Evaluation of Driving Efficiency and Safety with a Custom-Developed Simulation Scenario

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Abstract: In this paper, we present a custom-developed driving simulation scenario and a vehicle model developed to evaluate driving efficiency and safety. The scenario includes different road sections, traffic conditions, and events, including a through road similar to a real road section in the city of Valladolid (Spain). The modeled vehicle is an ICE vehicle with manual or automatic gear shift. During a simulation, following a guided or a free route, the speed, rpm, gear, consumption, and traffic offences are showed in real time and stored in files for further processing. Six people drove in the scenario twice, one time with automatic gear shift and another with manual gear shift. An analysis of the results has been carried out to know the factors with influence on driving efficiency and safety. A significant relation between efficient and safe driving was found. People that took part in the experiments ranked the simulation scenario positively regarding ease of interaction, realistic experience, usefulness for driving learning, and entertainment capacity.

1 INTRODUCTION

Driving safety and efficiency are major topics worldwide with the growing number of vehicles and the complexity and variety of road networks. Although the rate of deaths relative to the world's population has stabilized and even declined considering the number of motor vehicles in the past years (World Health Organization, 2018), their figures are very high. They cause unacceptable human and economic costs in all the countries regardless their level of development. Particularly, road traffic injury is the leading cause of death for young adults aged until 29 years old. From these young adults, novice or drivers with low experience are a significant part. The increasing pollution levels, especially in urban areas, and the ongoing exhaustion of fossil fuels require to reduce their consumption. The use of efficient driving techniques and the progressive substitution of ICE (Internal Combustion Engine) vehicles for electric vehicles are necessary to address these problems. In short, the aim of achieving a safe and sustainable transport demands drivers with highly developed safe and efficient driving skills.

With the continuous progress in technology, simulation environments have increased their realism and learning potential. Thus, simulators can speed up the process of acquisition of skills necessary in many fields. Driving simulators make it possible the acquirement, development, and measurement of driving skills without the risks associated with real driving using varied roads and events where safety and efficiency can be quantified.

Driving simulators have been greatly used in training programs in different countries. For instance, in USA several projects based on driving simulators have been developed (Allen et al., 2007). In Brazil, simulation driving is included in the official learning to obtain a driving license. Moreover, driving simulators have also been used in many research studies in different fields such as engineering, psychology, and medicine (Zhao et al., 2018). Driving simulation research has a series of advantages compared to research based on real driving. One of the most important advantages is the capability to create virtual environments with fully controllable parameters that would be, at the very least, challenging and expensive in real driving (Olstam et al., 2008).

In the presented work, a driving simulation

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scenario with different road sections and traffic events and a vehicle model to analyze the driving efficiency and safety are presented. Both the scenario and the vehicle model have been developed with the Unity game engine (Unity, 2019). Unity is one of the most used game engines in limited budget projects and allows to develop games and graphical applications. Besides, it is possible to export the applications to 27 different platforms including PC, mobile, and console ones. An important feature of the last version of Unity is its integration with virtual reality platforms such as Oculus Rift.

Our driving simulator shows in real time and stores in files for further processing, not only information about the user's vehicle (position, speed, rpm (revolutions per minute), gear, and fuel consumption), but also the traffic offences committed during simulation. This information can be used to analyze the different simulations fulfilled by the drivers so that conclusions can be drawn about their driving competence.

The rest of the paper is organized as follows. Section 2 presents the state of the art on driving simulators. Afterwards, Section 3 explains the developed driving simulation scenario and user's vehicle. Section 4 details the obtained experimental results and, finally, Section 5 draws the main conclusions about the presented simulator.

2 DRIVING SIMULATORS

A simulator is a hardware and software configuration in which, through algorithms, the behavior of a process or physical system is replicated. In the education field, simulators are means to form concepts and to build knowledge and also means for their application to new contexts that people, for several reasons, cannot have access to from the methodological context where their learning is developed. Simulators have educational advantages such as the providing of open learning environments based on real models and that users adopt an active role, turning themselves into the builders of learning from their own experience. To name some examples, simulation has been applied to fields so different as nuclear power engineering (Cui et al., 2017) and pediatric emergency medicine education (Sagalowsky et al., 2016) with satisfactory results.

All the above mentioned is clearly applicable to driving simulators. Although there are driving simulators aimed at the pupils learning to drive (Simumak, 2019) from which they can learn to drive from scratch, most of these simulators aim to entertain leaving aside the development of competences towards responsible driving. (Stinchcombe et al., 2017) found a statistically significant association between video game experience and risk-taking behaviors (large values of speed and crashes) when the participants had to drive in a scenario developed specifically to assess a particular skill such as handling. As a consequence, simulators for learning and assessing safe and efficient driving should be carefully designed to reinforce proper driving behaviors through the provision of feedback.

In the last years, driving simulators have been used in many research studies for a wide variety of purposes. With them, drivers' reactions to different situations, which are not feasibly replicated on real roads, can be analyzed. Their suitability to assess the behavior of drivers and as a means to learn safe and efficient driving skills has been shown. (Lee et al., 2018) demonstrated that a driving simulator methodology including instructions, realistic traffic scenarios, and adaptive analytical methods is suitable to study drivers' behavior and their interactions with road users. (Yuan et al., 2019) studied the safety effects of weaving length, traffic condition, and drivers' characteristics in mandatory lane change behavior using a simulator. (Almeida et al., 2014) presented a simulation scenario based on the Serious Game concept to develop way-finding behaviors in emergency situations. (Meng at al., 2019) studied the relation among drivers' characteristics, fatigue, and performance in an experiment with 50 taxi drivers. (Bıçaksız et al, 2019) investigated the relation of functional and dysfunctional impulsivity with driving style by measuring driver behaviors on a driving simulator. All the research studies mentioned above obtained interesting findings and meaningful results. Focused on driving efficiency, (Zhao et al., 2015) developed an eco-driving support system based on a driving simulator that was validated as a useful tool to save fuel consumption and reduce emissions. (Jamson et al., 2015) studied with a simulator the tradeoff between driving efficiency and safety using systems embedded in the vehicle to advise the driver about the use of the throttle pedal. They showed that efficiency can be improved using these systems. (Pampel et al., 2015) carried out a simulator study showing that drivers have mental models of eco-driving that they do not use when instructed to drive normally.

In driving simulators, scenarios to analyze the level of driving efficiency and safety, the relation between them, and the results produced as a function of them can be included. When people see themselves in a real driving environment such as a city with heavy traffic or a complex junction, they may think that they will be unable to face that challenge. In particular, driving anxiety is common in older adult drivers, which can contribute to decisions to limit or avoid driving (Taylor et al., 2018). Driving simulators enable users to face many of these problems in a virtual environment without endangering the user or other drivers and to obtain driving skills to overcome these problems, in such a way that these skills can be applied when they face similar situations in real driving. The users can also get used to the vehicle controls through simulations, manipulating them with the steering wheel, pedals, and gear lever similarly to in a real vehicle. For that purpose, different types of peripherals can be used, from controls to complete driving cabin, including devices such as Logitech G27 or Fanatec CSL Elite Wheel Advanced Pack. Obviously, simulators enable users to repeat simulations in a scenario and to deal with certain events many times. Besides, it is possible to simulate real situations that would be practically impossible to do voluntarily in a real environment. Situations such as a vehicle stopped in the middle of a road or a pedestrian crossing a road unexpectedly are events that can be replicated in a simulator easily. This will enable simulator users to be better prepared for unusual situations that may find in the future. Simulators can also be utilized to make studies about how certain agents, such as fatigue (Meng et al., 2019), physical or psychological state of the driver, medicine, drugs (Bergeron et al., 2014), alcohol consumption (Van Dyke et al., 2014), or age (Freydier et al., 2014; Ledger et al., 2019), can influence driving capacity significantly.

Lastly, it is important to mention that simulators can gather data in a simple way. Thus, users can have access to information of the fulfilled simulations and observe their evolution. This enables drivers to see and be aware of their mistakes and committed traffic offences and what aspects they should improve to avoid them in the future.

3 CUSTOM-DEVELOPED DRIVING SIMULATION SCENARIO

We have developed a driving simulation scenario of 7.7 km covering different types of roads and traffic elements and events that drivers should address adequately. The Unity game engine has been used to create the scenario. Unity was adopted in many serious game projects (Unity, 2019; Rodrigues et al., 2018; Almeida et al., 2014). It is compatible with a great range of 3D design tools such as Blender and 3ds Max and allows to develop 2D and 3D games. A part of the scenario is similar to a section of a through road in the city of Valladolid (Spain). This section has been extended with other sections to complete the scenario. The upper section is an interurban road with one lane per direction and the lower section is an interurban road with two lanes per direction (partly in slope).

The user’s vehicle has been modeled with the Unity module Realistic Car Controller, which can be adapted to achieve the features and behaviour of the desired vehicle. This vehicle is a Volkswagen Passat Highline 2.5 V6 from 2001. We chose a sedan vehicle close to the average age of vehicles in Spain. We have adapted the parameters and GameObjects of the Realistic Car Controller module, such as rigid body, mesh collider, wheel collider, cameras, lights, and box trigger. To model the fuel consumption, we have determined graphs setting the dependency of the speed and the current gear on the fuel consumption. The vehicle can be driven not only with manual gear shift but also with automatic gear shift. It must be noted that automatic vehicles will be much more common in the future as all electric vehicles are automatic. The driver can also select front-wheel drive, rear-wheel drive, or all-wheel drive before the simulation.

To include the rest of the vehicles in the scenario, we have used the Unity module Easy Traffic. 1460 waypoints have been distributed in the scenario and different vehicles such as pickup trucks, sedan and off-road vehicles, and motorcycles move along different waypoints and with different speeds. The density of vehicles can also be configured. Pedestrians are included in the scenario, which walk on the sidewalk, can cross the pedestrian crossings, wait for a green traffic light, or even cross a road unexpectedly to study the response of the driver.

The peripheral input device used in the simulator is the Logitech G27, which includes steering wheel, gear lever, and clutch, brake, and throttle pedals. The levers and buttons of the Logitech G27 have been configured to associate them with actions such as start the engine or switch on or off the lights or the turn signals.

A system to control the traffic offences has been added in the scenario. The most important computed traffic offences are: exceed the speed limit, drive under the minimum speed, failure to stop at a stop sign, failure to stop at a traffic light, failure to yield at a yield sign, not switch on the corresponding turn light in a turn, in an overtaking, or entering or leaving a road, be closer than the minimum distance to the vehicle ahead, drive off the road, wrong-way driving, not letting a pedestrian cross a pedestrian crossing, striking a pedestrian, collision with other vehicle, and collision with street furniture. When an offence is committed, its type together with the time and the position of the user's vehicle in the scenario are recorded. Besides, a textual message is shown in the scene to inform the driver about the offence if this configurable option is selected before the simulation. Apart from the offences, the position, speed, rpm, selected gear, and fuel consumption are recorded with a configurable sampling rate. After the simulation, data is stored grouped as a function of the driver, easing the access and comparative study of the results.

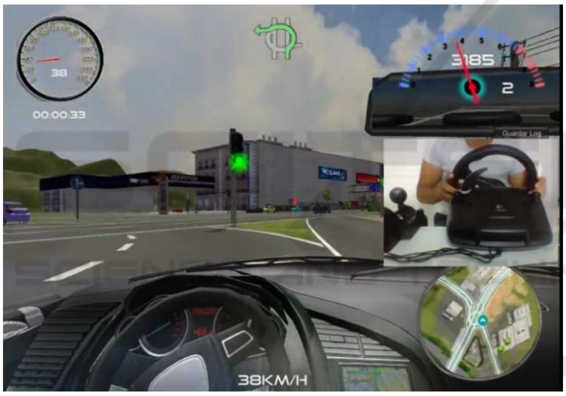

Figure 1: Simulation scene with the camera inside the vehicle.

Figure 2: Simulation scene with the camera outside the vehicle.

Before the simulation, the user can choose to have a guided or free route. There is a Unity camera inside the vehicle so that the driver can have a field of view similar to real driving as shown in Fig. 1. On the top left corner of the scene, there is a speedometer and on the top right corner there is an rpm meter and a number with the selected gear. The user can turn their view left or right by pressing particular buttons on the steering wheel. On the bottom right corner of the scene, there is a map, similar to a map shown by GPS navigation devices, with the location of the vehicle in the scenario, which is updated in each frame. An image of the user while driving is added on the right part of the scene shown in Fig. 1. While driving, the user can change from the view present in Fig. 1 to a view outside the vehicle, as shown in Fig. 2, which can be interesting for learning purposes. Fig. 3 shows a scene with the camera inside the vehicle after turning the view left to see the left mirror. Fig. 4 shows a scene with a textual message on the right informing about the recently committed offence of not letting a pedestrian cross a pedestrian crossing.

Figure 3: Simulation scene with the camera inside the vehicle.

Figure 4: Simulation scene with the camera outside the vehicle.

4 EXPERIMENTAL RESULTS

Six users drove in the simulation scenario along the same guided route. They drove in the scenario twice, firstly with automatic gear shift and secondly with manual gear shift. Table 1 shows the characteristics of the users that we asked them about to study their influence on the driving performance. Tables 2 and 3 show the data obtained with the automatic and manual gear shift, respectively. The percentage of time in 1st gear also includes the time that the engine was idle due to a red traffic light or for other reasons such as letting pedestrians cross a pedestrian crossing. From these tables, a clear variation of the fuel consumption among the users can be observed as a function of their driving profiles. Conversely, the differences between the automatic gear shift and the manual gear shift are generally small for each driver. All users but user #6 have consumed more with manual gear shift, with an average fuel consumption increase of 0.4 l/100 km with manual gear shift. This was partly caused by the longer time in 1st gear than in 2nd gear with manual gear shift, unlike with automatic gear shift. Users #2 and #6 have achieved a lower fuel consumption with manual gear shift by using longer gears (4th and 5th gears) more time than the rest of the users, which have used shorter gears more time than required in efficient driving. Another related factor influencing the higher driving efficiency for users #2 and #6 was the higher average speed they have achieved.

Tables 4 and 5 show the offences the users have committed with the automatic gear shift and manual gear shift, respectively. The speeding offence was the most frequent as the simulator strictly records the speeds larger than the speed limit of 50 km/h in the through road and of 90 km/h in the two interurban sections. Although the user #2 had a larger average speed both with automatic and manual gear shift, he or she was not the driver with the largest number of speeding offences. The users with the lowest number of offences were the #3 and #6, both with 8 offences. The user #6 was the most efficient driver with manual gear shift and one of the most efficient with manual gear shift. The user #3 was one of the most efficient drivers with both gears. Conversely, the user #1 was the driver that committed the most number of traffic offences with both automatic and manual gear shift and was also the driver with the highest average fuel consumption with both automatic and manual gear shift. Thus there was a relation between driving efficiency and safety as users that drove more efficiently also drove safer and vice versa.

Regarding the overall number of offences, there was a decrease of 36% with automatic gear shift, partly because the drivers did not have to pay attention to the clutch and gear lever to shift among gears. There has not been found a relation between some users' characteristics (age, driving experience, videogame experience, and annual mileage) and the level of driving efficiency and safety as the two users with the most efficient driving (#2 and #6) have different characteristics' profiles, like the two users with the safest driving (#3 and #6). Similarly, the users with the least efficient driving (#1 and #4) and the users with the least safe driving (#1 and #5) have different characteristics' profiles. From these results, it must be noted, on the one hand, that driving profiles are complex and difficult to be related to the drivers' characteristics and, on the other hand, that a high videogame experience has not had influence on a better performance in the simulation scenario, which supports the use of the scenario in driving research studies.

After using the simulator, the six users were asked about the more relevant aspects of its use. Table 6 shows the results of the users' feedback. All the aspects were rated positively above 7 out of 10 and the overall rating was 7.7. The simulator was considered a useful tool for driving training due to its ease of interaction and similarity to real driving. Moreover, the simulator kept them entertained.

Table 1: Characteristics of the six users that took part in the experiments in the simulation scenario.

User	Age	Driving experience (years)	Videogame experience	Annual mileage(km)
#1	33	15	Low	14,000
#2	24	6	High	6,000
#3	25	7	Moderate	10,000
#4	26	8	Low	30,000
#5	26	8	High	1,000
#6	44	16	Low	12,000

Table 2: Data of the routes in the simulation scenario with automatic gear shift.

User	#1	#2	#3	#4	#5	#6	Average
Time	12´16´´	10´33´´	12´01´´	11´52´´	11´11´´	11´54´´	11´37´´
Average speed (km/h)	47.7	57.9	47.9	46.7	48.8	46.7	49.2
Average fuel consumption (l/100km)	8.2	6.5	7.1	8.0	7.6	7.4	7.46
% of time in 1st gear	26.1	27.5	27.5	26.7	20.2	24.1	25.3
% of time in 2nd gear	29.7	31.3	27.3	36.3	33.1	33.6	31.8
% of time in 3rd gear	28	18.6	29.5	16.9	33.1	27.3	28.0
% of time in 4th gear	9.7	15	15.7	20.1	13.6	6.3	13.3
% of time in 5th gear	6.5	7.6	0	0	0	8.7	3.7

Table 3: Data of the routes in the simulation scenario with manual gear shift.

User	#1	#2	#3	#4	#5	#6	Average
Time	12´02´´	9´33´´	11´53´´	13´15´´	12´13´´	11´41´´	11´46´´
Average speed (km/h)	49.4	57.5	47.7	46	46.4	49.3	49.3
Average fuel consumption (l/100km)	8.8	6.9	7.5	8.3	7.7	6.2	7.5
% of time in 1st gear	34.3	15.4	30.5	30.6	28.2	24.3	27.2
% of time in 2nd gear	11.6	24.5	24.4	29.1	24.1	14.9	21.4
% of time in 3rd gear	37.7	27.1	13.6	35.1	28.2	25.8	27.9
% of time in 4th gear	16.4	26	31.6	5.2	11.9	35	21
% of time in 5th gear	0	7	0	0	7.6	0	2.4

Table 4: Traffic offences in the simulation scenario with automatic gear shift.

User	#1	#2	#3	#4	#5	#6	Total
Exceed the speed limit	3	3	1	1	4	1	**13**
Drive off the road	2	0	1	4	1	1	**9**
Failure to stop at a traffic light	0	0	0	0	1	0	**1**
Collision with other vehicle	1	0	0	0	0	0	**1**
Collision with street furniture	0	0	0	0	0	0	**0**
Not switch on the turn light in a turn	1	0	1	0	0	0	**2**
Total	**7**	**3**	**3**	**5**	**6**	**2**	**26**

Table 5: Traffic offences in the simulation scenario with manual gear shift.

User	#1	#2	#3	#4	#5	#6	Total
Exceed the speed limit	5	4	3	1	4	2	**19**
Drive off the road	2	0	1	3	2	3	**11**
Failure to stop at a traffic light	1	1	0	0	0	1	**3**
Collision with other vehicle	1	2	0	0	0	0	**3**
Collision with street furniture	0	0	0	0	1	0	**1**
Not switch on the turn light in a turn	1	2	1	0	0	0	**4**
Total	**10**	**9**	**5**	**4**	**7**	**6**	**41**

Table 6: Opinion of the users about driving in the simulation scenario.

User	#1	#2	#3	#4	#5	#6	Total
Ease of interaction (0-10)	6	8	7	8	7	7	**7.2**
Similarity to real driving (0-10)	8	8	6	7	7	8	**7.4**
Usefulness for driving learning (0-10)	8	7	8	8	8	8	**7.9**
Entertainment (0-10)	9	10	7	8	7	8	**8.2**
Total	**7.75**	**8.25**	**7**	**7.75**	**7.25**	**7.75**	**7.7**

5 CONCLUSIONS

In this paper, a custom-developed simulation scenario, which was created with the Unity game engine, has been presented. The scenario has different road sections, traffic conditions, and events. It can be used both for the learning of driving skills and the study of driving efficiency and safety. One section of the scenario is similar to a real road section in the city of Valladolid (Spain). Six people drove in the scenario twice, one time with automatic gear shift and another with manual gear shift. An analysis of the results has been carried out to know the factors that have a strong influence on driving efficiency and safety. Users that drove more efficiently also drove safer and vice versa. The relation between driving efficiency and safety states the importance of developing in parallel efficient and safe driving skills to achieve a better road traffic. People that took part in the experiments driving in the simulation scenario highlighted its ease of interaction, realistic experience, and usefulness for driving learning. Future data stored in the scenario simulations from many users will allow to carry out deep comparative analysis to associate the different drivers and their driving styles with their safety and efficiency level, and to assess the evolution in the development of driving competence.

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