was more than 0.5 and thus considered as good which shows that the data set is an adequate representation of the predictor involved in each cluster.

Table 32: Cluster Analysis for the P2 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	2

Cluster Quality

Clusters

Input (Predictor) Importance

▨1.0 ▨0.8 ▨0.6 ▨0.4 ▨0.2 ☐0.0

Cluster	1	2
Label		
Description		
Size	52.0% (234)	48.0% (216)
Inputs	Gender Male (100.0%)	Gender Female (100.0%)
	Age 18-30 years (23.9%)	Age 18-30 years (31.0%)
	P2Duration 3 (67.5%)	P2Duration 3 (73.1%)

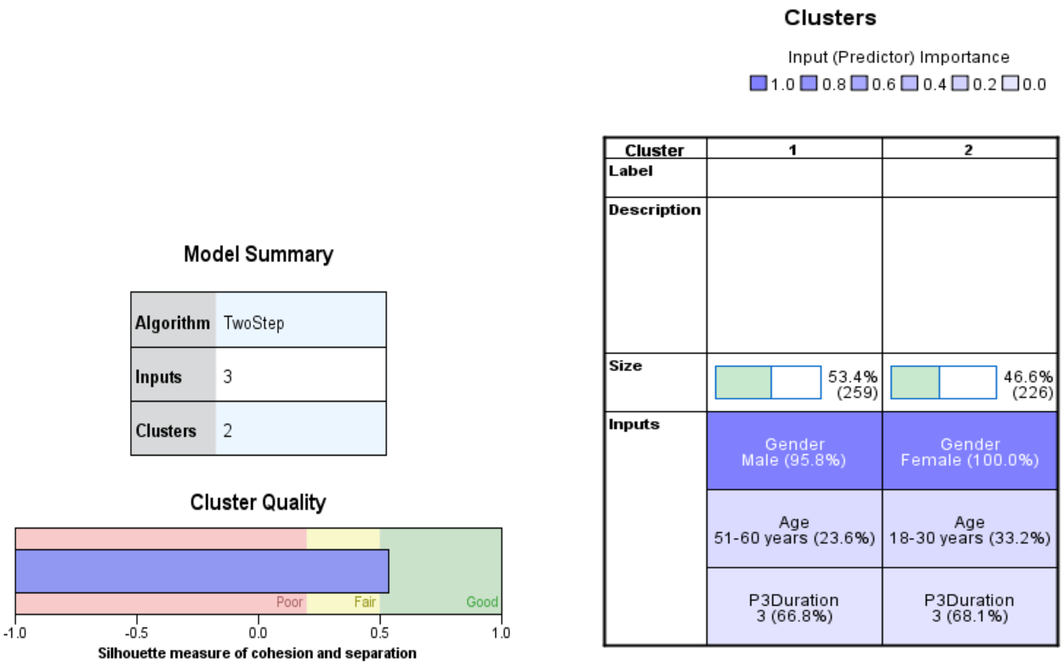
5.3.12.2 The Cluster Analysis for driving scenario without secondary task and with visual and auditory alert (P3)

Table 33 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, two clusters were produced in the P3 Scenario. These clusters show that:

i. The first cluster involves 259 participants whilst the second cluster involves 226 participants;
ii. Cluster 1 consists of 95.8% male participants while the most dominant characteristics of this cluster were the 51-60 year age group (23.6%) with a PRT of 3 seconds;
iii. Cluster 2 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (33.2%) with a PRT of 3 seconds.

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, was more than 0.5 and thus considered as good which shows that the data set is an adequate representation of the predictor involved in each cluster.

Table 33: Cluster Analysisfor the P3 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	2

Cluster Quality

Clusters

Input (Predictor) Importance

▨1.0 ▨0.8 ▨0.6 ▨0.4 ☐0.2 ☐0.0

Cluster	**1**	**2**
Label		
Description		
Size	53.4% (259)	46.6% (226)
Inputs	Gender Male (95.8%)	Gender Female (100.0%)
	Age 51-60 years (23.6%)	Age 18-30 years (33.2%)
	P3Duration 3 (66.8%)	P3Duration 3 (68.1%)

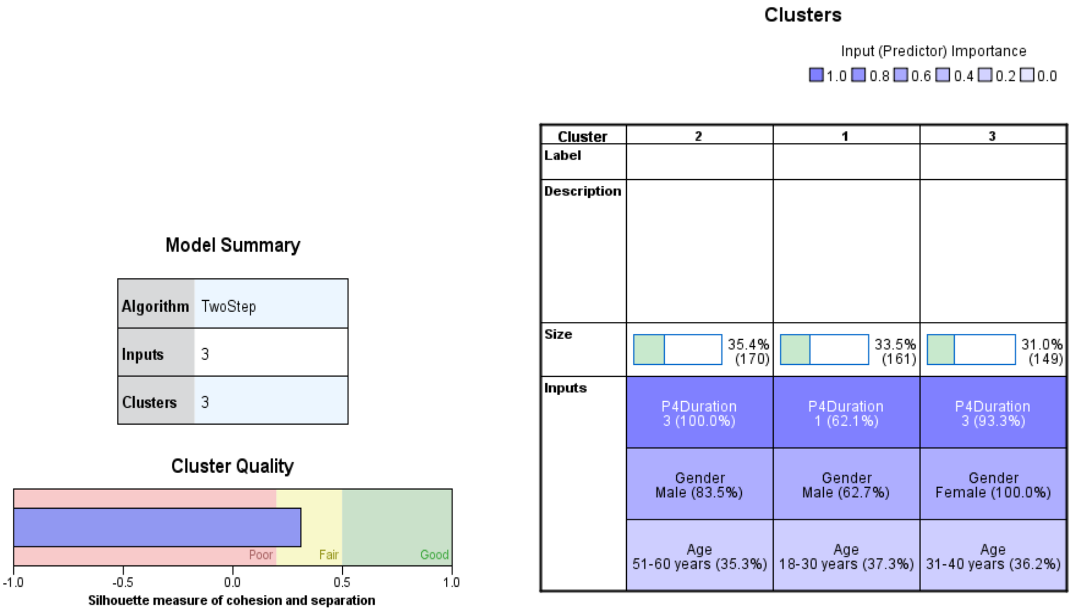
5.3.12.3 The Cluster Analysis for driving scenario with secondary task of watching a video and with visual alert (P4)

Table 34 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, three clusters were produced in the P4 Scenario. These clusters show that:

i. The first cluster involves 161 participants, the second cluster involves 170 participants and the third cluster involves 149 participants;
ii. Cluster 1 consists of 62.7% male participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (37.3%) with a PRT of 3 seconds;
iii. Cluster 2 consists of 83.5% male participants, while the most dominant characteristics of this cluster were the 51-60 year age group (35.3%) with a PRT of 3 seconds;
iv. Cluster 3 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 31-40 year age group (36.2%) with a PRT of 3 seconds.

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, is fair because its value is less than 0.5. This shows that the predictor significance is lower and that means that other variables could be examined in order to achieve a better quality model.

Table 34: Cluster Analysisfor the P4 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	3

Cluster Quality

Clusters

Input (Predictor) Importance

■1.0 ■0.8 ■0.6 ■0.4 □0.2 □0.0

Cluster	2	1	3
Label			
Description			
Size	35.4% (170)	33.5% (161)	31.0% (149)
Inputs	P4Duration 3 (100.0%)	P4Duration 1 (62.1%)	P4Duration 3 (93.3%)
	Gender Male (83.5%)	Gender Male (62.7%)	Gender Female (100.0%)
	Age 51-60 years (35.3%)	Age 18-30 years (37.3%)	Age 31-40 years (36.2%)

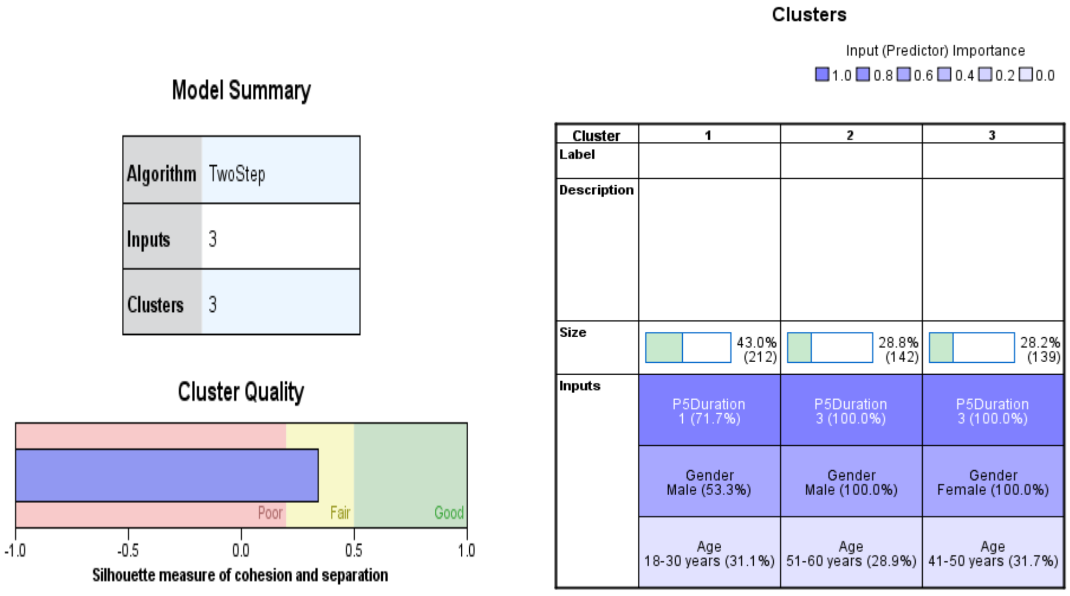
5.3.12.4 The Cluster Analysis for driving scenario with secondary task of watching a video and with visual and auditory alert (P5)

Table 35 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, three clusters were produced in the P5 Scenario. These clusters show that:

i. The first cluster involves 212 participants, the second cluster involves 142 participants and the third cluster involves 139 participants;
ii. Cluster 1 consists of 53.3% male participants, while the most dominant characteristics of this cluster were the 18-30 year age group (31.1%) with a PRT of 1 second;
iii. Cluster 2 consists of only male participants (100%), while the most dominant characteristics of this cluster were the 51-60 year age group (28.9%) with a PRT of 3 seconds
iv. Cluster 3 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 41-50 year age group (31.7%) with a PRT of 3 seconds.

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, is fair because its value is less than 0.5. This shows that the predictor significance is lower and that means that other variables could be examined in order to achieve a better quality model.

Table 35: Cluster Analysisfor the P5 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	3

Clusters

Cluster	1	2	3
Label			
Description			
Size	43.0% (212)	28.8% (142)	28.2% (139)
Inputs	P5Duration 1 (71.7%)	P5Duration 3 (100.0%)	P5Duration 3 (100.0%)
	Gender Male (53.3%)	Gender Male (100.0%)	Gender Female (100.0%)
	Age 18-30 years (31.1%)	Age 51-60 years (28.9%)	Age 41-50 years (31.7%)

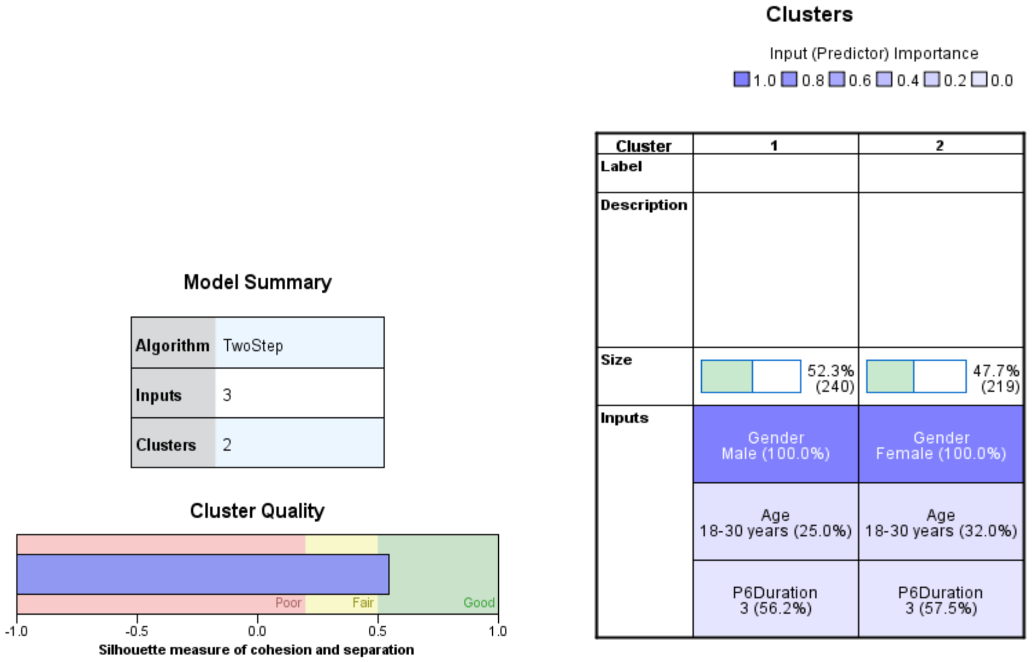
5.3.12.5 The Cluster Analysis for driving scenario with secondary task of sending and reading sms messages and with visual alert (P6)

Table 36 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, two clusters were produced in the P6 Scenario. These clusters show that:

i. The first cluster involves 240 participants whilst the second cluster involves 219 participants;
ii. Cluster 1 consists of only male participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (25.0%) with a PRT of 3 seconds;
iii. Cluster 2 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (32.0%) with a PRT of 3 seconds.

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, was more than 0.5 and thus considered as good which shows that the data set is an adequate representation of the predictor involved in each cluster.

Table 36: Cluster Analysisfor the P6 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	2

Cluster Quality

Clusters

Input (Predictor) Importance

Cluster	1	2
Label		
Description		
Size	52.3% (240)	47.7% (219)
Inputs	Gender Male (100.0%)	Gender Female (100.0%)
	Age 18-30 years (25.0%)	Age 18-30 years (32.0%)
	P6Duration 3 (56.2%)	P6Duration 3 (57.5%)

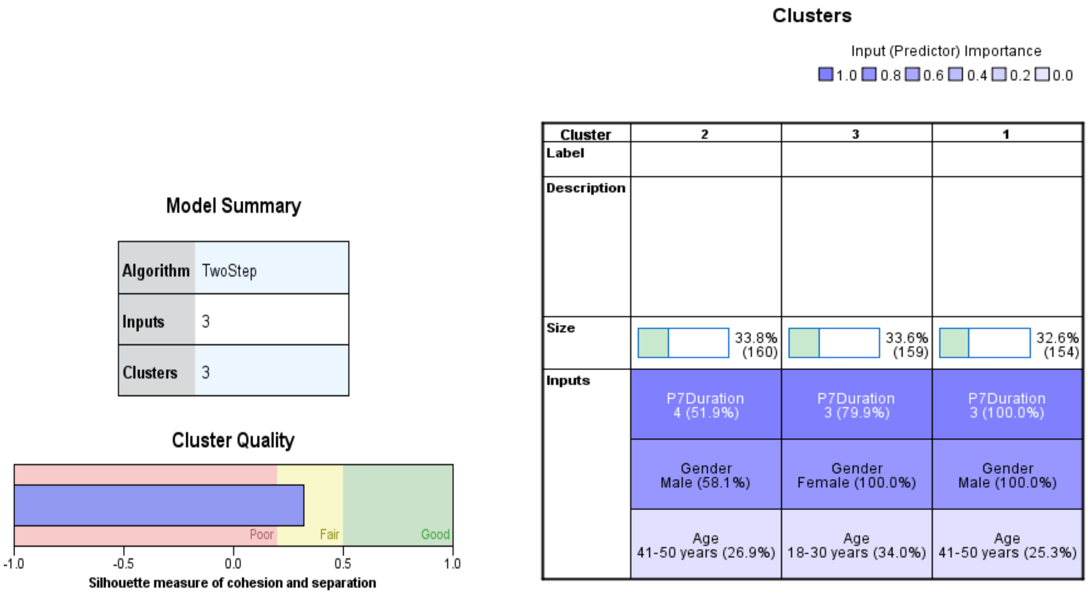
5.3.12.6 The Cluster Analysis for driving scenario with secondary task of sending and reading sms messages and with visual and auditory alert (P7)

Table 37 shows that the cluster had three inputs being the gender, age and the PRT. After carrying out the Cluster Analysis, three clusters were produced in the P7 Scenario. These clusters show that:

i. The first cluster involves 154 participants, the second cluster involves 160 participants and the third cluster involves 159 participants;
ii. Cluster 1 consists of only male participants (100%), while the most dominant characteristics of this cluster were the 41-50 year age group (25.3%) with a PRT of 3 seconds;
iii. Cluster 2 consists of 58.1% male participants, while the most dominant characteristics of this cluster were the 41-50 year age group (26.9%) with a PRT of 3 seconds.
iv. Cluster 3 consists of only female participants (100%), while the most dominant characteristics of this cluster were the 18-30 year age group (34.0%) with a PRT of 3 seconds

The quality of the cluster, expressed as a silhouette measure of cohesion and separation, is fair because its value is less than 0.5. This shows that the predictor significance is lower and that means that other variables could be examined in order to achieve a better quality model.

Table 37: Cluster Analysisfor the P7 Scenario



Model Summary

Algorithm	TwoStep
Inputs	3
Clusters	3

Cluster Quality

Clusters

Input (Predictor) Importance

Cluster	2	3	1
Label			
Description			
Size	33.8% (160)	33.6% (159)	32.6% (154)
Inputs	P7Duration 4 (51.9%)	P7Duration 3 (79.9%)	P7Duration 3 (100.0%)
	Gender Male (58.1%)	Gender Female (100.0%)	Gender Male (100.0%)
	Age 41-50 years (26.9%)	Age 18-30 years (34.0%)	Age 41-50 years (25.3%)

5.4 Computing the 85th Percentile Perception-Reaction Times

The 85th Percentile value perception-reaction times of the data set obtained for each driving scenario can be calculated using the definition of the z-score. The z-score is defined as (Pierce, 2017):

$z = (x-\mu)/\sigma$ and thus $x = \mu + z\,\sigma$ ....(16)

where:

- x is the value
- μ is the mean
- σ is the standard deviation.

For a normal distribution, the value can be calculated from the z-score. The value of the z-score for the 85th Percentile can be found in various tables and has a value of 1.036. (see:http://www.pindling.org/Math/Statistics/Textbook/Chapter2_descript_stat/Graphs/z_scores_table.htm).

The standard deviation, σ, is a measure of how spread out the numbers are and is explained by the formula as follows (LaMorte, 2016):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^2}$$

.... (17)

However when the sample is used as an estimate of the whole population, the Standard Deviation formula changes to Sample Standard Deviation, s, and is explained by the formula as follows (LaMorte, 2016):

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\overline{x})^2}$$

.... (18)

where:

- $\overline{x}$ is the sample mean instead of μ (population mean)
- s is the Sample Standard Deviation instead of σ
- N-1 is used instead of N as Bessel's Correction.

The Population Deviation, σ, is unknown however the Sample Standards Deviation, s, is a good estimation of σ, particularly where the sample size is large as in this case with a sample size of 514 participants.

The values for μ and σ for the six scenarios P2, P3, P4, P5, P6 and P7 are as follows, as obtained from the SPSS and shown in Table 38:

Table 38: Descriptive Statistics

Descriptive Statistics

		P2Duration	P3Duration	P4Duration	P5Duration	P6Duration	P7Duration
N	Valid	450	485	480	493	459	473
Mean		3.05	2.69	2.68	2.48	2.84	3.12
Std. Deviation		1.100	.906	.979	.937	1.174	1.235

The results of the survey gave the anticipated perception-reaction times for drivers performing a secondary task in a Level 3 automated vehicle. A Correction Factor of 1.35 was multiplied with the anticipated perception-reaction times to obtain the unexpected perception-reaction times. These anticipated perception-reaction time were obtained from the survey.

Hence, for each different driving scenario, the 85th Percentile Unexpected Perception-Reaction Time is as follows in Table 39. This was calculated using the z-score formula and corrected using the Correction Factor of 1.35 as established by Johansson and Rumar (1971):

Table 39: Results of Web-Based Survey and Correction Surprise Factor showing Perception-Reaction Time for the different Driving Scenarios

Driving Scenario	85th Percentile Unexpected Perception-Reaction Time
P2	4.19
P3	3.63
P4	3.69
P5	3.45
P6	4.06
P7	4.40

As explained previously, the first two scenarios, hence P2 and P3, did not include a simulated in-vehicle distraction and the participant had the possibility to familiarize with what was expected from the web-based survey following the written instructions which had been provided. These first two scenarios acted as a learning tool for the participant prior to attempting the simutation of the P4, P5, P6 and P7 scenrios which included a simulated in-vehicle distraction.

For the purposes of establishing a value for the unexpected perception-reaction time, the scenarios P4, P5, P6 and P7 will be considered because they are the results of the data set for the simulation in a Level 3 automated vehicle where the driver is performing a secondary task.

With reference to the scenarios P4 and P5, where the driver was simulating a secondary task of watching a video with sound, the average unexpected perception-reaction is 3.57 seconds. In the scenarios P6 and P7, where the driver was simulating a non-auditory secondary task of writing an sms, the average unexpected perception-reaction time is 4.23.

CHAPTER 6: DISCUSSION and CONCLUSION

6.1 Discussion

6.1.1 Relationship between Country of Origin and Perception-Reaction Time

From a total of 23 different European countries, only 24.65% of the respondents of the web-based survey were non-Maltese citizens. There were a total of 127 non-Maltese respondents out of a total of 514 respondents. The large percentage of Maltese respondents was due to the fact that the web-based survey was distributed primarily within Maltese government departments, agencies and parastatal authorities. Given the relatively small percentage amount of respondents per country, the dataset was differentiated only between Maltese and Non-Maltese European Union residents.

From the results obtained in this research document it resulted that, with regards to drivers in a Level 3 automated vehicle involved in a secondary task, Maltese EU Citizens are scoring significantly higher perception-reaction times than the Maltese in the P2 and P3 scenarios only (control scenarios without an in-vehicle distraction). In the P2 scenario, the perception reaction time of non-Maltese EU citizens was 2.81 seconds whilst the time for Maltese citizens was of 3.12 seconds. In the P3 scenario, the perception reaction time of non-Maltese EU citizens was 2.54 seconds whilst the time for Maltese citizens was of 2.74 seconds. There was no significant difference in mean reaction times between the two groups of participants in the other driving scenarios. The data collected is not sufficient to establish the reason for these results.

6.1.2 Relationship between Gender and Perception-Reaction Time

The data from the web-based survey showed that, out of a total of 514 respondents, 51.6% were male whilst 48.4% were female with a 1.06 male/female ratio. The results of the survey showed that females have longer perception-reaction times than men in all scenarios. In P3 and P4 driving scenarios the p-values are less than 0.05 level of significance and hence the females are scoring significantly higher perception-reaction times. It is to be noted that the P3 scenario did not include any secondary task and was intended to be the control and to help the survey participant to get used to the survey. In the research carried out by Moir and Jessel (1991) it resulted that reaction times tends to be longer for females however they also concluded that although this difference was statistically significant, as in the case of the results for P4 scenario of this research document, however they are not practically significant.

Although the perception-reaction times for females were higher than those for men, including in the P2, P3, P5, P6 and P7 scenarios, thus confirming the research carried out by Green (2013), Noble et al (1964), Welford (1980), Adam et al (1999) and Botwinich & Thompson (1966), the p-value was more than 0.05 level of significance. This means that there was no significant difference in mean perception-reaction times for the P2, P3, P5, P6 and P7 scenarios and the results of this research did not show any gender discrepancy. This confirms the results of the research carried out by Kroemer et al (1994) which concluded that gender difference relevant to perception-reaction times are minimal to none.

However, from the results of the Cluster Analysis it resulted that when gender and age are combined, both these two predictors are statistically significant. The Cluster Analysis also showed that for the P2, P3 and P6 scenarios there is a perfect distinction between males and females showing that there is a different behavior between males and females when gender is combined with age. The Ordinal Regression Model showed that gender was not statistically significant for the P2, P6 and P7 scenarios.

6.1.3 Relationship between Age and Perception-Reaction Time

The results obtained for the P4, P5, P6 and P7 are the simulation for a driver in a Level 3 automated vehicle where the driver is engaged in a secondary task, other than driving, and is alerted to resume the driving function. The results were classified into five age groups, namely, 18-30 years, 31-40 years, 41-50 years, 51-60 years and 61+ years. The results for the P2, P3, P4, P5 and P6 scenarios show that participants of different age groups scored significantly different perception-reaction times in all driving scenarios since the p-values are all less than 0.05.

The results show that the perception-reaction time increases with age where the 18-30 years age group had the shorter perception-reaction times and the 61+ age group had the longest perception-reaction times. This reflects the perception-reaction results of the research carried out by Warshawsky-Livne & Shinar (2002) albeit their research was carried out for Levels 1 and 2 automation. Similarly, the results of the Cluster Analysis show that when age is combined with gender, both these two predictors are statistically significant. Also, for each scenario, the Cluster Analysis revealed that the 18-30 year age group is statistically significant and formed one or more clusters in each scenario. The 61+ age group did not form any clusters in any of the six scenarios.

However, research carried out by Clark & Feng (2016) examined the effect of age differences on driving performance in a Level 3 AV whilst engaged in an in-vehicle secondary task other than driving. The participants of this study involved 17 paticipants with an age group from 18 to 35 years and 18 participants with an age group from 62 to 81 years (Clark & Feng, 2016). The results showed that there was no difference in the response to takeover alerts between the older and younger groups of drivers. These results are different from those of Warshawsky-Livne & Shinar (2002) and from the results obtained in the research document for the scenarios from P2 to P6. Also, research carried out by Warnes et al (1993) showed that, when alerted at a time where they were tasked with a distraction, the elder drivers were significantly faster in their perception-reaction time than the control group.

In the case of the P7 scenario, where the driver is involved in replying and typing an sms and is alerted by a visual and auditory alert, there was no significant difference in mean reaction times between the different age groups of the participants since the p-value exceeds the 0.05 criterion. This result reflects the conclusions of Clark & Feng (2016) and of Warshawsky-Livne & Shinar (2002). The difference between the P6 and P7 scenarios is that the P6 scenario has only a visual alert whilst the P7 scenario has both visual and auditory alerts. Thus it had a multisensory alert.

However it is to be noted that the in-vehicle secondary task of the older drivers in the experiment by Clark & Feng (2016) was a conversation. The secondary task for the P7 scenrio in this document was reading and writing an sms which poses a higher load on the cognitive capacity of a person. Thus the different nature of the in-vehicle secondary task is a critical difference which impacts the results obtained and makes it difficult to compare the outcomes of the two experiments.

It is to be noted that the group of drivers who would reach the age of 65 by the year 2010 were born in the 1940s and after. Hence they were more educated, had better driver education, were in better health and had driven on the roads in the modern age. Given that the cognitive trends are variable in incidence and also variable in their impact on driver performance, thus the older drivers of the future may actually show less decline, related to central processes, in driving performance (Koppa, 2003).

6.1.4 Relationship between Driving Experience and Perception-Reaction Time

Studies which were carried out by Olson & Sivak (1986) and by Underwood et al. (2005) investigated hazard perception skills in older drivers. In both researches there was no significant difference in perception-reaction times between younger and older drivers (Horswill et al, 2008). However it is to be noted that, in both researches, the sample sizes were very small (Horswill et al, 2008). Research carried out by Quimby & Watts (1981) involved a larger sample of 65+ years drivers as part of a cross-age sample and it resulted that the ability to perceive a hazard peaks at the age of 55 years and then declines.

It has to be noted that the majority of older drivers have considerable driving experience which compensates for defects due to age, Horswill et al (2008) considered it possible that hazard perception performance might not decline in healthy older drivers. However the research carried out by Horswill et al (2008) resulted in the fact that older drivers had slower perception-reaction times to traffic conflicts and that the ability to perceive a hazard diminishes with age even for healthy older drivers due to cognitive and vision issues.

The results obtained from this research, through the web-based survey simulating a driver in a Level 3 automated vehicle, show that participants with different driving experience scored significantly different perception-reaction times in all driving scenarios, except for thr P7 scenario, since the p-values are all less than 0.05. The results obtained show that participants who have 41 years or more driving experience scored the highest mean perception-reaction times than the other groups of driving experience in the P2, P3, P4, P6 and P7 scenarios. The results for these scenarios, except for the P5 scenario, show that the greater the amount of driving experience, that is the older the driver is, the greater was the mean perception-reaction time.

This is because the greater the driving experience means that the driver is older. This confirms the results obtained by Horswill et al (2008) and by Quimby & Watts (1981) where their experiments showed that the ability to perceive a hazard peaks at the age of 55 years and then declines. For the P5 scenario, the results show that the mean perception-reaction time for the 31-40 years driving experience scenario is the highest value. This result is similar to the result obtained for the elationship between age and driving experience where there was no significant different for the P7 scenario for the different age groups. The results are similar as expected because the age and years of driving experience complement each other.

6.1.5 Relationship between Disabilities and Perception-Reaction Time

No research was found which investigates the impact of disabled persons acting as operator or supervisor in a Level 3 automated vehicle. However, given that for a disabled person to obtain a driving license he/she must have the necessary ability to drive safely in a Level 1 and 2 automated vehicles, hence, those same driving skills and criteria would apply for a Level 3 vehicle.

Of the six respondents, four suffer from musculoskeletal disabilities namely, full/partial paralysis/weakness/amputation of upper limbs, Muscular Dystrophy Disease and spinal injuries and the remaining two suffer from a disability which was not listed in the drop-down menu of the web-based survey.

The results obtained from the web-based survey show that for the control scenarios of P2 and P3 and for the P4, P5, P6 and P7 scenarios, namely the scenarios involving the driver performing a secondary task other than driving in a Level 3 automated vehicle, there was no significant difference in mean reaction times between the disabled and non-disabled groups of participants holding a driving license since the p-values exceed the 0.05 criterion. This confirms the results of the performance studies carried out by Koppa et al (1980) which showed that the driving performance of disabled people is not distinguishable from that of non-disabled persons. It also confirms that the driving license is issued to disabled persons when it is confirmed that they can operate a vehicle safety on the roads (NHTSA, 2015).

6.1.6 Relationship between Type of Alert and Type of Distraction on Perception-Reaction time

6.1.6.1 Effect of Type of Alert

It is to be noted that the unexpected perception-reaction time for the scenario P5 (visual and auditory alert) was 3.45 seconds and was less than for the scenario P4 (visual alert only) which was 3.69 seconds. This was also the case for the P2- P3 scenarios where the unexpected perception-reaction time for the scenario P3 (visual and auditory alert) was 3.63 seconds and was less than for the scenario P2 (visual alert only) which was 4.19 seconds. The results of the web-based survey are shown in Table 40.

Table 40: Results of Web-Based Survey showing Perception-Reaction Time and Type of Alert for the different Driving Scenarios

Driving Scenario	85th Percentile Unexpected Perception-Reaction Time	Type of Alert
P2	4.19	Visual
P3	3.63	Visual & Auditory
P4	3.69	Visual
P5	3.45	Visual & Auditory
P6	4.06	Visual
P7	4.40	Visual & Auditory

The P2-P3 scenarios did not involve any secondary task acting as a distraction and were the control. The P2-P3 scenarios were also important becase they were a tool for the participant to familiarize with the survey and what was expected to be done. It is to be noted that the PRT value for the P2 scenario is more than for the P3 scenario and this is explained because the P2 scenario was the first scenario where the participant was still familiarizing with the survey and also the P2 scenario consisted only of a visual alert whereas the P3 scenario consisted of a visual and auditory alert.

Clearly the perception-reaction time was less when an auditory and visual alert (multisensory) were used. The P4- P5 scenarios involved a secondary task, acting as a distraction in a simulated Level 3 automated vehicle. This task involved watching a video with sound. These results reflect the results of the research carried out by Kemp (1973), Thompson et al (1992), Shelton & Kumar (2010) and Mishra & Gazzaley (2012) which concluded that the reaction time for auditory alerts is less than that for visual alerts. However, the unexpected perception-reaction time for the scenario P7 (visual and auditory alert) was 4.40 seconds and thus was more than for the scenario P6 (visual alert only) which was 4.06 seconds.

In the P6-P7 scenario, where the typing and reading of an sms text message was the distraction, the perception-reaction time for audiovisual alert P7 scenario was 0.34 seconds longer than that for the visual alert only P6 scenario. This does not reflect the results of the research carried out by Mishra & Gazzaley (2012) where it resulted that the reaction time was less for the multisensory alert when compared to the visual alert only. The reason that the perception-reaction time for P7 was more than for the P6 scenario was investigated further in relation to the distraction itself rather than the type of alert.

6.1.6.2 Effect of Type of Distraction

Singh (2010) and Green (2013) reported that the use of mobile phones, in-car displays, wireless devices and Personal Digital Assistant (PDA) devices was the most common causes of secondary task distraction in vehicles. This type of distraction resulted in low severity and higher severity traffic collisions and crashes.

Research carried out by Dogan et al. (2017) involved using a driving simulator study to examine the effect of secondary tasks, other than driving, on the monitoring behavior and transition of control of a driver in a vehicle equipped with a Traffic Jam Assist. The results showed that the in-vehicle alert had an impact of the monitoring behavior of the drivers but not their performance during the takeover of control from the vehicle (Dogan et al., 2017). Also the results showed that when the driver is engaged in a secondary task, other than riving, the reaction time is longer (Dogan et al., 2017). However it is to be noted that focus of this study was to investigate the importance of a transition period and not to establish PRT during a vehicle takeover (Dogan et al., 2017).

For the scope of this research, two forms of distraction were used as the secondary task simulated by the web-based survey in a Level 3 automated vehicle. The in-car display was a video and the cell phone use was the reading and writing of a text message.

This research document examines the effects of cognitive, visual and biomechanical distractions on the perception-reaction time of a driver in a Level 3 automated vehicle and the results obtained from the web-survey were as follows in Table 41.

Table 41: Results of Web-Based Survey showing Perception-Reaction Time, Type of Alert and Type of Distraction for the different Driving Scenarios

Driving Scenario	85th Percentile Unexpected Perception-Reaction Time	Type of Alert	Type of Distraction
P2	4.19	Visual	No distraction. Control
P3	3.63	Visual & Auditory	
P4	3.69	Visual	Watching a video. Cognitive, visual & auditory.
P5	3.45	Visual & Auditory	
P6	4.06	Visual	Typing & Reading a Text Message. Cognitive, visual & biomechanical.
P7	4.40	Visual & Auditory	

The results of the research carried out by Wickens & Hollands (2000) show that the ability of the driver to perceive and respond to a hazard is limited both by the volume of information to be processed and also by the rate at which it is expected to be processed. This is because humans have limited cognitive resources and when the task is greater than the capacity of the human, the driving performance suffers (Hole, 2007; Shinar, 2007).

As described above, for the scenarios P6-P7 with the typing and reading of an sms text message as the visual, cognitive and biomechanical distraction, the perception-reaction time for audiovisual alert of scenario P7 was 0.34 seconds longer than that for the scenario P6 with the visual alert only. According to the research by Kemp (1973), Thompson et al (1992), Shelton & Kumar (2010) and Mishra & Gazzaley (2012), the perception-reaction time for the audiovisual alert of P7 should have been shorter than P6 because the auditory alert is processed faster in the brain. Hence this unexpected result is being analysed further down in the discussion. For the control scenarios P2-P3 which had no distractions and for the scenarios P4-P5 which had the visual and cognitive distraction in the form of watching a video, the audiovisual alert resulted in shorter perception-reaction times.

The difference between the P4-P5 scenarios and the P6-P7 scenarios is the type of distraction. The P4-P5 scenarios consist of a cognitive, auditory and visual distraction and the P6-P7 scenarios consist of the cognitive, visual and the biomechanical distraction. In the case of the P6-P7 scenario, the limited cognitive resources of the human had to respond to a combination of the cognitive, visual and biomechanical distractions. These caused the perception-reaction performance to degrade resulting in longer perception-reaction times for the P6-P7 scenario. Hence the P6-P7 scenarios created additional demand on the limited cognitive resources of the participants and so impaired the efficiency in their perception-reaction performance. This was reflected in higher average perception-reaction times than those evidenced in the P2-P3 scenario and the P4-P5 scenario.

Cooper et al (2011) examined the risks involved when text reading and when text writing whilst driving on a closed driving course. The 42 participants in the research drove under a control scenario, under a text reading scenario and under a text writing scenario (Cooper et al, 2011). The participants had to respond to a green LED light which was mounted on the hood of the vehicle within the eye level of the driver (Cooper et al 2011) and which alerted the driver to respond. Hence the experiment consisted of a visual alert only. The results obtained showed that the perception-response time of the participants writing a text message was longer by a factor of 2.45 when compared to the control (Cooper et al, 2011). Also, the time period when the participants were reading a text message was longer by a factor of 1.87 when compared to the control (Cooper et al, 2011).

The statistical analysis by Cooper et al, (2011) showed that the perception-reaction times to the visual alert for the control, the text reading condition and the text writing condition, were all significantly different. This showed that text writing causes a significantly greater impairment when compared to text reading whilst driving (Cooper et al, 2011). As a consequence, although the type of alert is a determining factor in perception-response times, however the type of distraction also is a determining factor. This is confirmed also by the research carried out by Hole (2007), Hurts et al (2011), Shinar (2007), Ranney et al (2000), Treat et al (1979), Dingus et al (2006), D'Addario (2014), Green (2000), Green (2013), The Royal Society for the Prevention of Accidents (2017), Singh (2010), Lee et al (2004), WHO (2011), Louw et al (2015), Mishra & Gazzaley (2012) and Blanco et al (2015).

The P6-P7 scenarios have a combination of reading a text message and writing a text message as the secondary task in the simulated Level 3 automated vehicle. Given that, according to research carried out by Cooper et al (2011), the perception-response time for typing a text message was significantly longer than that for reading a text message, hence the unexpected longer perception-reaction time for the P7 scenario (when compared to the P6 scenario) may have been attributed to the specific type of text-message distraction (rather than by the different type of alert) which occurred in that moment when the alert was given during the P7 scenario. It is not possible to determine from the data collected as part of this research whether the audiovisual alert was given when the survey participant was actually in the stage of reading the text message as the distraction or whether the participant was in the stage of typing the text message or whether the participant was both reading and texting the message at the same time.

Cooper et al (2011) determined that the driver perception-reaction time is doubled when distracted by reading or typing a text message and that drivers engaged in such secondary distraction are less capable of reacting to a critical roadside scenario. The results by Cooper et al (2011) showed that the perception-reaction time without texting was between 1 to 2 seconds however the perception-reaction times while texting increased to 3 to 4 seconds. The perception-reaction times obtained from the web-based survey of this research document were of 4.06 seconds for the P6 scenario and 4.40 seconds for the P7 scenario and thus these values reflect the results of the research carried out by Cooper et al (2011).

With reference to the P4-P5 scenarios, where the driver was engaged in the secondary task of watching a video with sound, the average unexpected perception-reaction is 3.57 seconds. For the scenarios P6-P7, where the driver was engaged in the secondary task of reading and writing a message, the average unexpected perception-reaction time is 4.23 seconds. It is being concluded that the difference in the average perception-reaction times between the P6-P7 and P4-P5 scenarios is because the reading and typing of a text message creates a higher demand on the limited cognitive resources of the survey participants and thus resulting in longer average perception-reaction times as reported by Hole (2007), Cooper et al (2011) and Shinar (2007).

Also it is being suggested that the benefits in reduced perception-reaction times by the audiovisual alert over the visual alert are effective only up to a certain point which is determined by the demand on the cognitive resources which is created by the type of distraction. In the case of this research, it is suggested that the audiovisual advantage over the visual disadvantage does not apply for a secondary task which involved the reading and writing of a text message. Also, as established in this research and as described previously, for the p-values for the relationship between age and driving experience with PRT for the P7 scenario, it resulted that there is no significant difference between the age groups which further suggests that when the cognitive limit of the human has been exceeded there is no significant difference in the PRT across different age groups.

Similarly for the results obtained in the Ordinal Regression Model, it is observed that there is a pattern which is followed for the PRT values in the P2-P3 and P4-P5 scenarios however this pattern is no longer followed for the P6 and P7 scenarios. Notwithstanding, the results obtained still confirm the importance of having a multisensory alert in a Level 3 automated vehicle where drivers are permitted to engage in a secondary task. This is because, as reported by Cooper et al (2011), drivers were 11 times more likely to miss the visual alert whilst texting and hence the auditory alert would become more important.

6.1.7 Relationship between hue and perception-reaction time

The research carried out by Balakrishnan (2014) showed that the red hue reduces visual choice reaction and thus reduces the processing time in both men and women. In a research carried out by Coley et al (2008), where the perception-reaction time was used as a measure to determine driver alertness, a alert red rectangular bar was used in the experiment. Hence it is concluded that the red visual alert used in the web-survey was adequate and it is recommended that visual alerts are based on the use of a red or green colour. It is also being recommended that any visual alert systems used in automated vehicles should be red or green.

6.1.8 Impact of the Predictors Collectively on the Perception-Reaction Time

The results of the Gamma Regression Model, shown in Table 42 estimated the impact of the predictors (Age, Gender, Driving License, Driving Experience, Country of Residence, Disability) collectively on the dependent variable (perception-reaction time) for each different driving scenario.

Table 42: Results of the Gamma Regression Model showing Significant Predictors

Scenario	Predictors				
	Age	Gender	Driving License	Driving Experience	Country of residence
P2	Not significant	Not significant	Not significant	Group <10 yrs experience have 1.163sec av. PRT less than 41+ yrs group	Maltese have 0.213sec av. PRT more than EU counterparts
P3	Group <30yrs have 0.830sec av. PRT less than 61+ yrs group	Males have 0.303sec av. PRT less than females	Not significant	Not significant	Not significant
P4	Group <30yrs have 0.693sec av, PRT less than 61+ yrs group	Males have 0.257sec less av. PRT than females	Licensed drivers have 1.281sec av. PRT less than non-licensed	Not significant	Not significant
P5	Not significant	Males have 0.239sec av. PRT less than females	Not significant	Group <10 yrs experience have 0.208sec av. PRT less than 41+ yrs group	Not significant
P6	Group <30yrs have 1.230sec av. PRT less than 61+ yrs group	Not significant	Not significant	Not significant	Not significant
P7	Not significant	Not significant	Licensed drivers have 0.910sec av. PRT more than non-licensed	Group <10 yrs experience have 0.187sec av. PRT less than 41+ yrs group	Maltese have 0.285sec av. PRT less than EU counterparts

The results of the Gamma Regression Model show the following important points:

i. the results of the P6 and P7 scenarios show that gender is not a significant predictor when the secondary task is writing and reading an sms;
ii. the Age and Driving Experience predictors complement each other and either one or the other results as a significant predictor in all scenarios. Similarly, age was found to be a significant predictor in the Cluster Analysis. For all cases, the younger age group/least driving experience group have shorter average perception-reaction times than their older counterparts. This is also reflected in the results obtained in the Ordinal Regression Model;
iii. comparing the P4 and P5 results shows that, although males have shorter average perception-reaction time than females for both scenarios, however with the multi-sensory alert, this difference between male and female average perception-reaction time is less. Therefore multi-sensory alerts may potentially reduce the gender difference in relation to the dependent variable. However for the P6 and P7 scnearios,

where the cognitive capacity of the human is exceeded, there is no statistically significant difference between males and females;

iv. comparing the results for P6 and P7, both of which have different alerts but the same secondary task, and considering that the age and driving experience predictors complement each other, it results that the younger age group have a shorter average perception-reaction time than their older counterparts;

v. comparing the P4 and P6 results shows that, with the same type of visual alert but different secondary tasks for both cases, the respondents who do not exceed 30 years of age have shorter average perception-reaction times than their older counterparts exceeding 61 years of age;

vi. comparing the P5 and P7 results shows that, with the same type of multi-sensory alert but different secondary tasks, respondents who have less than 10 years driving experience have shorter average perception-reaction times than respondents with more than 41 years of driving experience.

6.1.9 Perception-Reaction Times Adopted in Design Guidelines of Different Countries

The importance of the perception-reaction time arises because it determines the total time for a driver to see an object, to identify it as an accident risk, to decide on the action to take and to start the action itself (Green, 2013). The minimum stopping sight distance on the road is to be long enough to enable a vehicle travelling at the design speed to come to a stop before colliding with an object (Maze & Plazak, 2000). The object presenting the roadside hazard is taken as being an unexpected object which is large enough to necessitate evasive action by the driver (Fambro et al, 1997).

Stopping sight distance is calculated using basic principles of physics and parameters which AASHTO defines as a sum of two components, namely brake-reaction distance and braking distance (Fambro et al, 1997). One of the most important and most basic aims in road design is that a driver can identify a hazard on the road and have sufficient time to avoid a collision (Gelinne, 2017). Generally, the vehicle drivers must also associate the approaching hazard with fixed objects along the roadside to establish whether the object is at a standstill or if it is moving (Fambro et al, 1997). The concept of sight stopping distance is important because it is a quantifiable value which can be used in the design geometry of the road (Hall & Turner, undated).

The perception-reaction time is determined by the complexity of the decision required to be taken (Green, 2013). The decisions taken at intersections and interchanges are more complex (U.S. Department for Transportation, 2009) however the web survey adopted for this study does not consist of such complex roadside scenarios. It only involved a driver, who is performing a secondary task other than driving, following an alert signal in a simulated Level 3 automated vehicle. In the AASHTO model to determine sight stopping distances it is assumed that the driver moves the foot from the accelerator pedal to the brake pedal as a response and that this is done with sufficient force to immediately lock the wheels (Fambro et al, 1997).

In the case of the survey carried out, the response to the alert is that the survey participant moves the hand and clicks on the computer screen as a response. Further to the driver response, the AASHTO model proceeds to calculate the sight stopping distance based on the laws of physics and does not factor in the driver any further (Fambro et al, 1997). The laws of physics adopted take into consideration speed, tyre (coefficient of) friction and road gradients (Arjun, 2019). This same mode is used also for the calculations in the DMRB and CEDR reports. In all the different sight stopping distance standards reviewed, the values used for speed, perception-reaction time and coefficient of friction differ however the same laws of physics and model apply.

All standards use a fixed perception-reaction time which is 2 seconds for DMRB and CEDR and 2.5 seconds for AASHTO and NCHRP. Such perception-reaction time is used for all the calculations to determine the sight stopping distances. However this means that the model is not sensitive to the actual behaviour of a human where this value would probably change depending on the vehicle speed and type of roadside scenario (Fambro et al, 1997). It was noted that changes in perception-reaction time actually resulted in changes in the distance travelied at the design speed and hence SSD was dependent on speed (Glennon, 1870). The increase in SSD became significant at higher speeds in relation to changes in perception-reaction time (Glennon, 1870). Hooper and McGee (1983) differed from this claiming that the braking component of stopping sight distance became the dominant factor at higher speeds, even though a significant distance was travelled during the increased perception-reaction time.

The research carried out by Hooper and McGee (1983) recommended different perception-reaction times for different design speeds. The recommended perception-reaction times varied between 1.5 to 3.0 seconds (Hooper & McGee, 1983). The 2.5 seconds adopted by AASHTO and recommended by NCHRP and the 2 seconds adopted by DMRB and CEDR fall within this range of perception-reaction times. This recommended range between 1.5 to 3.0 seconds is interpreted on the premise that the 2.0 and 2.5 second parameters adopted are inclusive of nearly all drivers in nearly all stopping sight distance scenarios.

The upper value of 3.0 seconds recommended by Hooper and McGee (1983) is applicable for the roadside scenarios, such as intersections and interchanges, which necessitate more complex decisions and where the perception-reaction time required is longer (Hooper & McGee, 1983). The research carried out differs from the research carried out by Hooper and McGee (1983) because it calculates the perception-reaction time in a simulated Level 3 automated vehicle with the driver performing a secondary task.

Given that the perception-reaction time is considered to be extremely important for road design due to safety reasons, thus this research recommends that the average value of unexpected perception-reaction times for scenario P6 and P7 is used for road design when there is a mix of Levels 1, 2 and 3 automated vehicles on the road network where such unexpected perception-reaction time is 4.23 seconds. This is because the P6 and P7 scenarios are the worst case scenarios which resulted from the survey undertaken.

The results obtained in this research for the perception-reaction time, hence 4.23 seconds, exceed the perception-reaction time range as recommended by Hooper and McGee (1983) where such time exceeds the perception-reaction time of 3 seconds for complex decision in complex roadside scenarios for a Level 1 and 2 vehicles. Also this PRT value of 4.23 seconds exceeds the 2 second advance warning time period and confirms the research carried out by Mok et al. (2017) which resulted that a 2 second advance warning is not sufficient for the driver to safely re-engage in the driving task.

However this 4.23 second PRT value is slightly less than the 5 second advance warning established by Gold et al. (2013) and Zhang et al. (2018) whereby the lower limit of 5 seconds was considered to be challenging but manageable for visually distracted drivers to safely resume the driving task. In view of this, it is to be noted that Zhang et al. (2018) also stated that the actual time which the driver requires to resume the control of the vehicle depends on the drivng task and the context of the roadside scenario.

6.1.10 Comparison of Perception-Reaction Time with CEDR, AASHTO, DMRB, Austroads and German Standard (RAA) values

This unexpected perception-reaction time value of 4.23 seconds which resulted from this research is considerably higher than the 2 seconds unexpected perception-reaction time established in the CEDR Report. Using the equation specified earlier, the Sight Stopping Distance values, as based on the CEDR established parameter values, are as follows in Table 43:

Table 43: Stopping Sight Distances in CEDR

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2s and Coefficient of Friction of 0.377										
Recommended SSD by CEDR (m)	26	39	54	71	90	111	135	160	188	217

Source: Weber et al. (2016)

The CEDR SSD values are for Levels 1 and 2 vehicles and are intended to allow sufficient distance to enable the driver to perceive and react in a timely manner to ensure safety. However the SSD values for Level 3 Automated Vehicles, which are being suggested by this research document, are intended to allow sufficient distance to enable the vehicle to alert the operator, engaged in a secondary task, to perceive and react in a timely manner.

Based on the 4.23 seconds unexpected perception-reaction parameter value established by this research, the Coefficient of Friction as established by CEDR and using the formula for the calculation of Sight Stopping Distances, the revised SSD values would be as follows in Table 44:

Table 44: Stopping Sight Distances recommended by this research document

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 4.23s and Coefficient of Friction of 0.377										
Recommended SSD by this Research (m)	45	64	85	108	134	161	190	222	256	291

Therefore the SSD values resulting from the unexpected perception-reaction time resulting from this research are considerably higher than the SSD values established by CEDR. For a speed of 120km/h, the SSD values resulting from this research are 34% higher than those established by CEDR and for a speed of 80km/h, the SSD values are 45% higher. Thus the difference between the SSD values decreases with increased speed because it is only the first part of the SSD model equation that is affected by the unexpected perception-reaction time resulting from this research, where:

SSD=Distance travelled during perception-reaction time + Braking Distance

Thus,

$$SSD = 0.278V_0 t + (V_0^2/254f) \quad \text{……} (19)$$

The second part of the equation remains the same as for the CEDR values because the results obtained from this research affect only the perception-reaction time, t, which is only in the first part of the equation. Given that this research resulted in higher perception-reaction times, hence the distance travelled during perception-reaction stage is longer than for the values of CEDR.

Based on a perception-reaction time of 2.5 seconds and a coefficient of friction which varies according to design speed, the existing SSD values in AASHTO are as follows in Table 45:

Table 45: Stopping Sight Distances in AASHTO

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2.5s and Coefficient of Friction varies between 0.4 for a speed of 30km/h to 0.28 for a speed of 120km/h										
Coefficient of Friction	0.4	0.38	0.35	0.33	0.31	0.30	0.30	0.29	0.28	0.28
AASHTO SSD Existing (m)	29.6	44.4	62.8	84.6	110.8	139.4	168.7	205.0	246.4	285.6

Source: Fambro et al, 1997

Clearly the SSD values resulting from the unexpected perception-reaction time obtained from this research are slightly higher than the SSD values established by AASHTO. For a speed of 120km/h, the SSD values resulting from this research are 1.9% higher than those established by AASHTO and for a speed of 80km/h, the SSD values are 15.5% higher. Similarly to the comparison with the CEDR values, the difference between the SSD values decreases with increased speed because it is only the first part of the SSD model equation that is affected by the unexpected perception-reaction time resulting from this research. However, there is a less marked difference between the AASHTO SSD values and the SSD values resulting from this research because:

i. given that the perception-reaction time of AASHTO is 2.5 seconds, this is greater than the 2 seconds established by CEDR.
ii. for speeds exceeding 40km/h, the coefficient of friction used by AASHTO is less than the 0.377 value used for the calculation of the SSD values based on the perception-reaction time obtained from this research. The higher coefficient of friction results in lower braking distances.

The NCHRP document recommended a revision of the AASHTO SSD values so that they can be based on the below average drivers who detect an unexpected object in the road and stop the vehicle prior to collision (Fambro et al, 1997). The recommended SSD values are as follows in Table 46:

Table 46: Stopping Sight Distances recommended for AASHTO by NCHRP

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2.5s and Deceleration rate as 3.4m/s^2										
AASHTO SSD Recommended (m)	31.0	45.9	63.1	82.5	104.2	128.2	154.4	182.9	213.7	246.7

Source: Fambro et al, 1997

Thus the SSD values resulting from the unexpected perception-reaction time obtained from this research are higher than the SSD values recommended by NCHRP for the AASHTO values. For a speed of 120km/h, the SSD values resulting from this research are 18% higher than those recommended by NCHRP and for a speed of 80km/h, the SSD values are 25% higher.

Thus similarly to the comparison with the existing AASHTO and CEDR values, the difference between the SSD values decreases with increased speed because it is only the first part of the

SSD model equation that is affected by the unexpected perception-reaction time resulting from this research. Thus the recommended parameter value for perception-reaction time of 2.5 seconds results in shorter distances travelled during perception-reaction time than for the results of this research with a time of 4.23 seconds. However, it is to be noted that, in this case, the difference is also due to the fact that the SSD calculation was based on the model using deceleration rate to calculate the Braking Distance as follows:

$SSD = 0.278V_0 t \quad + \quad 0.039(V_0{}^2/a)$

For the CEDR and existing ASSHTO SSD values, the Braking Distance calculation is based on the coefficient of friction. This model was also used to calculate the SSD based on the perception-reaction time resulting from this research.

This unexpected perception-reaction time value of 4.23 seconds which resulted from this research is considerably higher than the 2 seconds unexpected perception-reaction time used in the DMRB values. Using the equation specified earlier, the Sight Stopping Distance values, as based on the DMRB established parameter values, are as follows in Table 47:

Table 47: Stopping Sight Distances in DMRB

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2s and Coefficient of Friction of 0.25										
DMRB SSD values (m)	31	47	70	90	120	145	178	215	252	295

Source: DMRB, 2002

For a speed of 120km/h, the SSD values resulting from this research are 1,4% less than those used by DMRB and for a speed of 80km/h, the SSD values are 11% higher. Thus, except for the SSD values resulting for speeds exceeding 120 km/h, similarly to the CEDR values and AASHTO, the SSD values obtained form this research are higher. Also, although the DMRB calculation takes a perception-reaction time of 2 seconds like CEDR, the coefficient of friction used by DMRB is 0.25 which is much less than the 0.377 value used by CEDR. In this case, the differences between the DMRB SSD values and the SSD values resulting from this research are because:

i. the perception-reaction time used by DMRB is 2 seconds and this is much less than the 4.23 seconds resulting from this research, thus the DMRB results in shorter distance travelled during perception-reaction time;
ii. for all speeds, the coefficient of friction used by DMRB is 0.25 which is less than the 0.377 value used for the calculation of the SSD values based on the perception-reaction time obtained from this research thus the DMRB results in longer braking distance.

This unexpected perception-reaction time value of 4.23 seconds which resulted from this research is considerably higher than the general minimum reaction time of 2 seconds used in the Austroads values. Austroads use the same model equation used for this research document and the Sight Stopping Distance values, as based on the Austroads established parameter values, are as follows in Table 48:

Table 48: Stopping Sight Distances in Austroads

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2s and Coefficient of Friction of 0.36										
Austroads SSD values (m)	27	40	55	73	92	114	139	165	193	224

Source: Fanning, 2016

For a speed of 120km/h, the SSD value resulting from this research is 29.9% more than those used by Austroads and for a speed of 80km/h, the SSD values are 41.2% higher. All the SSD values obtained from this research are higher than those used in Austroads. Also, although the Austroads calculation takes a perception-reaction time of 2 seconds like CEDR, the coefficient of friction used by Austroads is 0.36 which is slightly less than the 0.377 value used by CEDR. In this case, the differences between the Austroads SSD values and the SSD values concluded from this research are because:

i. the perception-reaction time used by Austroads is 2 seconds and this is much less than the 4.23 seconds resulting from this research, thus the Austroads results in shorter distance travelled during perception-reaction time;
ii. for all speeds, the coefficient of friction used by Austroads is 0.36 which is less than the 0.377 value used for the calculation of the SSD values based on the perception-reaction time obtained from this research thus the Austroads results in longer braking distance.

This unexpected perception-reaction time value of 4.23 seconds which resulted from this research is considerably higher than the general minimum reaction time of 2 seconds used in German design standards Richtlinien für die Anlage von Autobahnen (RAA). The Sight Stopping Distance values, as based on the RAA established parameter values, are as follows in Table 49:

Table 49: Stopping Sight Distances in RAA

DESIGN SPEED (km/h)	30	40	50	60	70	80	90	100	110	120
STOPPING SIGHT DISTANCE (m) using Perception Reaction Time as 2.0s and Coefficient of Friction varies between 0.35 for a speed of 60km/h to 0.15 for a speed of 120km/h										
Coefficient of Friction	-	-	-	0.35	0.31	0.28	0.23	0.20	0.17	0.15
RAA SSD Existing (m)	-	-	-	65	85	110	140	170	210	255

Source: Harwood et al., 1998

For a speed of 120km/h, the SSD value resulting from this research is 14.1% more than those used by RAA and for a speed of 80km/h, the SSD values are 46.4% higher. All the SSD values obtained from this research are higher than those used in RAA. Also, although the RAA calculation takes a perception-reaction time of 2 seconds like CEDR, the coefficient of friction used by RAA varies between 0.35 and 0.15 for the higher speed of 120km/h. These values are less than the 0.377 value used by CEDR. In this case, the differences between the RAA SSD values and the SSD values resulting from this research are because:

i. the perception-reaction time used by RAA is 2 seconds and this is much less than the 4.23 seconds resulting from this research, thus the RAA results in shorter distance travelled during perception-reaction time;
ii. for all speeds, the coefficient of friction used by RAA is less than the 0.377 value used for the calculation of the SSD values based on the perception-reaction time obtained from this research thus the RAA results in longer braking distance.

Table 50 (Table 3 reproduced below) summarises the values for SSD assessed above for this research document, CEDR, AASHTO, NCHRP, DMRB, Austroads and RAA.

Table 50: Summary of Stopping Sight Distances for CEDR, AASHTO, NCHRP, DMRB, Austroads and RAA

Criteria	This research	CEDR[1,6]	AASHTO[2]	NCHRP[2]	DMRB[3]	Austroads[4]	RAA[5]
PARAMETERS							
Coefficient of Friction	0.377	0.377	from 0.4 for 30km/h to 0.28 for 120km/h	-	0.25	0.36	from 0.35 for 60km/h to 0.15 for 120km/h
Deceleration Rate(m/s^2)	-	-	-	3.4	-	-	
Perception-Reaction Time(sec)	4.23	2.0	2.5	2.5	2.0	2.0	2.0
DESIGN SPEED	Stopping Sight Distance						
30	45	26	29.6	31.0	31	27	-
40	64	39	44.4	45.9	47	40	-
50	85	54	62.8	63.1	70	55	-
60	108	71	84.6	82.5	90	73	65
70	134	90	110.8	104.2	120	92	85
80	161	111	139.4	128.2	145	114	110
90	191	135	168.7	154.4	178	139	140
100	222	160	205.0	182.9	215	165	170
110	256	188	246.4	213.7	252	193	210
120	291	217	285.6	246.7	295	224	255

Sources: Weber et al. (2016)[1], Design Manual for Roads and Bridges (2002)[3], Fambro et al (1997)[2], Fanning et al (2016)[4], Harwood et al (1998)[5], Petegem et al (2014)[6].

Besides the difference in the coefficient of friction adopted for the calculation of stopping sight distances by CEDR, DMRB, AASHTO, NCHRP, Austroads and RAA, the perception-reaction times also differ. CEDR, DMRB, Austroads and RAA use a 2 second perception-reaction time whilst AASHTO and NCHRP use a 2.5 second value. In the NCHRP report, it is stated that the 90th and 95th percentile perception-reaction times to an unexpected hazard on the roadside were approximately 2.0 and 2.5 seconds respectively (Fambro et al, 1997). These values allow for the capabilities of most vehicle drivers, including elderly drivers (Fambro et al, 1997).

Although the 2.5 second perception-reaction time results in longer sight stopping distances however such 2.5 second value is established in AASHTO and the NCHRP recommends that it should be retained (Fambro et al, 1997). However the NCHRP report also states that where the road geometry requires other design control measures to ensure safety, a longer perception-reaction time is to be adopted (Fambro et al, 1997).

This is applicable to the objective of this research document and the results obtained therein whereby other design control measures are required to meet the road safety challenges posed by a mix of Levels 1, 2 and 3 automated vehicles operating on the road concurrently. The results of this research show that for Level 3 automated vehicles 4.23 seconds perception-reaction time is required for the driver to resume the driving task.

This value exceeds the perception-reaction time values of the design guidelines referred to above with which the comparisons have been made and referred to. It also confirms the validity and the importance of the results of this research document. In the event that the existing design standards for SSD are retained, such distances would not be sufficient to allow for the driver to resume the driving task in a timely manner.

The technology for automated vehicles is developing faster than what the existing road infrastructure can adapt to (Lombardo, 2018). This is because if the SSD is not sufficiently long, irrelevant of the amount of ultrasonic, radar, imaging and LiDAR sensors, the automated vehicle would still identify a critical scenario within a distance which is not sufficiently long to allow for the vehicle to give the alert and for the driver to perceive the alert and react accordingly.

Such scenarios are created on a daily basis. Permanent and fixed challenging roadside scenarios are memorized in the vehicle's digital road map and the distance ahead of alerting the driver is to be programmed according to the perception-reaction times required to ensure that the driver resumes the driving task in a timely manner. Therefore such programmed perception-reaction times and their corresponding SSD should reflect the results of this research document. It is clear as described above that these times exceed the values in established and existing standard specifications.

However, the unexpected roadside scenarios pose a different challenge. An example of the most critical challenges are road works, low-angle sunlight causing glare, unexpected incidents, obstructions and fast-approaching emergency vehicles (Oliver et al, 2018; Public Sector Consultants & Centre for Automotive Research, 2017). Such unusual and unstructured scenarios make it difficult for the automated vehicle technology to classify (Oliver et al., 2018). Processes and road side environments which are structured are easier to automate than ambiguous environments and it is recognised that many driving environments are the latter (Oliver et al., 2018).

The engineers designing the automated vehicle technology cannot forecast every possible combination of scenarios which can happen on the road (Oliver et al, 2018). These scenarios show the importance of vehicle to infrastructure technology. Such technology is imperative so that the information is transmitted to automated vehicles wirelessly and in real time to ensure that the whole roadside operations are carried out safely, accurately and reliably, within the context of many different situations and conditions (Lombardo, 2018; Public Sector Consultants & Centre for Automotive Research, 2017).

It is to be emphasized that as the automated vehicle technology becomes more refined and developed, the roadside scenarios which require human intervention will be more complex, ambiguous and difficult to address thus placing more demand on the human perception-reaction time (Oliver et al, 2018).

Automated vehicle technology is based on the concept of the learning process which takes place in the automated vehicles where once an incident has occurred on the road and has been understood by the vehicles, the fix can be rolled out across all vehicles (Oliver et al., 2018). Even at this stage, the fix being relayed across all vehicles needs to occur in a timely manner to enable the driver to resume the driving task, if the scenario so requires, and this will depend on the perception-reaction times established in this research document. This is a radically different concept of traffic management which will also revolutionise the way Road Traffic Control Centres operate. These centres will be collecting and processing aggregate data from infrastructure and automated vehicles (Public Sector Consultants & Centre for Automotive Research, 2017).

Such Traffic Control Centres will depend on roadside units which will transmit and receive data from nearby automated vehicles (Public Sector Consultants & Centre for Automotive Research, 2017). Such road side units will be comprised of a processor, data storage and communication systems (Public Sector Consultants & Centre for Automotive Research, 2017).

Also, a secure communications network between the Traffic Control Centre, the road side units and the vehicles is necessary to eliminate the risk of hacking and such data being transmitted will be voluminous (Public Sector Consultants & Centre for Automotive Research, 2017). This is because cyber attacks are becoming more frequent and Internet-of-Things devices are the most vulnerable (Sohrweide, 2018). However the most problematic would be a hack in the automated vehicle system and hence it is important to make them hacker-proof (Sohrweide, 2018).

6.2 Summary of Conclusions

6.2.1 Summary of Person-Specific Characteristics in relation to Perception-Reaction Times

The above review of the web-survey data obtained can be summarized in points as follows:

1. Maltese EU Citizens are scoring significantly higher perception-reaction times than the Maltese in the P2 and P3 scenarios only (control scenarios without an in-vehicle distraction). There was no significant difference for the P4, P5, P6 and P7 scenarios;
2. Females scored significantly higher perception-reaction times for the P4 scenario only however when gender and age are combined, both these two predictors are statistically significant and that for the P2, P3 and P6 scenarios there is a perfect distinction between males and females.
3. The perception-reaction time increased with age and years of driving experience, which are correlated, except for the P7 scenario where there was no significant difference;
4. The perception-reaction time was lowest for the younger age groups for all scenarios; Similarly, for each scenario, the Cluster Analysis revealed that the 18-30 year age group is statistically significant and formed one or more clusters in each scenario;
5. With regards to the scenarios having a distraction, there was no significant difference in the perception-reaction time between the disabled and non-disabled groups of participants;
6. The perception-reaction times obtained for the different scenarios are as follows in Table 51 (Table 41 reproduced) hereunder:

Table 51: Results of Web-based Survey showing Perception-Reaction Time, Type of Alert and Type of Distraction for the Different Driving Scenarios

Driving Scenario	**85th Percentile Unexpected Perception-Reaction Time**	**Type of Alert**	**Type of Distraction**
P2	4.19	Visual	No distraction. Control
P3	3.63	Visual & Auditory	
P4	3.69	Visual	Watching a video. Cognitive, visual & auditory.
P5	3.45	Visual & Auditory	
P6	4.06	Visual	Typing & Reading a Text Message. Cognitive, visual & biomechanical.
P7	4.40	Visual & Auditory	

The above table shows that:

i. the multi-sensory alert gave lower perception-reaction times for the P2, P3, P4 and P5 scenarios;
ii. the multi-sensory alert had a longer perception-reaction time for the P7 scenario than for the P6 scenario. This is because there are higher demands on the cognitive resources of the participants results in causing the perception-reaction performance to degrade thus resulting in higher perception-reaction times.
iii. it is thus also being suggested that the audio-visual alert advantage over the visual alert is effective only up to the point determined by the demand on the cognitive resources of the participant where, in this research, this point was reached for the reading and typing of a text message distraction.

7. The red hue of the visual alert box was adequate for the survey because it reduces visual-choice reaction and reduces processing time;
8. The perception-reaction times obtained for the predictors collectively (Gamma Regression Model) were as in Table 52 hereunder:

Table 52: Summary of Results of the Gamma Regression Model showing Significant Predictors

Scenario	Predictors for Average Perception-Reaction Time				
	Age	Gender	Driving License	Driving Experience	Country of residence
P2	Not significant	Not significant	Not significant	<10yrs PRT < 41+yrs	Maltese PRT > other EU
P3	<30yrs PRT < 61+yrs	Males PRT < females	Not significant	Not significant	Not significant
P4	<30yrs PRT <61+yrs	Males PRT < females	Licensed PRT < non-licensed	Not significant	Not significant
P5	Not significant	Males PRT < females	Not significant	<10yrs PRT < 41+yrs	Not significant
P6	<30yrs PRT <61+yrs	Not significant	Not significant	Not significant	Not significant
P7	Not significant	Not significant	Licensed PRT > non-licensed	<10yrs PRT < 41+yrs	Maltese PRT < other EU

These results showed that:

i. gender is not a significant predictor when the distraction is reading and typing and sms
ii. multi-sensory alert reduce gender difference in relation to perception-reaction time
iii. the age and driving experience predictors complement each other having one or the other results as a significant predictor in all scenarios. Similarly, age was found to be a significant predictor in the Cluster Analysis;
iv. the younger age groups have lower perception-reaction times for all scenarios than their older counterparts both for different alerts (and same secondary task) and for same alerts (but different secondary task). Similaly, for all scenarios in the Cluster Analysis, the younger age group/least driving experience group have shorter average perception-reaction times than their older counterparts. This is also reflected in the results obtained in the Ordinal Regression Model;

6.2.2 Summary of Guidelines for Perception-Reaction Times for This Research and for Different Countries

a. Perception-Reaction Times Adopted in Design Guidelines of Different Countries

The importance of the perception-reaction time arises because it determines the total time for a driver to see an object, to identify it as an accident risk, to decide on the action to take and to start the action itself. The minimum stopping sight distance on the road is to be long enough to enable a vehicle travelling at the design speed to come to a stop before colliding with an object. All standards use a fixed perception-reaction time which is 2 seconds for DMRB, CEDR, Austroads and RAA and 2.5 seconds for AASHTO and NCHRP and this means that the model is not sensitive to the actual behaviour of a human where this value would probably change depending on the vehicle speed and type of roadside scenario.

b. Use of 85th Percentile Perception-Reaction Time in Design Guidelines of Different Countries

The perception-reaction time varies from one driver to another because it is person specific and hence it is defined by a distribution and not by a fixed value. For the scope of this research document, the perception-reaction time of 4.23 seconds was established as the 85th percentile values of the data sets.

c. Comparison of Perception-Reaction Time with CEDR, AASHTO, DMRB, Austroads and RAA values

The following Table 53 (Table 50 reproduced) hereunder, is a summary of the SSD values for the different standards and parameters being reviewed as follows:

Table 53: Summary of Stopping Sight Distances for CEDR, AASHTO, NCHRP, DMRB, Austroads and RAA

Criteria	This research	CEDR[1,6]	AASHTO[2]	NCHRP[2]	DMRB[3]	Austroads[4]	RAA[5]
PARAMETERS							
Coefficient of Friction	0.377	0.377	from 0.4 for 30km/h to 0.28 for 120km/h	-	0.25	0.36	from 0.35 for 60km/h to 0.15 for 120km/h
Deceleration Rate(m/s^2)	-	-	-	3.4	-	-	
Perception-Reaction Time(sec)	4.23	2.0	2.5	2.5	2.0	2.0	2.0
DESIGN SPEED	Stopping Sight Distance						
30	45	26	29.6	31.0	31	27	-
40	64	39	44.4	45.9	47	40	-
50	85	54	62.8	63.1	70	55	-
60	108	71	84.6	82.5	90	73	65
70	134	90	110.8	104.2	120	92	85
80	161	111	139.4	128.2	145	114	110
90	191	135	168.7	154.4	178	139	140
100	222	160	205.0	182.9	215	165	170
110	256	188	246.4	213.7	252	193	210
120	291	217	285.6	246.7	295	224	255

Sources: Weber et al. (2016)[1], Design Manual for Roads and Bridges (2002)[3], Fambro et al (1997)[2], Fanning et al (2016)[4], Harwood et al (1998)[5], Petegem et al (2014)[6].

The above table yields the following conclusions:

i. The perception-reaction time in a Level 3 Automated Vehicle is greater than the perception time in a Level 1 and 2 vehicles for all standards adopted in road design and accident investigation;
ii. From the existing guidelines and standards for SSD, DMRB have the longest SSD because they adopt a lower coefficient of friction;
iii. The AASHTO SSD values are slightly less than those for DMRB because they adopt a greater coefficient of friction. Although the perception-reaction time is greater however it affects only the first part of the model equation to establish the time travelled during perception-reaction time;
iv. NCHRP recommends amendments to the AASHTO standards and such changes to the parameters resulted in lower SSD;
v. The SSD for CEDR are the lowest distances which were examined in this report because the parameters consist of the highest coefficient of friction and the lower perception-reaction time. This thus resulted in both lower distances travelled during perception-reaction time and lower braking distances;
vi. The results obtained for the perception-reaction time parameter in this research resulted in the longest SSD values except for the SSD at and above 120km/h which are slightly less than those for DMRB;
vii. The greatest difference in SSD values between the values established through this research and other established values are most prominent for speeds of and exceeding 80km/h. These values are the most critical as they are the SSD values which lie beyond

the visual capabilities of the driver for detecting small during daytime and for detecting larger objects with low contrast at night-time;

viii. The SSD values established by this research document exceed the values in the existing standards and guidelines except for the SSD value in DMRB for a design speed of 120km/h. However, if a lower coefficient of friction were to be used to establish the recommended SSDs for this research document, the distances would considerably exceed the DMRB values.

The results of this research show that for Level 3 automated vehicles 4.23 seconds perception-reaction time is required for the driver to resume the driving task and this value exceeds the perception-reaction time values of the design guidelines referred to above. This confirms the validity and the importance of the results of this research document. If the existing design standards for SSD are retained, such distances would not be sufficient to allow for the driver to resume the driving task in a timely manner.

6.3 Limitations of this Research Document

The research which was carried out focussed on the impact of the distraction created by a secondary task, other than driving, on the perception-reaction time of a driver in a Level 3 automated vehicle.

Due to the limitations of the software used to create the web-based survey, the 85th Percentile with SPSS only got whole numbers because the raw data comprised of discrete values. To resolve this problem, the z-score method was used to calculate the 85th Percentile perception-reaction time.

The research was carried out using a motionless web-based survey which simulated the driving scenario in a Level 3 vehicle with a filmed driving video during which two types of alerts appear (a red button and a red button with a sound signal) and was not actually a driving simulation survey. The web-based survey had the advantage of the possibility of reaching more potential survey participants than when participants need to be summoned to the location of the driving simulator. Hence, given the nature of the data which needed to be collected, a web-based survey was the most convenient option however this created the constraint that participants had to have access to the internet to be able to participate in the survey.

As with all studies which are not carried out on the road, there are concerns and reservations regarding the validity of the results obtained when these are compared to the real driving scenario. With the use of the web-based survey, the survey participants failed to experience the acceleration, deceleration and braking inputs. Therefore the web-based survey might have altered the degree of relevance of these factors. It is also to be noted that with the web-based survey, the survey participant is aware that there is no consequence of a traffic accident in a virtual environment and hence the participant might not appreciate the urgency of hazards which would thus affect the perception-reaction times. To address this aspect, the ideal would be that the results of the research would be compared with similar on-road studies.

However, it is also to be noted that the nature of such research, if carried out on the real road, would pose a number of accident risks. The closest on-road study identified in the Literature Review was the research which was carried out by Cooper et al (2011). It involved driving on the real road however, for safety reasons, such was carried out in a controlled closed track. The results of this research document were generally in agreement with the results obtained by Cooper et al (2011). Due to the safety risk involved in on-road studies, very few such on-road studies are carried out.

It was important to limit the duration of the web-survey so as not to discourage potential participants (Andrews et al., 2003). For this reason, trial survey runs were designed in the survey itself and the first two scenarios, namely P2 and P3, acted as both the trail run for the participants and also as the control because they did not involve a distraction. Another issue with the survey total duration time was that, besides the control, only two different secondary tasks were identified, namely watching a video and reading and writing a text message. These two types of secondary tasks acting as the distraction were identified because, from the Literature Review carried out, it resulted that they were the most common causes for driver distraction (Singh, 2010). However, there are potentially other types of secondary tasks causing driver distraction in a Level 3 automated vehicle which were not investigated. It is also to be noted that the web-based survey itself posed constraints on the type of distractions which could be simulated.

The web-based survey posed another constraint which was of great importance to this research document. Given that the survey would be taken by participants on their computers or on their hand held devices, the survey could have been performed using a mouse, a touchpad or a smartphone. It was not possible to establish which method was used by the survey participants and hence such differences in the undertaking of the survey is a limitation in the survey itself. Also, the only alerts which were possible were the visual and auditory alerts. Also it was not possible to run the survey with only the auditory alert because the visual alert was actually part of the system where the participant registers the reaction carried out by pressing the red box. This red box acted as the visual alert and also acted as the reaction made by the participant. It was not possible to create a haptic alert however research carried out by Lee et al (2004) suggested that:

i. the participants involved in their research had perceived that the haptic type of alert was more effective than the graded or single stage auditory alert;
ii. from the two experiments carried out by Lee et al (2004), it was concluded that, when alerted by the collision warning system, the type of alert used had very little affect on the response of the drivers where they responded similarly to both haptic and auditory alerts.

The participants were unsupervised when they were participating in the survey and thus it is not known if the participants were actually performing other secondary tasks during the participation in the survey which may have influenced the results. In the survey scenario where the participant is watching a movie whilst driving, it was not possible to ascertain that the participant was actually indeed watching the movie video and not the driving video.

Given that the survey was unsupervised posed another limitation because, as a result, it was mandatory that the participants were informed before taking the survey of how the survey would work. This was inevitable as otherwise the participants would not understand what was expected from them. However such explanation also resulted in that the participants were expecting an alert and hence the data recorded was for EXPECTED perception-reaction times and not for SURPRISE perception-reaction times. This limitation was addressed by using the Surprise Correction Factor established by Johansson and Rumar (1971).

The web-based survey posed another issue which was related to the time which the data traveled between the survey participant and the servers where the survey data was stored. This transmission time was inevitably part of the PRT registered in the survey. Although the data is transmitted through the cell phones by radio waves, at some point, such data still needs to go through the wired networks of the Internet which are made up of fiber optic cable, coaxial cable or twister pair (Johnson, 2012). The fiber optic cable provides the fastest transmission because it is not effected by electromagnetic interference (Johnson, 2012).

Other factors which may be a cause of signal latency are the back and forth communication required when you access then a Web page is accessed and the download data (Johnson, 2012). There is also a brief necessary delay due to the communication between the device being used by the survey participant with the server where the data was being stored (Johnson, 2012). This happens to ensure synchronisation of the systems and also to ensure that the data has been transferred successfully (Johnson, 2012). The distance over which the data needed to be transferred also effected the time to arrive at the servers and there might have been bottlenecks at any hardware and witing which the data had to be transmitted through before reaching destination (Johnson, 2012).

The Convenience Sampling technique was used to recruit survey participants. It is to be noted that it was possible to use Convenience Sampling in this scenario because no additional inputs were necessary for the main research following the data collected from the survey (Bhat, 2020). This sampling method may pose a number of disadvantages which include sample bias, where the sample does not accurately represent the entire population and limitation in generalization (Bhat, 2020). To allow for this limitation, the following considerations were considered:

1. Collecting a relatively larger sample of data. The larger sample of data controls uncertainty and bias in Convenience Sampling (Skowronek, 2009). In the majority of the research studies evaluated in the literature review, the data sample did not exceed 50 participants, however, in the case of this research the data sample consisted of a total of 514 survey participants.
2. Diversification by distributing the questionnaires using different methods which included email invites, distribution through organizations, social media and adverts in a newsportal. Hence survey participants were recruited from multiple sources. It is recognised that diversity strengthens a Convenience Sample (Skowronek, 2009).

However, in spite of the above measures to improve the sample, such sample collected resulted that the proportion of the survey replies for the 61+ age group was smaller than the demographic proportion. The sample cohort for 61+ years was small because the survey was distributed in Maltese government departments at the places of work where the retirement age is 61 years and also because this was a web-based survey which required internet access and was thus distributed on social media where users are more likely to be younger in age. It was evident from the statistical results that the mean reaction time increased considerably for the 61+ age group. Despite that the size of this older cohort was smaller than expected, the statistical tests still yielded significant differences in the mean reaction times. It is well known that statistical inference improves when the sample size is increased and it is very likely that the p-value decreases further if a larger sample is considered, given that the mean reaction time and standard deviation remain the same.

One of the biggest challenges for this research to be carried out was the limited literature available on the perception-reaction times in Level 3 automated vehicles and also any other literature involving the automated vehicles themselves. Very few books were available and the literature was mostly obtained from papers and articles. This was expected at the onset of the research since automated vehicles are still at their infancy stage. Hence, much of the information which was found was related to studies carried out on Levels 1 and 2 automated vehicles. However, since the functions of the human body and brain are not different in a Level 3 automated vehicle, most research related to driver distraction and perception was adaptable and transferrable.

6.4 Recommended Further Research

The research carried out as part of this document was based on data obtained through a web-based survey which simulated a driver distracted by a secondary task and alerted to resume the driving task. This simulation, using a computer programme, allowed for the administration of repeated distraction and alert scenarios in a controlled environment to understand the perception-reaction time of drivers in relation to the secondary tasks afforded by automation. It also facilitated distribution of the survey itself thus participants were not required to visit the location of a driving simulator. However further research using field studies in the real roadside environment will improve our understanding of the performance of drivers with these technological advancements in vehicles, including their trust and endorsement of automated vehicles and the risks which are perceived (Merat et al, 2014).

This research document analysed how auditory and visual alerts affect perception-reaction times in a Level 3 automated vehicle when the driver is distracted with a secondary task other than driving. The data was collected through a web-based survey which only permitted the creation of a visual only alert and a combination of a visual and auditory alert. Haptic alerts are potentially an effective alternative to auditory alerts which may reduce the perception-reaction time and the alert annoyance (Lee et al, 2004). Haptic alerts were shown to be more effective than visual alerts in alerting pilots to mode changes in cockpit automation showing that haptic alerts are an effective alert in 'event-driven and information-rich situations' (Lee et al, 2004).

Research carried out by Lee et al (2004) in the driving scenario showed that haptic alerts were preferred to auditory alerts. It is therefore recommended that further research is carried out to examine the benefits of haptic alerts in respect of the impact on perception-reaction time of a driver engaged in a secondary task in an automated vehicle. This is especially important because the results of this research document suggest that the effectiveness of the alert depends on the level of cognitive demand created by the secondary task (distraction). This is because human beings have finite attention resource capacity and thus adding information processing tasks and competing with the same sensory modality results in a reduction of efficiency and an increase in errors (Dulas, 1994).

The results for the perception-reaction time of this research document were used to recommend the revised sight stopping distances for level terrain to accommodate a mix of Level 1, 2 and 3 automated vehicles on the road network. However sight stopping distances are also required for vertical curves and for offsets through horizontal curves (Neuman 1989). Thus further research is recommended to examine the impact of Level 3 automated vehicles on sight stopping distances of vertical curves and offset through horizontal curves.

Also, existing sight stopping distances do not properly make allowance for the inefficiencies in the braking systems and operation of heavy vehicles (Hooper & McGee, 1983). This includes the sight stopping distance recommended in this research. Based in research carried out by Hooper & McGee (1983), it is suggested that heavy vehicles are unable to come to a stop within the existing sight stopping distances. Thus it is recommended that further research is carried out in relation to the characteristics of heavy vehicles and their braking efficiency. This is extremely important especially when higher levels of vehicle automation are integrated in heavy vehicles and platooning systems have become operational on the public roads.

Throughout this research document the perception-reaction times and sight stopping distances being recommended did not make a distinction between their use for the design of new roads and their use for the reconstruction of existing roads. Hence, a revision of sight stopping distances to accommodate a mix of Levels 1, 2 and 3 automated vehicles creates considerable impact on design, expenditure and work programmes. It is recommended that further research is carried out on the impact of the recommended revisions in relation to the effect on road reconstruction projects whereby the main challenge will be related to the road alignments which must be either re-aligned, re-constructed or where a design exception is necessary. This impact will create other issues which include additional costs, thus more strain on budgets, and work programmes. Ignoring such road alignment adjustments might expose road authorities and/or agencies to liability issues (Neuman, 1989) especially since legislation generally places the responsibility for road safety on the national road authorities/agencies.

The study carried out by Merat et al (2014) showed that drivers need about 40 seconds to resume stable and appropriate control of driving when they engage in the driving task from automation. This 40 seconds tie period follows the perception-reaction time period which was evaluated in this research document. The report by NHTSA (2013) considers these 40 seconds as a 'comfortable transition time' in their guidelines on Level 3 automated vehicles. Further research is needed to examine how this 40 seconds time period required to resume adequate driving control affects the situation awareness of the driver and the ability to manage unexpected situations which the automated technology in the vehicle would not be able to manage.

The existing road network poses the biggest challenge to the deployment of Level 3, 4 & 5 automated vehicles due to faded line markings, damaged road signage, damaged street lighting and other deficiencies which have compelled the car industry to further develop the automated vehicle sensor technology and mapping system to address such deficiencies (Major, 2016). Automated vehicles rely on cameras, sensors, radars and laser-mapping to determine their location and they utilize the pavement markings to comprehend the roadside scenario however the quality and consistency of such markings can differ from one location to another (Vock, 2016).

Better standardisation of road signs, markings, lighting, more consistent road design and structures are needed to facilitate readability by the vehicle technology (Whitelaw-Jones, 2016). According to Hardin (2016), having consistency in road markings is important for the autonomous vehicle industry however this could be a considerable challenge because of the difference between highways, arterial and distributor road and local roads.

During a debate hosted by PubAffairs Bruxelles on connectivity and digitalization of motor vehicles in Europe, the audience seemed to agree that European countries are less advanced than the United States in relation to the changes to the infrastructure which is needed to meet the technological advancement of automated vehicles (The Self-Driving Convo, 2016). Further research is recommended to be carried out to address the issue regarding the standardisation of road signage and line markings and to further examine the necessary adjustments to specifications of road design standards because these are required for the safe operation of automated vehicles.

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Appendix 1: Road Accidents and Incidents encountered during Google Testing

May 2010 (Google, May 2015)

An accident occurred on the Central Expressway in Mountain View, California. The vehicle was a Google Prius model automated vehicle and it was operating in manual mode by a test driver. The AV stopped at a traffic light intersection in Ferguson Drive and was rear-ended by an approaching vehicle. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

August 2011 (Google, May 2015)

An accident occurred on Charleston Road in Mountain View, California. The vehicle was a Google Prius model automated vehicle and it was operating in manual mode. The AV was not being used as part of the testing programme by a test driver but it was being used by an employee to run an errand. The AV rear-ended a vehicle that was stopped in traffic. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

October 2012 (Google, May 2015)

An accident occurred on Amphitheatre Parkway in Mountain View. The vehicle was a Google Prius model automated vehicle and it was operating in automated mode. The AV stopped at a traffic light junction and was rear-ended by an approaching vehicle. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

December 2012 (Google, May 2015)

An accident occurred on Highway 101S in Mountain View near the Moffett exit. The vehicle was a Google Lexus model automated vehicle and it was operating in manual mode. The AV was being operated in a roadside scenario whereby a disabled vehicle and emergency vehicles were stationary in the hard shoulder. The AV was rear-ended by a vehicle approaching at approximately 40km/h. No injuries were sustained by the persons in the vehicles. The rear part of the AV incurred some damage.

March 2013 (Google, May 2015)

An accident occurred on highway 680S in San Jose. The vehicle was a Google Lexus model AV and it was operating in automated. The AV was moving at about 70km/h and another vehicle, which was traveling in the adjacent right hand lane, veered into the side of the AV. On collision, the test driver assumed manual control by operating the steering wheel. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

October 2013 (Google, May 2015)

An accident occurred on Rengstorff Avenue in Mountain View. The vehicle was a Google Lexus model automated vehicle and was operating in manual mode. The AV was moving a less than 5km/h and was slowing to a stop at the approach to an intersection. The AV was rear-ended by an approaching vehicle. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

March 2014 (Google, May 2015)

An accident occurred on Highway 101N near Belmont. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was stationary in traffic and it was rear-ended by an approaching vehicle which was, in turn, originally hit from behind by another vehicle. No injuries were sustained by the persons in all of the three vehicles. The AV incurred some damage.

July 2014 (Google, May 2015)

An accident occurred on Phyllis Avenue in Mountain View. The vehicle was a Google Lexus model AV and it was operating in manual mode. The Google AV was stationary and was about to turn right into Grant Avenue. An approaching vehicle collided with the rear bumper of the AV. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

February 2015 (Google, May 2015)

An accident occurred at the junction of El Camino Real c/w View Street. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was traveling in a northbound direction in El Camino Real and another vehicle, which was traveling in a westbound direction, did not stop at the stop sign when it came to the junction. The AV was hit at the right rear quarter panel and on the right rear wheel. The AV's automated technology had detected the approach speed and direction of travel of the other vehicle and had responded by having started to apply the brakes. Moments before the collision, the test driver of the AV engaged in manual control in response to the braking operation of the AV technology. Thus the AV was in manual mode at the moment of the collision. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

April 2015 (Google, May 2015)

An accident occurred at Mountain View at the traffic light junction between Castro Street c/w El Camino Road. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was proceeding northbound in the outer lane of Castro Street and stopped at the red light at the intersection of Castro Street c/w El Camino Road. Whilst the AV was turning right, it detected an eastbound approaching vehicle on El Camino Road. The AV stopped to yield to the approaching vehicle. The vehicle which was approaching the AV from behind did not brake and collided with the AV bumper at approximately 8km/h. No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

April 2015 (Google, May 2015)

An accident occurred at the traffic light junction of California Street c/w Shoreline Boulevard in Mountain View. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV stopped at a red light at the intersection. Another vehicle tried to overtake the AV from the right-hand side brushed lightly against one of the sensors on the AV located on the mirror on the driver's side of the vehicle. No injuries were sustained by the persons in the vehicles. The AV did not incur any damage to the body and nor to the sensor.

May 2015 (Google, May 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 9 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 1627591 km
- In manual mode: 1281440 km
- Average automated driving on public streets in one week: 16000 km

Road Accident:

An accident occurred at a traffic light junction at Shoreline Boulevard c/w El Camino Road in Mountain View. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was travelling southbound and was stationary in queue at a red light at the traffic light junction. A vehicle proceeding from behind, at about 2km/h, collided with the rear bumper and sensor of the AV. No injuries were sustained by the persons in the vehicles. The AV incurred some damage to its rear sensor and bumper.

June 2015 (Google, June 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 25 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 1702625 km
- In manual mode: 1313836 km
- Average automated driving on public streets in one week: 16000 km

4 June 2016 (Google, June 2016)

Road Accident:

An accident occurred at the traffic light junction of California Street c/w Rengstorff Avenue. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was stationary and was rear-ended by a vehicle approaching at a speed less than 1 km/h No injuries were sustained by the persons in the vehicles. The AV incurred some damage.

18 June 2015 (Google, June 2015)

Road Accident:

An accident occurred at the traffic light junction of California Street c/w Bryant Street. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was stationary at the red light on the straight-ahead only lane. A vehicle located behind the AV moved at about 6km/h and proceeded to turn left and hit the rear bumper of the AV. No injuries were sustained by the persons in the vehicles. The AV incurred some damage to the rear bumper.

1 July 2015 (Google, July 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 25 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 1772163 km
- In manual mode: 1355230 km
- Average automated driving on public streets in one week: 16000 km

Road Accident:

An accident occurred at the traffic light intersection of Phyllis Avenue c/w Martens Avenue. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was moving at about 17km/h and decelerated to a stop at the red light. The vehicle approaching from behind was traveling at about 20km/h and failed to decelerate and stop and collided with the AV. The driver, co-driver and rear passenger of the AV reported whiplash whilst the driver approaching from behind reported minor neck and back pain. The AV incurred some damage to the rear bumper whilst the other vehicle had considerable damage to the front section.

20 August 2015 (Google, August 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 25 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 1864937 km
- In manual mode: 1412162 km
- Average automated driving on public streets in one week: 16000 km

Road Accident:

An accident occurred at the intersection of Shoreline Boulevard c/w High School Way in Mountain View. The vehicle was a Google Lexus automated vehicle and was operating in automated mode. As the AV approached the intersection, a pedestrian started to cross on the pedestrian crossing. The AV slowed down and the driver engaged in manual mode. A vehicle approaching from behind at about 15km/h was changing lanes and rear-ended the AV. The AV test driver reported minor back pain. The AV incurred some damage to the rear left bumper. The other vehicle incurred moderate damages to the front part of the vehicle.

September 2015 (Google, September 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 25 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 1948394 km
- In manual mode: 1466518 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

None for the month of September 2015.

October 2015 (Google, October 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 25 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 12040822 km
- In manual mode: 1510564 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

None for the month of October 2015.

2 November 2015 (Google, November 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 30 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2125549 km
- In manual mode: 12538164 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

An accident occurred at the traffic light junction located at Clark Street c/w El Camino Road in Mountain View. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode and traveling northbound along Clark Street. The AV was stationary at the red light. A vehicle approached from behind and rear-ended the AV at an approach speed of about 5km/h. No injuries were sustained by the persons in the vehicles. The AV incurred some damage to the passenger side headlight, vehicle hood, and front bumper.

December 2015 (Google, December 2015)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 30 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2208299 km
- In manual mode: 1561691 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

None for the month of December 2015.

January 2016 (Google, January 2016)

Vehicles being tested on the roads:

- 22 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 33 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2284741 km
- In manual mode: 1591521 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

None for the month of January.

14 February 2016 (Google, February 2016)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 33 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2337052 km
- In manual mode: 1637427 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

An accident occurred at El Camino Road. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV pulled to the right-hand lane to prepare for a right-hand turn. The AV came to a stop because there were sand bags along a storm water drain under repair. After waiting for other vehicles to pass, the AV moved towards the centre of the lane and collided with the side of a bus which was traveling at about 18km/h. The AV had detected the bus however the AV had predicted that the bus would yield as the AV was ahead of it. Further to this accident, the AV software was reviewed whereby it has been programmed that buses and larger vehicles are less likely to yield to an AV. No injuries were sustained by the persons in the vehicles. The AV incurred damage to the left front fender, the left front wheel and to one of the sensors on the driver’s side.

14 March 2016 (Google, March 2016)

Vehicles being tested on the roads:

- 21 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 33 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2411142 km
- In manual mode: 1683995 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

An accident occurred at the traffic light junction at W. Anderson Lane c/w Burnet Road in Austin. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. The AV was stationary behind traffic at a red light and was rear-ended by a vehicle approaching from behind at seed of 16km/h. No injuries were sustained by the persons in the vehicles. The AV incurred some damage to the rear bumper whilst the other vehicle incurred moderate damage to the front bumper.

April 2016 (Google, April 2016)

Vehicles being tested on the roads:

- 23 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2518593 km
- In manual mode: 1747374 km
- Average automated driving on public streets in one week: 16000-24000 km

7 April 2016, (Google, April 2016)

Road Accident:

An accident occurred at the traffic light junction at Bryant Street c/w Oregon Expressway in Palo Alto. The vehicle was a Google Lexus model automated vehicle and was operating in automated mode. The AV was stationary behind traffic at the red light. A vehicle tried to pass on the right shoulder of the AV grazing the passenger side of the AV. No injuries were sustained by the persons in the vehicles. The AV did not incur any damage.

28 April 2016 (Google, April 2016)

Road Accident:

An accident occurred at the intersection between Nita Avenue c/w San Antonio Road in Palo Alto. The vehicle was a Google self-driving prototype vehicle and was operating in automated mode. The prototype stopped at the intersection prior to making a right-hand turn. The prototype vehicle stopped to yield to traffic approaching from the left. A vehicle proceeding from behind at about 12km/h rear-ended the prototype vehicle. No injuries were sustained by the persons in the vehicles. Both vehicles incurred minor damage.

May 2016 (Google, May 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2646009 km
- In manual mode: 1803289 km
- Average automated driving on public streets in one week: 16000-24000 km

Road Accident:

An accident occurred at Latham St. in Mountain View in the vicinity of the junction at Chiquita Ave. The vehicle was a Google self-driving prototype vehicle traveling in manual mode. The prototype vehicle was traveling at 14km/h when it collided with the central strip No injuries were sustained by the person in the vehicle. The AV incurred minor damage.

June 2016 (Google, June 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2777585 km
- In manual mode: 1865103 km
- Average automated driving on public streets in one week: 24000-27000 km

6 June 2016 (Google, June 2016)

Road Accident:

An accident occurred at Berkman Drive north of 51st Street in Austin, Texas. The vehicle was a Google prototype automated vehicle and was operating in automated mode. A vehicle crossed into the lane of the AV and collided slightly with the side. No injuries were sustained by the persons in the vehicles. Both vehicles incurred minor damage.

15 June 2016 (Google, June 2016)

Road Accident:

An accident occurred at the traffic light junction at Berkman Drive c/w 51st Street in Austin, Texas. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV was stationary at the red light and was rear-ended by another vehicle approaching at a speed of 5km/h. No injuries were sustained by the persons in the vehicles. The AV incurred a minor scrape on the rear bumper.

15 July 2016 (Google, July 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 2965210 km
- In manual mode: 1930291 km
- Average automated driving on public streets in one week: 32000-35000 km

Road Accident:

An accident occurred at the junction between Cuesta Driver c/w Springer Road in Los Altos, California. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV was stationary at the stop sign and was rear-ended by an approaching vehicle travelling at 11km/h. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to its rear hatch and rear sensor.

August 2016 (Google, August 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 3168924 km
- In manual mode: 2000061 km
- Average automated driving on public streets in one week: 32000-40000 km

8 August 2016 (Google, August 2016)

Road Accident:

An accident occurred at the junction between California Road c/w Rangstor Avenue n Mountain View, California. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV was stationary at Rengstor Avenue waiting for pedestrian to cross. A vehicle approaching from behind about 8km/g rear-ended the AV. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to its rear hatch and bumper.

9 August 2016 (Google, August 2016)

Road Accident:

An accident occurred at the traffic light intersection between Chandler Boulevard c/w Beck Driver in Chandler, Arizona. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. The AV was stationary at the red light and, as it was subsequently turning left at the green light, another vehicle moving at about 55km/h ran the red light and collided with the AV. No injuries were sustained by the persons in the vehicles. Both vehicles incurred moderate damage.

16 August 2016 (Google, August 2016)

Road Accident:

An accident occurred at the junction between Ray Road c/w Mckemy Avenue in Chandler, Arizona. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. The AV was travelling along a straight section at about 67km/h and was rear ended by another vehicle travelling at about 107km/h. The posted speed limit was 70km/h. No injuries were sustained by the persons in the vehicles. The AV incurred damages to the rear bumper and trunk. The other vehicle incurred significant damage to the front.

16 August 2016 (Google, August 2016)

Road Accident:

An accident occurred at the intersection between Phyllis Avenue and Grant Road in Mountain View. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV yielded to a vehicle proceeding southbound as it entered a right-turn slip road. The vehicle approaching from behind the AV rear-ended the AV. No injuries were sustained by the persons in the vehicles. The AV incurred damages to the rear bumper and trunk. The other vehicle incurred minor damage to the front bumper.

22 August 2016 (Google, August 2016)

Road Accident:

An accident occurred at the traffic light intersection between Desert Breeze Road c/w Ray Road in Chandler, Arizona. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. The AV was stationary at a red light and was rear ended by a vehicle approaching from behind at 11km/h. No injuries were sustained by the persons in the vehicles. The AV incurred moderate damage to the rear bumper.

September 2016 (Google, September 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 3382917 km
- In manual mode: 2053776 km
- Average automated driving on public streets in one week: 38000-42000 km

7 September 2016 (Google, September 2016)

Road Accident:

An accident occurred at the junction between San Antoino Road c/w Nita Avenue in Palo Alto. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV came to a stop and was rear ended by a shuttle van travelling at 11km.h as the AV was preparing to turn right. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to the rear bumper and trunk. The van incurred minor damage to the front bumper and right headlamp.

14 September 2016 (Google, September 2016)

Road Accident:

An accident occurred at El Camino Real in Los Altos near the intersection of Showers Drive. The vehicle was a Google prototype vehicle automated vehicle and was operating in automated mode. As the AV changed from the right lane to the middle lane, another car changed lanes right in front of the AV. The test driver of the AV took manual control of the AV and merged back into the right lane but was hit in the rear passenger side by an approaching vehicle in such right lane at about 37km/h. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to the rear passenger-side tire, quarter panel, and door. The other vehicle incurred damages to the front bumper and front fender on the driver side.

20 September 2016 (Google, September 2016)

Road Accident:

An accident occurred at the junction between Calderon Avenue c/w Dana Street in Mountain View. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. As the AV was making right turn into Dana Street, two pedestrians entered the pedestrian crossing in Dana Street. The AV driver assumed manual control of the vehicle and brought the AV to a stop to yield to the pedestrians. The AV was rear ended by a vehicle approaching at 7 km/h. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to the rear bumper whilst the other vehicle ncurred minor damage to the front bumper.

23 September 2016 (Google, September 2016)

Road Accident:

An accident occurred at the traffic light junction of Phyllis Avenue c/w El Camino Road in Mountain View. The vehicle was a Google Lexus-model automated vehicle and was operating in automated mode. As the AV was proceeding northbound at 35km/h and passed the green light, it started to slow down to yield to a vehicle proceeding westbound which was running the red light. The test driver changed to manual driving mode and the other vehicle hit the AV on the right side whilst travelling at 48km/h. No injuries were sustained by the persons in the vehicles. The AV incurred minor considerable damage to its front and rear passenger doors. The other vehicle incurred considerable damage to the front part of the vehicle.

26 October 2016 (Google, October 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 3589280 km
- In manual mode: 2107652 km
- Average automated driving on public streets in one week: 38000-42000 km

Road Accident:

An accident occurred on Shoreline Boulevard in Mountain View on the approach to El Camino Road. The vehicle was a Google prototype automated vehicle and was operating in automated mode. The AV entered a slip road to turn right into El Camino Road and stopped to yield to westbound traffic on El Camino Road. Another vehicle rear ended the AV as the AV started to move forward. No injuries were sustained by the persons in the vehicles. The AV incurred minor damage to the trunk whilst the other vehicle incurred minor damage to the front bumper.

November 2016 (Google, November 2016)

Vehicles being tested on the roads:

- 24 Lexus RX450h SUVs driving in automated mode on public roads in Mountain View, California
- 34 prototypes driving in automated mode in closed test sites

Kilometers driven since the start of the project in 2009:

- In automated mode: 3772605 km
- In manual mode: 2159249 km
- Average automated driving on public streets in one week: 32000-35000 km

Road Accident:

None for the month of November 2016.

Appendix 2: Disabilities which Effect Driving

Full/partial paralysis/weakness/amputation of upper limbs

Limb deficiencies or amputations can be acquired or congenital resulting in an impaired ability to manage vehicle controls (BMV, 2015). Following the amputation of a limb, the disabled person might no longer be in a position to drive safely. The type of amputation establishes the level of difficulty which the amputee will experience when using a standard equipped vehicle (Parkwood Hospital).

Research carried out by Fernandez et al (2000) concluded that there are more upper limb amputees who drive than lower limb amputees however the former require more vehicle adaptations to drive safely. Due to scarce literature regarding safe driving after upper limb amputations, the results of the effects of the different levels of amputation are inconclusive (Burger et al, 2013). Following upper limb amputation, most disabled people need a minimum of one car adaptation to ensure that the driving operation is carried out in a safe manner (Burger et al, 2013).

Muscular Dystrophy Disease

Muscular Dystrophy is the result of genetic mutations which impair the production of muscle protein that is required for healthy muscles (Newman, 2017). The disease consists of a collection of thirty different conditions which result in muscle weakness and degeneration (Newman, 2017). This is a degenerative disease which impairs movement, effects breathing and the function of the heart (Newman, 2017). Early symptoms of the disease include pain and muscle stiffness, impaired running and jumping, problems sitting up and standing, learning problems and increased frequency of falls (Newman, 2017). Since this is a progressive disease, other symptoms emerge over time which include impaired or inability to walk, limited movements, breathing and swallowing problems, weak heart muscle (Newman, 2017).

Spinal Cord Injuries

About 12,500 injuries to the spinal cord happen in the United States every year (Spinal Cord Inc, 2018). A medical condition, trauma or lesion of the neural elements in the spinal cord results in cervical, thoracic or lumbosacral areas being damaged (BMV, 2015). Such injuries result in reduced motor and sensory operation of the upper or lower limbs and trunk (BMV, 2015). The extent of the damage depends on the level of the injury (BMV, 2015). As a result of the reduced ability to manage the vehicle controls, safe driving may be affected after such injury (BMV, 2015). The types of spinal cord injuries include (Spinal Cord Inc, 2018):

i. Tetraplegia which results from damage to the cervical spinal cord and such injuries are the most severe resulting in different levels of limb paralysis. Tetraplegia does not permit movement below the site of the injury and thus, the higher up the spine, the more sever the injury.
ii. Paraplegia which results in cessation of the movements from the lower half of the body resulting from damage to the thoracic spinal cord. The disability is more severe the higher it is to the top vertebra.
iii. Triplegia which results in cessation of movement in one arm and both legs and is caused by incomplete spinal cord injury.

Typical symptoms resulting from spinal cord injuries include (Spinal Cord Inc, 2018):

i. different levels of paralysis
ii. problems with breathing and pneumonia
iii. incontinence
iv. chronic pain and headaches
v. chronic nerve and muscle pain

Cerebral Palsy Disease

Cerebral palsy is a disease which affects the body in various ways including problems with movement, balance and posture (Alvarez, 2017). Damage or abnormal development in parts of the brain which control movement cause cerebral palsy and thus those affected do not have the ability to control and coordinate muscles (Alvarez, 2017). Other conditions are related to cerebral palsy which includes learning disabilities, impaired breathing, problems to control bladder and bowels, deformations of the skeleton, impaired hearing and vision (Alvarez, 2017).

There are three types of cerebral palsy namely (Alvarez, 2017):

i. Spastic where the muscles are still with awkward movements;
ii. Dyskinetic which impairs the coordination of movement and can be athetoid, which results in slow uncontrolled movement, or athaxic, which results in impaired balance and coordination;
iii. Mixed with a combination of spastic and athetoid conditions.

Alzheimer Disease

Alzheimer Disease is progressive and impairs memory, thinking, behaviour and other mental operations (Harvard Medical School, 2008) (Alzheimer's Association, 2018). This disease is the most common reason for onset of dementia and consists of brain disorders which impair intellectual, cognitive and social skills (Alzheimer's Association, 2018). The impaired cognitive functions impact social and occupational functions including the ability to drive (Dobbs, 2005).

The primary symptoms of Alzheimer's Disease are increased memory loss and mild confusion (Alzheimer's Association, 2018). These symptoms increase and eventually impair the ability to function at home and at work (Alzheimer's Association, 2018). The disease also impairs the ability to think and concentrate especially in relation to numbers and multi-tasking abilities are difficult (Alzheimer's Association, 2018). Brain changes cause depression, social exclusion, irritability, aggressiveness, disorientation, memory loss and delusions (Alzheimer's Association, 2018).

Researchers at Brown University carried out a study to establish the rate at which driving skills deteriorate in persons affected by the early stages of Alzheimer's Disease (Harvard Medical School, 2008). The study involved 84 patients effected by the disease and 44 healthy older drivers who acted as the control sample (Harvard Medical School, 2008). The participants undertook an on-road driving test whereby all healthy participants passed the test together with 88% of patients witih very mild Alzheimer and 78% of those with mild Alzheimer (Harvard Medical School, 2008). The participants of the experiment had an average age of 75 and did not include persons with dementia and with mild cognitive impairment (Harvard Medical School, 2008). A second test was carried out 18 months later where it resulted that the driving ability of all participants had deteriorated (Harvard Medical School, 2008) and those with mild Alzheimer became unsafe drivers twice as fast as those with very mild Alzheimer (Harvard Medical School, 2008).

Multiple Sclerosis Disease

Multiple Sclerosis is a progressive disabling disease which is an abnormal response of the immune system of the body and has varying symptoms (BMV, 2015). The disease attacks the myelin that coats the nerve fibers thus resulting in reduced communication between the brain and the rest of the body leading to permanent damage to the nerves (Mayo Clinic, 2017). Some people may exhibit few symptoms however other may have severe symptoms (BMV, 2015). The symptoms differ between individuals and at different stages depending on the affected nerve fibers (Mayo Clinic, 2017). The symptoms include (Mayo Clinic, 2017):

i. numbness or weakness in the limbs and muscles
ii. visual disturbance
iii. tingling or pain in different parts of the body
iv. neck movements cause electric-shock sensations
v. tremor and decreased coordination and balance
vi. speech disorder
vii. fatigue
viii. dizziness.

These symptoms cause problems with the maneuvering of vehicle controls and the driving operation especially in challenging situations (BMV, 2015). This is because such symptoms affect the skills which a person requires to drive safely, namely vision, memory, reflexes and flexibility in arms and legs.

Amyotrophic Lateral Sclerosis (ALS) Disease

Persons with ALS experience a progressive reduction of motor function which reduces the reaction times and causes weakness to the person (Knoche, 2018). It is a neurodegenerative disease in the nerve cells of the brain and spinal cord (MobilityWorks, 2018). Motor neurons connect the brain to the spinal cord and send impulses to the body (MobilityWorks, 2018). ALS degenerates these motor neurons and hence the brain loses its ability to control muscle movement (MobilityWorks, 2018). Cognitive changes and increased time to assess a typical driving situation result in a reduced ability to be a safe driver (Knoche, 2018). The loss of control over the muscles occurs slowly but progressively and the person does not generally realize the changes to his body (Knoche, 2018).

At the onset of the disease, the symptoms indude muscle weakness and muscle softness or tightness (MDA, 2018). Cramps and fasciculations may be experienced (MDA, 2018). The symptoms may be limited to one area of the body only or may affect more than one area (MDA, 2018). The person experiences fatigue, reduced balance and weakness in the grip (MDA, 2018).

Gradually the symptoms spread throughout the body (MDA, 2018). Muscles become paralyzed or weak and fastciculations proceed (MDA, 2018). Unused muscles contract, driving is no longer possible and the person experiences weakness in swallowing and breathing muscles (MDA, 2018).

In the final stages of ALS, the majority of the voluntary muscles are paralyzed and breathing is severely impaired (MDA, 2018). Mobility is greatly reduced and speech, chewing, swallowing and drinking are no longer possible (MDA, 2018).

Parkinson’s Disease

The physical symptoms of Parkinson’s Disease include trembling, bradykinesia, instability and rigidity, dementia and mood fluctuations (BMV, 2015). Such symptoms cause reduced reaction times, vehicle controls are managed with difficulty and there is reduced ability in complicated driving scenarios (BMV, 2015).

Huntington’s Disease

Huntington’s disease is a genetic disease which is fatal and progressive (Huntington’s Disease Society of America, 2018). It causes the nerve cells in the brain to breakdown and impairs the physical and mental abilities of those effected by it (Huntington’s Disease Society of America, 2018). The symptoms of Huntington’s Disease are described as having the ALS, Parkinson’s and Alzheimer’s diseases occurring together (Huntington’s Disease Society of America, 2018).

The symptoms include changes to personality and mood resulting in depression, memory loss and reduced judgement, imbalance and movements which are involuntary, impaired speech and difficulty in swallowing (Huntington’s Disease Society of America, 2018).

The early stages of the disease show small impairments to coordination and possibly some involuntary movements, reduced problem solving abilities and depression make a person less functional in their usual tasks (Huntington’s Disease Society of America, 2018). As the disease progresses, problems with movement increase and speech and swallowing are impaired (Huntington’s Disease Society of America, 2018). In the later stages, a person effected by this disease needs to be cared for by others where chocking becomes a problem and the person loses the ability to walk and speak (Huntington’s Disease Society of America, 2018).

Visual impairment

The driving task has an important visual component to ensure safety and driver performance (Owsley & McGwin, 2011). Visual acuity, visual finction and visual screening are all aspects which determine effective vehicle control (Owsley & McGwin, 2011). Research has concluded that there is a weak correlation between visual acuity and driver safety however, although peripheral, this correlation is very important. Also, visual acuity is strongly related to various attributes of driver performance (Owsley & McGwin, 2011).

Auditory impairment

Hearing is a very important criterion for safe driving (Phillips, 2016). Hearing, together with vision, help us perceive what is happening in the surrounding roadside environment (Phillips, 2016). Generally, during driving, we hear occurrences before we see them (Phillips, 2016). Thus hearing disability can have a considerable adverse impact on safe driving (Phillips, 2016).

A study was carried out by The Journal of the American Geriatrics Society in 2010 where the participants were 107 adults between the ages of 62 to 88 (Phillips, 2016). The level of hearing impairment varied between the participants and the experiment required the participants to drive on a closed-road circuit and report on the road signs along the circuit (Phillips, 2016). They were also expected to avoid any road safety hazards which they encountered (Phillips, 2016). They were required to drive the track under three different scenarios being firstly without any distractions, secondly with auditory distractions and thirdly with visual distractions (Phillips, 2016). The experiment concluded that participants with impaired hearing performed worse when driving with distractions and they exhibited less ability to avoid safety hazards (Phillips, 2016). Also they completed the circuit in a longer period of time (Phillips, 2016). This shows that the additional effort to hear a degraded auditory signal is a source of distraction from other cognitive operations thus impairing safe driving (Wolf, 2018).

Dementia

Dementia is a progressive disease and eventually all those effected by dementia eventually lose their ability to drive safely (Dobbs, 2005). (Alzheimer's Society, 2018). Driving is a complex task which necessitates quick perception-reaction times together with sensory (auditory and visual) and manual skills (Alzheimer's Society, 2018). To ensure safe driving, a range of abilities are required which include (Alzheimer's Society, 2018):

i. attention and concentration to address multiple driving tasks;
ii. visual and spatial skills to calculate relative distances;
iii. problem-solving abilities to react correctly to roadside occurrences;
iv. judgement skills to interpret the roadside scenario;
v. perception-reaction skills to act in a timely manner to avoid collisions.

Persons affected by dementia exhibit problems related to a deterioration of the above mentioned abilities. Also, different classes of memory are essential for safe driving however the problems related to the symptoms outlined above tend to impair the ability to drive much sooner than issues related to loss of memory (Alzheimer's Society, 2018).

Attention Deficit Disorder (ADD)/Attention Deficit and Hyperactive Disorder (ADHD)

Both teenagers and adults who are affected by ADD or ADHD experience the same problems of impaired attention and increased levels of distraction during the driving task (Niolon, 2015). Although a greater amount of driving experience in adults increases their driving skills they must still keep in mind that their symptoms affect the safety level of their driving (Niolon, 2015).

Weiss et al (1979) published the first study which examined the relationship between ADHD and driving. The study concluded that adults and teenagers who suffer from ADHD had a greater risk of traffic collisions and their vehicles incur larger damages (Weiss et al, 1979).

Research carried out by Barkley & Cox (2007) resulted that car accident damages for persons suffering from ADHD were two-and-a-half times more expensive to repair than for drivers without the condition. Further research also showed that drivers with ADHD have four times greater risk of being involved in traffic accidents (Niolon, 2015).

One common ADHD symptom in adults is hyperfocus (Emmerson, 2014). This occurs when a person focuses on something with such rigor that everything else is overlooked (Emmerson, 2014). This poses a high safety risk for an adult (Emmerson, 2014). In adults, frustration resulting from the ADHD condition leads to impulsive behaviour (Emmerson, 2014). Additional distractions, both in-vehicle and outside the vehicle, continue to increase the safety risks (Emmerson, 2014).

The ADHD related symptoms of distraction, lack of attention and impulsive behavior results in that teenagers suffering from such condition are likely to have a lesser driving ability when compared to other teenagers (CHADD, 2018). Hence such teenagers have a higher chance of a vehicle collision and potentially a higher risk of committing traffic contraventions (CHADD, 2018). These increased risks are a result of the difficulties in carrying out the driving task and other related symptoms which include impaired judgment and reduced risk inhibitions (CHADD, 2018). Lack of attention results in driver distraction and impulsive behaviour results in poor judgment (CHADD, 2018).

Appendix 3: Country Codes for Survey Data

ID	Name
1	Albania
2	Andorra
3	Armenia
4	Austria
5	Azerbaijan
6	Belarus
7	Belgium
8	Bosnia and Herzegovina
9	Bulgaria
10	Croatia
11	Cyprus
12	Czech Republic
13	Denmark
14	Estonia
15	Finland
16	France
17	Georgia
18	Germany
19	Greece
20	Hungary
21	Iceland
22	Ireland
23	Italy
24	Kazakhastan
25	Kosovo
26	Latvia
27	Liechtenstein
28	Lithuania
29	Luxembourg
30	Macedonia (FYROM)
31	Malta
32	Moldova
33	Monaco
34	Montenegro
35	Netherlands
36	Norway
37	Poland
38	Portugal
39	Romania
40	Russia

41 San Marino
42 Serbia
43 Slovakia
44 Slovenia
45 Spain
46 Sweden
47 Switzerland
48 Turkey
49 Ukraine
50 United Kingdom (UK)
51 Vatican City

Appendix 4: Disability Codes for Survey Data

ID	Name
1	ADD/ADHD
2	ALS
3	Celebral Palsy
4	Alzheimer Disease
5	Dementia
6	Full/Partial paralysis/weakness/amputation of upper limbs
7	Impaired eyesight (not applicable to users of prescription glasses)
8	Impaired Hearing
9	Muscular Dystrophy Disease
10	Multiple Sclerosis Disease
11	Spinal Injuries
12	Huntington's Disease
13	Other

Appendix 5: Survey Data

ID	Gender	Age	Driver	LicenceYear	ResidenceID	P2Duration	P3Duration	P4Duration	P5Duration	P6Duration	P7Duration	DisabilityID
1	M	44	Y	26	31	2	2	1	2	1	2	NULL
2	M	54	Y	35	31	2	1	2	1	2	3	NULL
3	F	42	Y	18	18	3	2	3	2	2	2	NULL
4	M	28	Y	10	31	2	1	2	1	1	1	NULL
5	M	60	Y	42	31	3	2	2	2	3	3	NULL
6	M	51	Y	33	31	23	2	1	2	2	2	NULL
7	F	41	Y	18	31	2	1	2	1	1	1	NULL
8	M	32	Y	14	31	2	1	1	1	1	1	NULL
9	F	41	Y	21	31	2	2	3	2	2	3	NULL
10	F	45	Y	27	31	2	2	1	2	1	2	NULL
11	M	45	Y	27	31	2	2	2	1	1	1	NULL
12	F	30	Y	12	7	19	2	1	2	2	2	NULL
13	M	44	Y	26	31	2	2	2	1	2	2	NULL
14	M	41	Y	23	31	2	1	1	1	1	1	NULL
15	F	26	Y	6	31	2	1	1	1	1	1	NULL
16	M	39	Y	20	31	3	2	1	1	1	2	NULL
17	M	60	Y	40	31	118	2	2	1	3	2	NULL
18	F	30	Y	12	28	2	1	1	1	1	2	NULL
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319	F	44	Y	23	31	2	297	359	2	244	74	NULL
320	F	39	Y	8	31	3	2	2	1	2	5	NULL
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333	F	48	Y	38	31	38	2	2	2	2	2	NULL
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340	F	34	Y	10	31	3	1	1	2	2	1	NULL
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395	M	73	Y	58	31	7	3	2	7	167	2	NULL	
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398	M	40	Y	6	31	2	2	2	1	2	2		11
399	M	35	Y	15	31	2	2	2	2	2	2	NULL	
400	F	50	Y	25	31	2	2	2	2	1	2	NULL	
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436	M	43	Y	25	31	2	1	1	1	2	3	NULL
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453	F	29	N	NULL	23	2	2	2	2	2	2	NULL
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455	F	44	Y	20	31	9	3	3	2	3	4	NULL
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465	F	25	Y	8	18	2	2	2	2	2	2	NULL	
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467	F	69	Y	43	31	5	4	2	2	4	3	NULL	
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477	M	55	Y	35	13	2	2	2	2	5	2	NULL	
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