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Artificial Intelligence Rationale for Autonomous Vehicle Agents Behaviour in Driving Simulation Environment

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1. Introduction

In recent times, in-vehicle notifications have proliferated with a focus on the exhibition of technological prowess rather than the fulfilment of actual driving needs. In effect, information portrayed by automotive infotainment devices, while useful, is often ignored by the driver due to field of view limitations associated with traditional instrumentation panels. Not surprisingly, under poor visibility conditions and at motorway-level driving speeds, such systems do not effectively present useful information to the user.

Contemporary Head-Up Display (HUD) experiments have focused on adapting the aviation-specific characteristics of HUDs to driver-specific needs, obsolescing functionality and simplifying operations where necessary. The more mature approach of these preceding works has revealed that although in-vehicle HUD technological advances have overcome most implementation issues, the related user-centred interface design is in its infancy prohibiting the HUD's unique features from being successfully exploited. Towards addressing this issue, in previous work, we have designed and implemented a functional prototype of a Human Machine Interface (HMI). Specifically, the proposed HMI system introduces a novel design for an automotive HUD interface, which aims to improve the driver's spatial awareness and response times under low visibility conditions. Particular emphasis has been placed on the prioritisation and effective presentation of information available through vehicular sensors, which would assist, without distracting, the driver in successfully navigating the vehicle. In order to evaluate the effectiveness of the proposed HUD system, we developed a driving simulator based on an open source racing program. Leveraging an open source solution has resulted in manageable levels of incurred expenses whilst allowing us to deliver a flexible simulation application for HUD evaluation.

This chapter discusses the artificial intelligence (AI) as developed for the agent vehicles of our open source driving simulator. The simulator was explicitly designed to measure driver's performance when using the proposed HUD interface and compares its effectiveness to traditional instrumentation techniques. Intuitively, human cognition complexity poses the largest challenge for creating a model of life-like driver's behaviour for any type of traffic flow. Presuming that specific driving characteristics apply to all human drivers, as dictated by common sense, an attempt was made to form a generic reaction

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pattern from a list of possible reactions to given situations. The AI embedded in participating vehicles in the simulations embraced certain assumptions, which are outlined later in the chapter. In this way the development time required for the AI routines was reduced by discounting rare occurrences that would indicate a severely misbehaving and irrational human driver. However, it was deemed necessary to develop AI controlled vehicles that could perform potential human miscalculations in order to enhance the realism of the simulation scenarios and their degree of mapping to real-life situations. Imitation of human error by the robot vehicles, such as failure to brake on time, became a simulation feature that substantially enhanced the driver's immersion in the synthetic environment.

Overall, this chapter elaborates on the modelling process of the agent vehicle's AI and discusses contemporary attempts to develop similar AI simulations for other simulation facilities. Notably, throughout this work, a concerted effort was made to ensure that the simulator scenarios were fair representations of potential real-world accident-prone situations; this has been made possible after attentive examination of the statistical data on driving scenarios provided by the Strathclyde Police Department situated in the City of Glasgow, UK.

2. Proposed HUD simulation

Early attempts to employ Head-Up Displays (HUDs) in automotive environments were greatly influenced by research in aviation and subsequently exhibited limitations and side-effects derived from the misuse of Human Machine Interaction (HMI) principles. Overall, the largely uncritical adoption of aviation HUD technologies held back the potential of automotive HUD use as conveyors of information provided by vehicular sensors. Even under such unfavourable conditions, however, research results have indicated an improvement in the driver's response time in some studies, which in turn hint on the potential of such systems. Recently, contemporary HUD experiments have focused on adapting the aviation specific characteristics of HUDs to driver-specific needs, obsoleting functionality and simplifying operations where necessary. The more mature approach of these preceding works has revealed that although in-vehicle HUD technological advances have overcome most implementation issues, the related user-centred interface design is still in its infancy prohibiting the HUD interface's capabilities from being successfully exploited. This study introduces a novel design for an automotive HUD interface which aims to improve the driver's spatial awareness and response times under low visibility conditions, offering only the crucial incoming information in a graphical representation manner. As such, a working prototype of a HMI has been designed and implemented to fulfil these requirements (Charissis et al. 2008a). Particular emphasis was placed on the prioritisation and effective presentation of information available through vehicular sensors, which would assist, without distracting, the driver in successfully navigating the vehicle under low visibility conditions (Charissis et al. 2008c). The harmonic collaboration between the human (driver) and machine (vehicle) elements has been supported by utilizing the machine as a collecting and distilling hub of information. Essentially, the human agent has been urged towards improved decision making through careful consideration of user characteristics and needs. That positive effect on the driver has been achieved by conveying the distilled information through the visual cues of the HUD interface reducing driver's response times

in critical situations (Steinfeld & Green, 1995; Charissis et al. 2008b). In order to evaluate the system's effectiveness we used two simulation scenarios in subsequent user trials. These simulations required that substantial attention be given to the AI development in the computer-controlled vehicles. The following sections elaborate on the development of the driving simulator and the programming of the AI vehicles.

3. Driving simulator as an evaluation tool

Driving simulators are an indispensable tool used both in the automotive industry and academic research. Current state of the art simulators include the U.S. National Advanced Driving Simulator (NADS) (Papelis, 1994; Chen et al., 2001), the Swedish National Road and Transport Research Institute (VTI) (Nordmark et al., 2004; VTI, 2007), the Transport Research Laboratories (TRL, 2007) and the Leeds Advanced Driving Simulator (LADS, 2007) in the U.K. These sophisticated simulators can take into consideration numerous driving factors such as deceleration and acceleration forces, weather conditions etc., as well as be able to record, analyse and evaluate the results in real time (Kantowitch, 1999). However, the construction, upgrade and servicing costs of such elaborate hardware and software components can often be prohibitively high. Overall, and in view of conducting academic research, the task of designing and implementing a driving simulator, even one of low fidelity, can involve substantial financial overhead. Hence, academic institutes often rent the facilities of traffic research centres or automotive industry studios which offer specialised driving simulators for testing various automotive systems and devices. Intuitively, the existence of certain financial constraints may require the generation of alternative solutions.

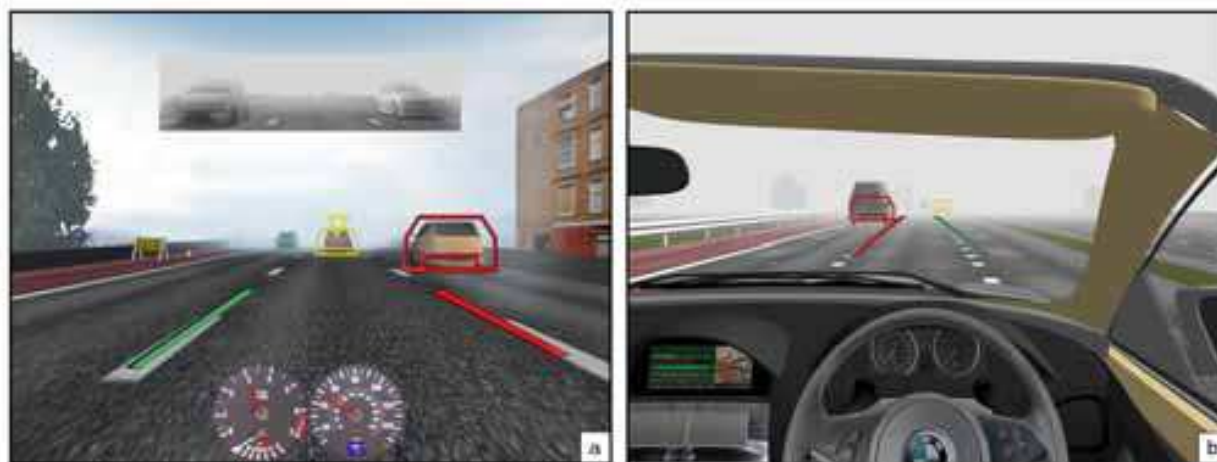


Figure 1. A screenshot of the (a) open source driving simulator and (b) the VR driving simulator developed based on the open source set-up.

As the use of a driving simulator was necessary for the evaluation of the prototype HUD interface, we opted for an alternative low-cost approach. After careful consideration of the available funds and time constraints, the decision was reached to purchase off-the-shelf hardware components and develop the code on the open source TORCS platform (Wymann, 2006; Centelles, 2006). This solution accounts for a manageable level of expenses whilst delivering a flexible simulation application for HUD evaluation purposes.

The reconstruction of accident events in a synthetic driving environment required the deployment of life-like driving virtual participants in the scene, thus a fleet of “intelligent” vehicles which could make maneuvering decisions in real-time and mingle orderly to form mixed traffic environments was deployed in the simulations examined here. The following section presents the challenges encountered during the implementation of realistic AI for the traffic vehicles involved in the events.

4. Open Source Driving Simulator (OSDS)

Recent advancements in processing capacity and graphic representation technologies for personal computers have significantly reduced the cost of realistic computer-generated environments. This vastly increased computational ability allows for vehicle and environment simulation that can reasonably approximate the definition performance of significantly more expensive driving simulator models (Hogue et. al. 2005). Singular PC units are able to support various features of a simulation process. Nevertheless, multitasking computation can potentially overload the system and affect the simulator’s performance (screen refresh rate); therefore the simulation process has to be optimised with the view to meet the needs of the experiment (Rosenthal et al., 2003).

A solution to the issue of singular unit performance can be achieved by clustering numerous PC simulators to effectively form a much more capable whole. In this case, PC simulators can divide the tasks and execute them separately; this combinatory approach amplifies the system’s capabilities and may even reach the processing power of high-end servers as used for complex simulations. This newly formed breed of driving simulators has been adopted by high-end industrial and academic simulation facilities worldwide such as the Advanced Institute of Science and Technology (AIST) driving simulator at Tsukuba, Japan, the Transport Research Laboratory (TRL) in the UK and so on. However, even though the computational costs have been minimised, these facilities still uphold immense operating costs for upgrading, maintaining and running their systems.

A more cost effective approach is the development on open source software able to simulate various vehicles and driving conditions. These specialised simulators can be easily customised to create a sufficiently realistic environment for testing various driving scenarios. Nonetheless, as the majority of such programs have been developed for gaming purposes, namely racing, they require substantial changes to the core of the programme in order to comply with a real driving scenario as discussed later in this chapter. The combination of off-the-shelf hardware (PC) and open source driving simulation software was, for our purposes, the most cost-efficient and flexible solution. The idea of creating such a custom-driving simulator benefited from input by various researchers from British, European and American universities (Charissis et al. 2006)¹. A screenshot of the developed simulator in action is shown in Figure 2.

¹ This work has benefited from the feedback and contributions of a number of colleagues from academic institutions including the computing science departments of the University of Glasgow, the University of California, Berkeley, Glasgow Caledonian University and Aristotle University, Thessalonica. Where applicable each contribution is clearly marked and identified in this chapter.



Figure 2. Screenshot of the driving simulator with the HUD interface

4.1 Open source driving simulator software development

We conducted extensive market research which indicated that financial costs for software and hardware development would be considerable for building a medium fidelity driving simulator. Renting a simulator facility was also not a viable option as the high daily rates could not be covered by the research funds. It was therefore vital for the study to develop a custom simulating system with minimum expenditure. This necessity led to collaborative work along with other researchers on the development of such a simulator.

The open source “The Open Racing Car Simulator (TORCS)” provided a suitable solution for the development of a custom driving simulator. Note that TORCS is a multiplatform, 3D car racing simulator based on OpenGL. This software formed the basis for the development of the OSDS. The source code was originally developed on the Linux platform but soon efforts were concentrated on the Windows operating system in order to ensure maximum compatibility with peripherals. The simulator’s vehicles, i.e. the “robot” drivers, can be treated as agents with customisable AI. The purpose of programming the AI for each “robot” enables the participant to programme the attribute of their own racing vehicles (agents). As a result racing competitions can be held amongst pre-programmed vehicles by different authors on the Internet, or locally with the user racing against the computer vehicles. The navigation of the vehicles can be achieved through the use of a keyboard, mouse, joystick or steering wheel. Due to the racing nature of the software, the robot

vehicles imported into the OSDS required substantial reprogramming in order to adhere to the British Highway Code. The following section will elaborate on the simulation of the HUD interface and the environment visualisation.

A. 2D HUD interface visualisation

The functionality of the HUD interface components have been transferred to the simulated environment they it would purportedly be in a real vehicle. The symbols were programmed to follow the movement of the vehicles and alter their size and colour according to the relevant distance from the user's vehicle. The two dimensional projection of the OSDS did not offer depth of field, which could have further enhanced the realism of the experiment. However, the advanced AI of the robot vehicles and the accurate superposition of the HUD symbols enhanced the sense of presence; the derived results were based on genuine driving efforts to respond to the accident events.

B. Simulation of low visibility conditions

Given that the primary aim of the study was to measure and compare drivers' response times in adverse weather conditions, such environmental conditions had to be replicated accordingly. A survey of weather conditions literature defines that dense fog results in low visibility conditions, which produce significant traffic flow disruptions typically below the 100m viewing distance mark (Cavallo et al. 1999; BBC Accidents, 2007). As such heavy fog, with visibility less than 50m, was simulated in four of the driving scenarios. Note that the visibility percentage could be adjusted via a simulation parameter achieve a satisfactory fog quality. Specific parts of the code were improved in order to simulate the desired fog conditions and realistic depth of field. The area of fog visualisation was revisited in our virtual reality driving simulator (VRDS) which particularly investigated the HUD's focusing distance as discussed in (Charissis et al., 2007b; Charissis & Naef, 2007).

C. 3D visualisation

To achieve a semblance to reality the testing track was designed and modelled based on a section of the M8 motorway in the outskirts of Glasgow, Scotland as depicted in Figure 3 (item b). The simulation model was set to deal only with motorways with three lanes in each direction and one hard-shoulder lane. In order to reduce the amount of 3D geometry, the track was simplified to only one direction, in this case the route from Glasgow to Edinburgh (anticlockwise). A closed circuit was created by seamlessly connecting three main motorways thus forming a triangular track shape. This model did not incorporate ramps on motorways or intersections on rural roads. 3D visualisations of the important intersections and most recognisable landmarks were incorporated in the final model as illustrated in Figure 4. Such visual cues helped the drivers to recognise the environment.

To populate the track, the 20 most popular vehicles, as seen on British roads, were modelled in low polygons geometry (gaming quality). Whereas the original program offered a wide choice of vehicles, the majority of them were racing cars and hence not appropriate for this experiment. The 3D objects and track were modelled using Alias Maya 6.5, and after a distilling process of exports in various formats, they were imported into the simulator using Track Editor and AC3D software. Additional alterations to the XML code were needed to allow compatibility with Windows XP.

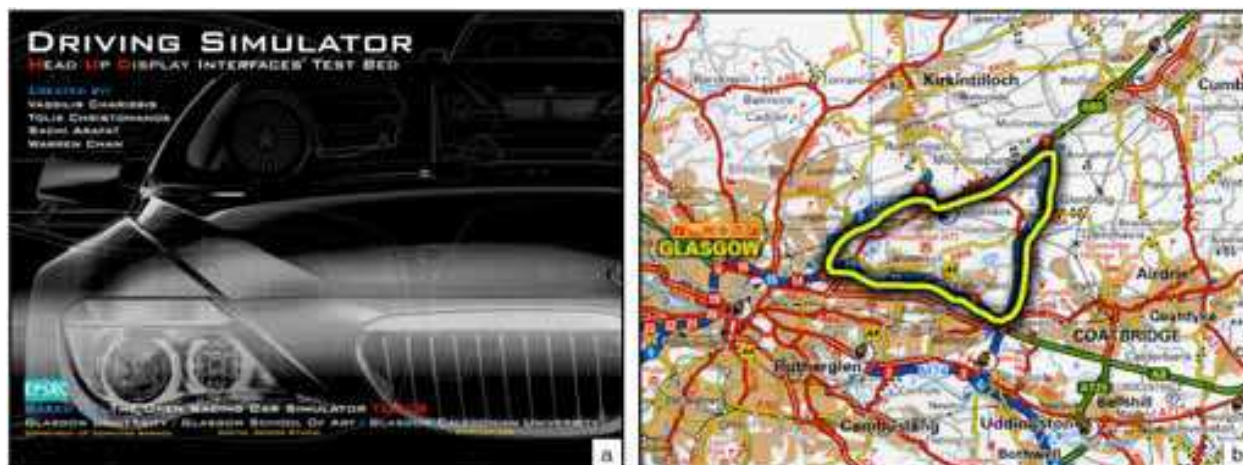


Figure 3. (a) Introductory screen of the OSDS, (b) Simulation track based on real motorway routes.



Figure 4. (a) Landmarks in real environment and (b) in the simulated track

4.2 Open source driving simulator hardware

The development of a cost efficient simulator could be mainly achieved by maintaining the costs of the hardware at minimum levels. However the keyboard or mouse solution did not seem appealing, as it could subconsciously be reminiscent to the user of a computer game. As a full-windshield HUD evaluation required a “close-to-real” driving environment it was deemed essential to purchase an “off-the shelf” steering wheel (Logitech Driving Force Pro GT4). This hardware item is categorised in the range of gaming products, however that particular steering wheel model offered a quite realistic feel (three rotation circles from left to right) and a well-implemented force feedback function (realistically transferring road bumps and the feeling of vehicle’s drifting or braking). Note that this component required additional programming as the open source programme failed at first to recognise the device automatically. The steering wheel was also accompanied with a bundle of other equipment which included foot pedals for accelerator and brake (see Figure 6).

The software was run on a custom built PC with dual 64bit processors (AMD Opteron-242) and a Quadro FX1100 graphics card. A frame-rate of 60-90 fps was effortlessly maintained by the system. Although the simulator could perform well on a low specification laptop, this

powerful dual processor system was built with the view to accommodate simultaneously more than one driver for future experiments.

Emphasis was also placed on the implementation of a driving cockpit environment; a real driving seat (a Gamepod, “bucket seat”) formed in large part the driver’s virtual “cockpit”. The seat stood on a railing system on the top of a metallic structure which also supported the minimalistic dashboard and the steering wheel. The railing system allowed users to alter the positioning of the seat, the steering wheel and the pedals to match their physical dimensions and driving preferences.

The relevant hardware and software equipment had to be accommodated in a facility that could host two-week long simulation trials and experimentation as driver reactions were recorded. The Glasgow Caledonian University generously offered the E-motion Lab of the Mathematical and Computing Sciences Department which was explicitly equipped with numerous recording and observation devices such as video cameras, eye-fixation recorders, motion detectors and a fully developed observation suite and control room. The academic staff aided us greatly in setting up the connection of the driving simulator devices to the facility’s additional equipment.

The observation suite hosted the driving simulator, which was projected on the lab’s Panasonic 42 inch plasma screen positioned approximately 2m away from the driver’s seat, as shown in Figure 5. The control room was equipped with monitors showing, in real time, the video stream from the cameras in the simulation area. The focus and the position of the cameras could be adjusted also in real time through a joystick on the control console in the observation room. The two videos could be seen either on separate monitors or both on the same window (screen on screen) thus enabling the researcher to observe the driver’s driving process (via a screen camera) and his/ her facial expression and posture (via a camera focused on the user) The following section presents the challenges encountered during the implementation of realistic AI for the traffic vehicles involved in the events.

5. Accident scenarios simulation

As Boer et al. (Boer & Ward, 2003) define it, an event is a situation requiring a corrective response such as, say, a situation arising when safety margins are violated. In order to evaluate the driver’s response to accident events, the AI vehicles employed in the simulation scenarios had to generate the right circumstances, which would eventually lead to such an event occurring.

Note that the agents involved in the simulated scenarios were programmed to react and manoeuvre according to the flow of traffic and external events, whilst demonstrating natural driving behaviour. Every vehicle would obey certain rules which “urged” it to imitate its real life counterpart while its overall behaviour was influenced by several factors. In particular, each vehicle calculated, in real time, information drawn from its surroundings (i.e. other traffic vehicles) as well as information about visible accident hotspots such as enclosing side barriers, bridges, traffic cones and so on. The above information was clustered in the agents’ intelligence creating logical links among possible events and responses, thus forming the framework for each individual agent’s AI.

The following subsection elaborates on the driving scenario development. Section 5.2 explicitly analyses the macroscopic and microscopic driving scenario approaches, which consequently form the generic AI attributes of the vehicle agents presented in Section 5.3. In turn Section 5.4 presents the drivers’ patterns infused in the agents’ driving attributes.

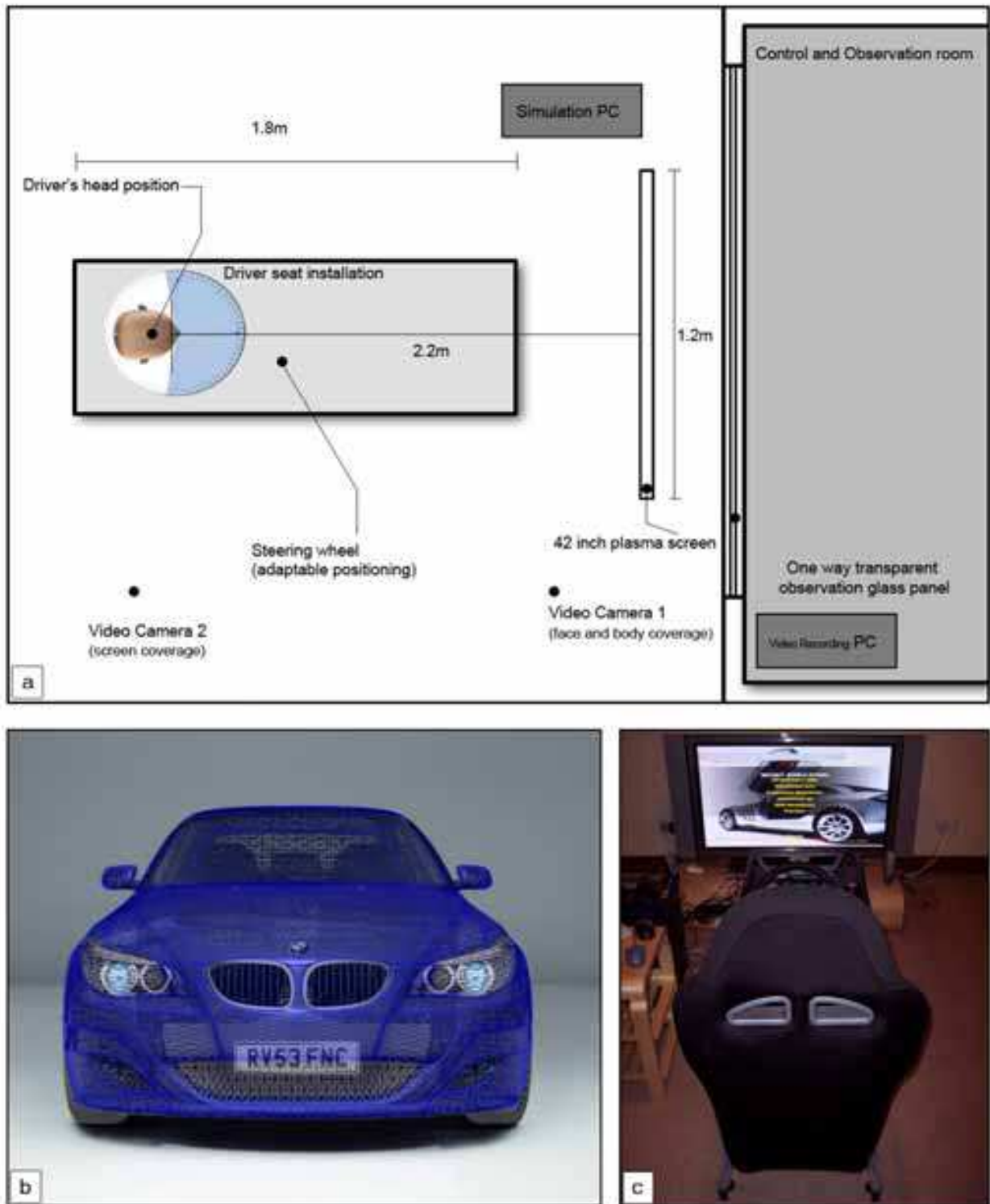


Figure 5. (a) Open Source Driving Simulator (OSDS) schematic top view, (b) example of 3D visualisation of simulated vehicle, (c) driving seat and positioning overview

5.1 Driving scenario development

The development of traffic scenarios was accomplished through careful inspection of data provided by actual traffic police reports. These statistics and planning diagrams aided in

predicting drivers' possible reactions (SPD, 2004). Subsequent analysis showed that two particular car-following scenarios occur fairly frequently and reveal a high fatality rate. A detailed description of both such scenarios is given later in this subsection; however, before an outline of the two scenarios may be presented, it is useful to denote certain constraints and considerations evident in both. Firstly, note that for validation purposes, the movement, speed and distances between the vehicles had to adhere to the British Highway Code.

Moreover, in order to enhance the realism of the simulation scenarios and their degree of mapping to real-life situations, the AI controlled vehicles had to perform potential human misjudgements. Imitation of human errors by the robot vehicles (i.e. failure to brake on time) is a simulation feature that substantially enhances a driver's immersion in the synthetic environment (Allen et. al., 1997). As the authors argue in Park et. al. (2004), the driver has to be challenged in order to react and produce driving skills that would normally apply in a real accident situation. Overall, two common driving situations of a "car-following" scenario were developed for the test-bed experiments based on observations and accident prompt strategies produced in previous research (Daganzo, 1999; Smith et al., 2003). All the scenarios were presented in a motorway environment with heavy fog featuring low visibility (clear view being available at under 50m distance).

The first scenario used in this work is a variation of a generic car-following model described in previous work (Brackstone & McDonald, 2003). In that work, the user drives along the motorway and after having travelled a distance of 2km, the lead vehicles brake abruptly, causing following vehicles to decelerate rapidly. Intuitively, this event increases substantially the chances of vehicle collision. A previous study focusing on mapping of driver's possible reactions in similar car following accident scenarios (Smith et. al., 2003) has suggested that a driver's performance is comprised of four driving states: low risk, conflict, near crash and crash imminent, corresponding to four different warning levels respectively. As such, the first scenario was developed along these guidelines in order to evaluate the HUD's ability to effectively convey these four collision states to the driver. Analysing the driver's performance under such discrete time segments, each mapping onto these four pre-collision periods, has provided the study with the ability to identify, for every stage, the impact of the added HUD information over a typical HDD.

The second scenario is a variation of the original car-following situation in which the user drives for 5km following a lead vehicles' group, without any major occurrences taking place. After 5km the road forms a sharp turn (120 degrees) underneath a bridge thus creating an accident-prone situation. The difficulty of the scenario is amplified by the adverse weather conditions, in this case heavy fog, which dramatically decrease the driver's visibility, and by the addition of slow moving traffic congestion positioned at the exit of the turn. As before, the four states of collision warnings observed in other work (Smith et. al., 2003), were infused in the rationale of the potential accident driving scenarios. In addition, collision-prone issues such as sharp turn negotiation and traffic congestion were also employed in order to investigate driver's performance with and without the assistance of the proposed HUD interface.

In both scenarios the user is forced to respond instantly, either by manoeuvring around the accident point or by braking. The robot vehicles involved in the scenarios are programmed to minimise the possibility of accident avoidance, as the experimental focus was to gather detailed measurements of drivers' response times and distance from the lead vehicle with respect to the accident event. A schematic overview of both scenarios is shown in Figure 6.

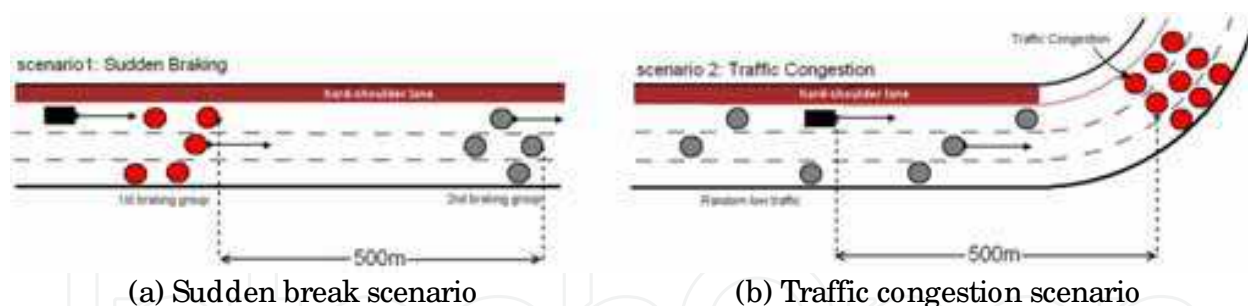


Figure 6. Simulation Scenarios

5.2 Macroscopic simulation approach

Investigation of driver behaviour modelling research demonstrated that the majority of high-fidelity traffic simulators utilise the macroscopic simulation method (Kuhl et al., 1995; Cremer, 1995; Papelis & Bahauddin, 1995). Predominantly, this method exploits mathematical models - often originated from fluid dynamics - that treat vehicles as particles in a homogenous flow. A sophisticated version of the macroscopic simulation method can identify three or more groups of vehicles inside the traffic flow which share identical characteristics (typically size and speed) such as cars, motorbikes and buses. This allows for some degree of control over the simulated traffic as these three main groups are characterised by different driving speeds and movements (Ehlert & Rothkrantz, 2001). Yet, these groups do not have any differentiating attributes between individual vehicles in the same group; individual driving characteristics are ignored in favour of simulation of very large numbers of vehicles moving in large urban or motorway complexes. Therefore the utility of the macroscopic approach lies mostly within generic traffic models and estimation of traffic pattern rather than the drivers' individual behaviour.

Evidently, imitation of real life occurrences requires collection of different vehicles, representations of their driving patterns and creation of potentially unpredictable traffic flows. Yet, a number of driving constraints should be considered and a simplification model should be applied in order to ease the simulator's calculating demands. Typically, when considering a macroscopic simulation scenario, variations therein depend on the number of different groups of vehicles. A group is defined as a set of vehicles that have the same driving pattern within a driving session. The scenarios used in this work were initially developed using the macroscopic method to define traffic flow complexity. In this simulation we opted for clustering of the vehicles into two main groups, named "Stop-aheads" and "Jammies", better control over the generation of the accident scenarios was achieved (Charissis et al., 2007a). These two groups had been particularly developed to play different roles in the accident simulation. Although both of them were seamlessly integrated into the generic flow, at a specific moment of the simulation they were scheduled to act according to a master-plan that initiated a potentially accident-causing event. At a predetermined moment the group of lead vehicles (named "Stop-aheads") brakes abruptly challenging the user to respond immediately. The second group (named "Jammies") mainly populated most of the motorway and in some cases developed condensed traffic sections or mini traffic jams. However, the integration of the two groups forming the traffic flow was not identifiable by the driver as an artificial construct because the robot vehicles were developed with additional singular driving characteristics, which provided the impression of autonomous behaviour. These are presented in Figure 7, which shows a diagram of the

main robot categories and their functions in the macroscopic and microscopic models respectively.

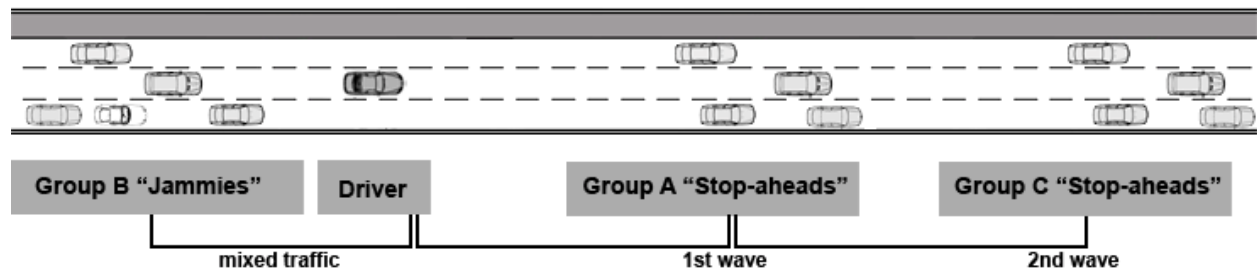


Figure 7. A diagram of the main robot vehicle categories.

5.3 Microscopic simulation approach

In addition the microscopic method was utilised to embed the AI into the robot vehicles and to create different driving profiles (one for each agent). This technique is predominantly used for accident reconstruction where specific agents have to perform particular roles in order to effectively reproduce the circumstances that created the accident. This in-detail approach could not be achieved solely by the macroscopic approach, as it does not address the impact to individual vehicles' problems on the traffic (accidents, vehicle break downs etc). Contrary it solely investigates the impact of such individual incidents on the whole traffic flow (Ehlert & Rothkrantz, 2001) rather the individual behaviour of neighbouring vehicles. Thus the individual behaviour of each agent catered for realistic interactions between the robots regardless of their group identity.

In the simulator the agent's behaviour can be altered by tweaking a set of parameters such as general speed, top speed for session, speed close to turns or linearity to lane (distance from centre of lane). Nevertheless, certain restrictions had to be pre-programmed for all the agents in order to keep autonomous behaviour within acceptable and law-abiding levels.

Summarising, both macroscopic and microscopic traffic simulation systems were embedded in the driving simulator. This combinatory simulation approach has been favourably rated in the literature for its successful realistic depiction of real traffic interactions (Shiraishi et al., 2004; Sahraoui & Jayakrishnan, 2005). As a measure of comparison it should be stated that the simulator used in this work handled approximately twenty vehicles; state of the art simulators which facilitate virtual traffic using real time generated scenarios may incorporate up to 100 participating vehicles created and controlled independently (Suda, 2006). However, a repetitive flow of vehicles inside the looped triangular circuit used in both scenario setups provided the illusion of constant moderate traffic of an endless number of travelling vehicles.

6. Embedding AI into vehicle agents

Intuitively, anticipation of human reactions presents a grandiose challenge for creating a model of life-like driver's behaviour for any type of traffic flow. Hypothesising that specific driving characteristics apply to all human drivers, as dictated by "common sense", an attempt was made to form a generic reaction pattern from a list of possible reactions to given situations (Yamanaka et. al., 2005; Sukthankar et al., 1996). The AI embedded in participating vehicles in the simulations embraced certain assumptions, which are outlined below. In this way the development time required for the AI routines was reduced by

discounting rare occurrences that would indicate a severely misbehaving and irrational human driver.

6.1 Simulated driving constraints

Exhaustive investigation into drivers' possible reactions identified a number of constraints and rules that define the unpredictable factors involved in such simulation model which seeks to re-enact specific accident, real-life scenarios. The constraints identified could be divided in two main categories namely; soft and hard constraints, which are introduced in turn.

The *soft-constraints* in a driving scenario are set either by road rules (the motorway code), which are obeyed in normal situations (i.e. avoiding collision with the neighbouring vehicles) or by the agent's behaviour (i.e. speed limited by 'fear of crashing'). Minor deviations in soft constraints are favourable in a simulated environment in order to depict closely the real-life behaviour of various drivers. However it is worthwhile to note that such soft-constraints are exactly the ones violated heavily in crash situations.

On the other hand, there are also certain *hard-constraints* (for instance driving opposite to the direction of the traffic flow), which if violated would render a model void of realism. The simulation parameters can therefore vary and a semblance to reality may be maintained as long as hard-constraints are not violated. If a particular set of simulation parameters stays within the soft-constraints then normal driving conditions are denoted; alternatively, any violation of these signifies a particular accident-prone traffic set-up such as the one in the car-following scenario where a collision might occur due to adverse weather conditions.

6.2 Vehicles' agents categories

Both driving accident events have been simulated by the agent vehicles that populated the track. In order to attain the seamless integration of the robot vehicles into the traffic flow, a large part of the initial open source code had to be re-written as it was originally designed for racing purposes only. The driving behaviour of 20 vehicles was individually reprogrammed to follow the Highway Code (e.g. speed limits, lane keeping, signalling, etc.). In the first scenario (sudden braking of the lead vehicles), the robot vehicles were divided into 3 groups called "traffic waves". The primary purpose of these waves was to intentionally constrain the users from exceeding the speed limit, which eventually implicated them in the car following accident events. The secondary objective of the waves was to augment the sense of realism. In particular, when the simulation started, the test car was positioned amongst the third wave of vehicles ensuring that the driver would be accompanied at all times during the simulation. At a predetermined point, the lead vehicles of the second wave were programmed to brake abruptly, thus instigating the accident scenario. The succeeding vehicles would then respond randomly to that event either by braking on time or by colliding with the front vehicles. Given that limited visibility due to simulated thick fog, the driver would have little time to decide on what action to perform. There were two common reactions: harsh braking or manoeuvring around the stopped vehicles via the hard shoulder lane. In the case where collision with the second wave was avoided, the first wave of vehicles repeated the same scenario after 300m therefore maximising in this way the possibilities of accident involvement.

Similarly, for the purposes of the second scenario, two traffic wave groups were formed: the accompanying group and the congestion group. Whilst the accompanying vehicles had the

same driving behaviour as in the first scenario, the congestion group had been allocated virtually motionless behind a sharp left turn, under a complex of bridges. This accident scenario can be equally hard to avoid when visibility is low as it is difficult to identify the sharp turn and traffic congestion in advance. Achieving a high level of realism for the scenarios was the most important element for the evaluation of the proposed HUD. The sense of immersion can be initially achieved by the presence of a sufficient number of vehicles on the track with a distinguishable variation of behaviours comparable to the variation found in reality.

A particularly interesting re-inaction of that driving pattern variation was achieved in the second scenario. As the user is driving along in the light traffic she encounters a sharp bend under a bridge and traffic congestion at the exit of the curve. It is worth noting that this scenario is actually a depiction of a real problem, so there were no other pre-programmed accident events taking place (like abrupt braking of the lead vehicles in the first scenario). The robot vehicles forming the traffic around the driver were expected to improvise and react in an appropriate manner. A variation of AI reactions was recorded when robot vehicles attempted to stop behind the static traffic: some tried to manoeuvre around and utilise the hard-shoulder lane while others crashed into the rear of the static traffic. The interaction amongst the different agents and groups considerably enhanced the feeling of realism as the driver could witness a realistic conclusion to the event.

As described in the microscopic method of the simulation, different categories of agents were deployed depending on their role in the forthcoming events. The major agents strongly instigated the particular key event (e.g. an imminent collision) and the observer agents indirectly influenced the final event. The ambiguity in any model is that in real life every driver can alter her category status with regards to a hypothetical accident. However, on hindsight of a particular key event the majority of the drivers behave in a similar fashion so as to be grouped appropriately.

6.3 Driving pattern investigation

In order for the simulation to become more realistic, it is often useful to add a degree of randomness to the distances between cars at the initial simulation setup as well as provide some variation to the simulation time.

Evidently the simulated groups have three specified soft-constraints, nevertheless, there are some hidden constraints generated from the vehicle models and road model. As more groups of vehicles with specific purpose are introduced, the number of constraints on driving behaviour increases and some control is introduced in the environment, leading to a 'test scenario' from which conclusive judgements can be drawn. When unpredictable events occur in a scenario it becomes harder to deduce the reason for the key event happening – as the user might get distracted by 'non-key events' taking place due to vehicles' variation; these affect the driver's reaction to the key event.

However, such variations do exist in reality due to the numerous differences in driving behaviours of real drivers. We discovered that to achieve both realistic variation and sufficient control necessary for the key event to take place, the driving time has to be sufficiently long. In this way, each group in a simulation can exhibit "personality" whilst their influence gets slightly diluted over time, so that their behaviour will not appear more peculiar than the key-event.

While developing the simulator and its associated AI we also took into consideration the possible design of the networking and systems backend which would be necessary for the

implementation of our HUD design in actual vehicles. We have argued, in related work, that the detection of the headway and positioning of the neighbouring vehicles can be accomplished by a collaborative Mobile Ad-hoc Networking System (MANETS) between vehicles and with the aid of GPS and sensors (Charissis & Papanastasiou, 2006).

7. AI simulation challenges and solutions

During the development of the driving simulation environment, the agent vehicles' autonomous reactions had been extensively tested in order to identify potential issues. Initial presumptions with regard to different driving patterns resolved most anticipated issues, yet some participants' unexpected behaviour reactions required more creative solutions (Green, 2005). In order to address the problems that occurred during the preliminary trials, we employed fundamental techniques used in similar cases in AI such as the Cognitive Simulation introduced by Newell, Shaw and Simon at the RAND Corporation and at Carnegie Institute of Technology (Dreyfuss, 1992). Originally this approach involved the collection of protocols from human subjects which were subsequently analysed to discover the heuristics that these subjects employed (Dreyfuss, 1992). More specifically, the following two solutions were applied to retain the driver amongst at least one of the traffic waves.

7.1 “Bandit-Driver” phenomenon

This phenomenon typically occurs in a driving simulation environment when the user reacts as if driving a “racing computer game”. In order to avoid such behaviour which alters considerably the real results, the users had been instructed to follow the Motorway Code for the entire duration of the experiment. Yet a number of users exceeded the speed limit substantially. This, however, resulted in an event-free journey as they had over-taken all the traffic waves. After experimenting with different speeds and chase techniques for the driving agents, we decided that one of the vehicles should play the role of the “super-car”. Therefore one of the vehicles had been given the ability to chase and dangerously over-take the “bandit-driver” forcing him/ her to slow down until the rest of the traffic would merge into the picture. That ability was triggered by a chosen agent as soon as the “bandit-driver” was out of range of any possible event (1km).

7.2 “Timid-Driver” phenomenon

The opposite of the previous case was the exceptionally slow driver, also referred to as a “timid-driver” (Daganzo 1999). Even when the robot vehicles were decelerating significantly, such drivers were travelling with a speed of less than 30 km/h thus maintaining a considerable distance from the preceding main traffic. This resulted once more in the participant missing out the accident events. The remedy to this was the incorporation of the “fear factor”. A model of a black truck participated in that role. The truck was travelling at a conveniently slow speed, following the slow vehicle in close proximity (not visible due to the fog-effect). So, when the user was permitting a greater distance than 1km from the last leading vehicle, the agent of that robot vehicle had been programmed to initiate a close-vicinity pursuit. If the driver persisted with the same driving pattern the truck would alarmingly sound its horn.

We considered that it might seem reasonable to exclude the results of both “bandit” and “timid” users from the final analysis. However, driving behaviours similar to the ones described above exist in real life; these extra agents were developed in order to embrace a wider breadth of driving patterns.

7.3 “Follower” phenomenon

This category of drivers typically followed closely the movements of the lead agent vehicles. As such they increased their level of anticipation significantly by simply imitating the driving behaviour of the simulated vehicles. Although such behaviour appears in real-life as well and in some respect may even be desirable, during simulation it does not accurately reflect the driver’s real intentions. This occurs as drivers feel that the simulation experiment will evaluate their own driving abilities instead of the effectiveness of the interface. In order to avoid such issues we enhanced the ability of the “jammies” to overtake and partially merge with the lead vehicles. That position exchanging and multiple unexpected manoeuvres blur significantly the roles between the agent vehicles for the participant.

8. Conclusions

This chapter presented the rationale and development process of an open source driving simulator which was exclusively created for the evaluation process of a prototype HUD interface. Financial limitations led to the exploration of new avenues for evaluating the prototype HUD. The simulator hardware was built using off-the-shelf components and the software was developed through customisation of an open source code game engine.

For evaluation purposes, equal emphasis was placed on was the development of an appropriate testing environment and suitable driving scenarios. To achieve a realistic mix of agent behaviour, the AI infused in the vehicles’ agents was thoroughly customised and designed to facilitate the accident events created to gauge driver reactions.

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