

Use of a Simulator to Assess the Application of Economic Driving Techniques by Truck Drivers

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Abstract— This paper presents the project and the development of a prototype for a truck simulator aimed at assessing the use of Economic Driving Techniques. We describe the techniques for economic driving and the way they are monitored, as well as the process of modeling and creating a virtual environment and the interaction devices used in the simulator. The simulation is accomplished by using a virtual desktop environment with hardware configuration similar to that in a real truck, in order to provide the user with a higher level of immersion. By testing drivers and economic driving instructors, it was possible to observe that the prototype can be used as a tool for assessing drivers and that the system is able to perceive a great part of the violations in the use of Economic Driving Techniques during the simulation similarly to a human expert.

Keywords- truck simulator; drivers trainings; driving assessment

I. INTRODUCTION

Since the mid-1950s there was a progressive increase in the number of trucks that travel in Brazilian roads, which required an increasing amount of qualified professionals to drive them. However, the initiatives to improve drivers' qualification started to occur recently, with the professionalization of transport companies and the great development of technologies used in trucks. These initiatives are due to the fact that truck drivers are no longer mere drivers of vehicles, as they are becoming essential for the development of transportation companies because the way they drive determines a considerable portion of the company's profitability.

In order to fill the demand for professional drivers, which in 2009 presented a deficit of 90 thousand professionals, many training centers that aim at training new drivers and promoting refreshing courses for drivers already on the market were developed. One of the most popular subjects in training courses is related to safe and economical trips by using Economic Driving Techniques. The concept of Economic Driving refers to the use of driving techniques that reduce fuel consumption, increase the lifespan of the parts, provide more safety to the driver and respect the traffic rules.

The assessment of the drivers' level of learning regarding the appropriate use of Economic Driving Techniques is performed subjectively by instructors who accompany drivers on experimental trips with about 3000 km. In addition to the high financial cost, this training method can present assessment problems due to several factors, such as instructor's fatigue, bad relationship between the instructor and the driver and

psychological pressure suffered by the driver for being assessed.

Aiming to improve the assessment methodology of current Economic Driving training programs, this study developed a model for training and assessment based on the use of a Virtual Reality (VR) simulator. Besides simulating a truck trip, this simulator monitors in real time the driver's actions and provides an objective assessment of how the driver conducted the truck and whether he complied with the guidelines of the Economic Driving Techniques or not.

Next chapter introduces key concepts for understanding Economic Driving Techniques. Chapter III presents a review of driving simulators used for training. Chapter IV presents the methodology used for modeling and developing the simulator. Then, Chapter V presents the the prototype assessment and Chapter VI shows the obtained results. Finally, Chapter VII presents the conclusions and also shows some possible improvements in the simulator.

II. ECONOMIC DRIVING TECHNIQUES

Economic Driving Techniques are a set of procedures that, when adopted, provide reduced fuel consumption, increase the lifespan of the parts, provide the driver with more safety and respect traffic rules.

There are several factors that increase fuel consumption and worn parts in a truck. According to [13, 14, 7], the consumption is directly related to the way the vehicle is driven and its correct maintenance. For [16] the cost of fuel and lubricants, followed by the parts used in maintenance, are the main responsible for the high variable costs in the final price of the freight.

The factors that help reduce fuel consumption and prevent premature wearing of parts include: keeping the engine speed within the torque range recommended by the manufacturer; traveling at a maximum speed of 80km/h; changing gear within the limits recommended by the manufacturer; avoiding idling or neutral position; performing gradual and scheduled braking; using engine braking only in favorable situations.

Another important factor is related to so-called "bad driving habits", which are actions that the driver performs without any need and that often are performed involuntarily, as it has become automatic. The most common bad driving habits and their effects are: traveling with your foot on the clutch; accelerating while changing gears or when the vehicle is being

turned off; keeping a hand on the gearstick ; accelerating the truck as soon as it is started, in order to reach its ideal temperature quickly.

III. RELATED WORK

In the literature review it was possible to identify vehicle simulators that focused on entertainment [3, 6], therapeutic treatments [10, 11] and educational purposes [4, 5, 8]. As this work focuses on drivers training, the educational simulators were emphasized, especially those seeking to monitor and analyze the actions of the driver [15, 12, 1].

We attempted to analyze the simulators that use virtual environments and interaction devices similar to the real ones, in order to provide a greater level of realism and immersion to the experience of driving a virtual vehicle.

Developed in 1996 by the University of Iowa's Oakdale Research Park in Coralville, the National Advanced Driving Simulator (NADS) has been constantly improved. The NADS inserts the user in an environment with a high level of immersion, using 15 projectors with high resolution, providing a 360° horizontal view and a 40° vertical view inside a CAVE, in which the user conducts a totally monitored vehicle [12]. In the virtual environment, the user can feel the accelerations and braking, and can have a real sense of distance and displacement.

The DLR Institute of Transportation Systems, in Germany, developed a simulator to evaluate the behavior of drivers in real traffic situations. This simulator consists of a vehicle inserted in a cabin on a mobile platform, where images are presented in a stereoscopic way on a screen that allows a 270° horizontal view and a 40° vertical view [15], providing the user with a high level of immersion.

In 2003, the UK's Road Haulage Modernization Fund (RHMF), a Department for Transport initiative, started using the Truck Driver Training Simulator (TDTS), which consists of a truck cabin and a projection screen offering approximately a 210° view of the simulated environment in a concave screen. The cabin has a hydraulic system of pistons that reproduces the movement of the truck on the road, such as curves, terrain relief and bumps. The vehicle is monitored through software that records the driver's actions at each point of the road, and is able to detect bad driving habits [2].

The CEIT-IK4 consortium, from Spain, began the development of Cabintec System, aiming the development of a fully controlled cabin, able to simulate situations that happen on trips of buses and trucks. The devices tested in the cabin are intended be entered in real trucks in order to increase security. In addition, the cabin is used to train drivers to make safer journeys [15]. The software was built on an open development platform created by BMW [9] and the hardware consists of a truck cabin mounted on 3DOF base. The systems uses three projection screens for viewing the virtual environment, forming a CAVE-like immersive environment.

This review aimed at evaluating the possibility of using an existing simulator for training drivers with economic driving

techniques. From this review, we concluded that this is not possible because:

- These simulators are designed as large systems and monolithic units, so that it is impossible to move them out of their installations without a high cost.
- Most of the simulators (excepting the CabinTec System) have a closed source code and very specific characteristics. These simulators are appropriated only for the experiments performed in each research project, which makes it impossible the inclusion of algorithms for detecting of violation the use of Economic Driving Techniques;
- The use of CAVE-like displays were discarded for this project due to the unavailability of this devices in Brazil;
- We could not identify, in analyzed simulators, the possibility of classifying the types of road with respect to relief, the existence of 3rd line and identification of the urban area, which is extremely important to evaluante of use of Economic Driving Techniques.

IV. MODELING METHODOLOGY AND DEVELOPMENT OF A DRIVING SIMULATOR

According to what was presented in the previous session, it is possible to see that in order to continue this project it would be necessary to make a new simulator to meet specific requirements, such as:

- Elaboration of a virtual environment suitable for the characteristics of Brazilian roads keep information on each segment, making the intelligent environment;
- Development of an action controller module to assess the drivers' behaviors in relation to Brazilian traffic laws;
- Automatic analysis of the use of Economic Driving Techniques;
- Availability of a equipments of truck cabin that can be easily assembled and disassembled, which provides mobility to the simulator without losing the characteristics of interaction with real equipment, aiming at increasing the users' sense of presence.

The process of evaluation and training was conducted at the Institute of Traffic Education and Transport (ISETT), which was taken as a case study for planning the simulator. This is a typical institution in the Brazilian driver training market, maintained by a group of transportation companies. During the training, an instructor evaluates subjectively how the driver controls the truck, registering the mistakes noticed during the training routes. However, this process is subject to failure because it is nearly impossible for the instructor to monitor all the driver's actions during the whole route, which may reach 3000 km and last about one week.

A. Choosing the simulation platform

In order to develop this prototype we researched open source driving simulators, in order to select software to be used as basis for implementing the virtual environment and for controlling new data input devices. After the research, TORCS - The Open Racing Car Simulator [6] was chosen.

TORCS is an open source racing car simulator, written in C++ and OpenGL, which incorporates a high quality physics engine, capable of representing collisions and effects of gravity, friction and inertia on the acceleration of vehicles. Moreover, it is a multiplatform system available for Linux, PowerPC, FreeBSD and Windows, which uses graphic libraries in the OpenGL standard and has a track generator. Another feature of TORCS that was taken into consideration for its selection as the basis for the simulator system was the existence and ease of adding new autonomous vehicles that can simulate the movement of traffic, simply by making the configurations in XML files.

For allowing a more realistic interaction between the driver and the simulator, the TORCS kernel was altered in order to accept data input devices similar to the controls of a truck (pedals, gearstick, switches, etc.). A module for controlling and monitoring the actions of the drivers was also included, in order to allow their assessment and ability to follow the rules prescribed by the Economic Driving Techniques.

B. Modeling the Simulator

In order to develop the simulator, it was necessary to research data about Brazilian roads and the necessary ways of monitoring for registering events during the simulations. For the stage of modeling the virtual environment, a route for the user to drive was developed, with suitable features for Brazilian roads, and a model of truck to perform the simulation was set.

In addition, the virtual vehicle models used in the simulation were obtained based on a visit to the ISETT headquarters, accompanied by the team of Economic Driving instructors from the Institute. The vehicle developed is a truck with dimensions of 2.60m wide, 12.20m long and 4.40m high, with total gross weight of 29T, 400hp of power and torque range from 1200 to 1400 RPMs (rotations per minute). The gear system of the truck is composed of 14 forward gears, distributed into two boxes (main and auxiliary) in addition to the low box, and two reverse gears. It also has settings for the engine brake and the stationary brake.

Figure 1. presents the virtual track and the truck, from driver viewpoint. This figure shows the rear-view mirror (A); a plate speed limit(B); the simulation time(C), the air brake meter (D); the tachometer (E), and speedometer (F); the reduced box indicator (G); the stationary brake indicator (H); and the engine braking indicator (I).

C. Monitoring and Data Analysis

In order to allow the simulation of situations that require the driver to use economic driving techniques, such as driving in urban route, traditional and electronic speed bumps, eight instructors from ISETT were interviewed. In these interviews, the following questions were asked:

- What are the drivers' most common mistakes?
- Which mistakes cause more loss to the companies?
- Which important events often do not occur in training trips?
- Which situations or mistakes are harder to be perceived by the instructors?

- What are the exceptions to the use of Economic Driving Techniques?
- What is the minimum knowledge of the truck that a driver needs?

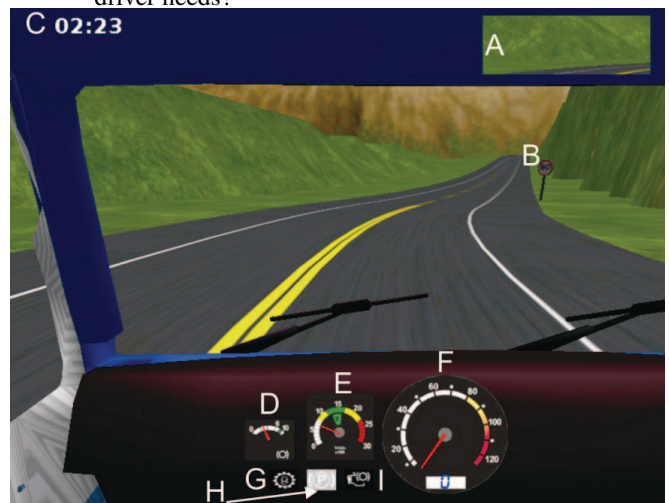


Figure 1. User visualization

From the answers reported by the instructors, a set of actions that should be monitored by the simulator was established, which are:

- Control of engine RPMs: the RPMs must be maintained within the economic range of the engine, and this is perceived through the tachometer, keeping the pointer inside the green line;
- Changing gears: the gears should be changed in the limits of the economic range and the driver must not drive in neutral;
- Starting the car: it should be started in 1st gear or, in special cases, in reverse gear or 1st tractor. It should also have a minimum amount of air brake in the cylinders;
- Sudden brakings: the service brake must be pressed gradually and smoothly;
- Use of the engine brake: the engine brake should be on only during descents and it should be operated with the engine in ideal or high RPMs.
- Use of the clutch: one should not drive with the foot on the clutch pedal, except in for changing gears;
- Speed Control: The driver must respect the speed limit indicated on signs along the route of the simulation;
- Position of the truck on the roadway: the roadway is the right place to travel, the driver must not travel on the shoulder.

Based on these items, it was planned a control module integrated into TORCS engine. This module receives data from physical input devices, analyzes them based on the types of track where the driver is at the right time and stores this data to create the final report of the simulation.

D. Development of the physical interface

Aiming to increase the degree of immersion of the simulator, a truck cab was assembled, with real equipment such

as steering wheel, accelerator, brake and clutch pedals, gearstick, stationary brake and engine brake (Figure 2.). The collection of data generated by these devices is accomplished with digital and analog sensors. The digital sensors were used to verify if a device, such as a key of the panel or of the gearstick, is on or off. The analog sensors were used for measures such as the force on each of the pedals of the truck and the number of turns of the steering wheel.

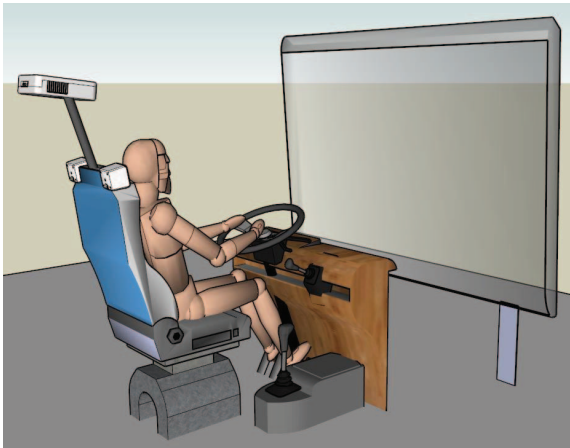


Figure 2. Physical configuration of the Simulator and user visualization

The gearstick is composed by a stick with free movements, such as the ones in a real gearbox. The stick has a switch, called shift, used by the driver to change the gearbox, and another switch to activate the reduced box. The gear system simulates a traditional gearstick in Brazilian trucks and is shown in Figure 3. In this system, each gear is equipped with a digital sensor that indicates its activation, besides the handle shifts.

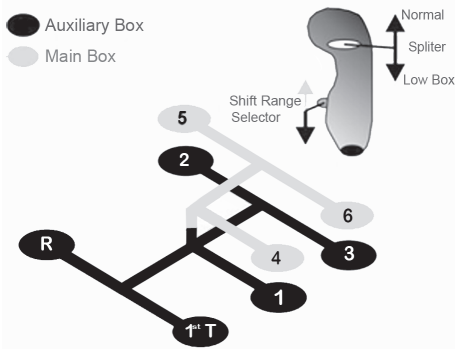


Figure 3. Outline of the gear shift

The pedals are responsible for most economic driving actions that the driver should perform. To give a greater sense of realism, the pedals of the simulator were equipped with springs that seek to simulate the physical characteristics of the activation of pedals in a truck with active hydraulic system. The movements of the pedals were captured via analog sensors, such as potentiometer, which perceive the driver's actions on each pedal. Figure 4. shows the characteristics of the installation of equipment on the pedals.

A real steering wheel with a mechanism that allows the driver to perform up to 5 laps around its axis was used for the steering wheel of the simulator. Data collection related to the spin of the steering wheel is performed through a pot equipped with a reduction pulley, as shown in Figure 5.

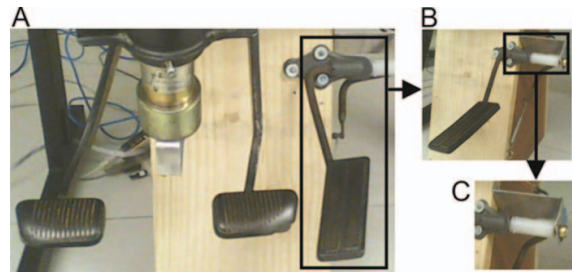


Figure 4. Control pedals (A), detail of the use of spring in the pedals (B) and detail of the use of pots for collecting data (C)

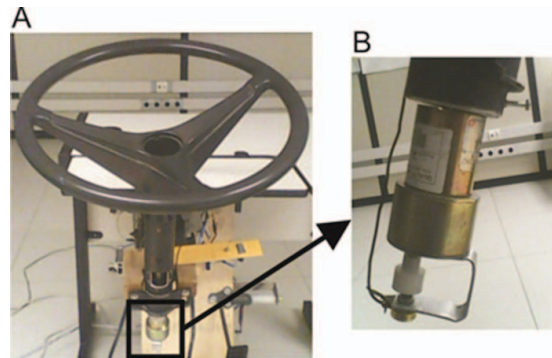


Figure 5. Steering wheel and steering wheel column (A) and detail of the RPM reduction system for reading data (B)

The brake system of the simulator is composed of stationary brake, engine brake and service brake. The stationary brake is activated by a switch located on the truck panel. The engine brake uses engine power to generate resistance in both axis and reduces the speed. In this case, it must be activated in the truck panel through the use of the brake pedal. The service brake is the brake pedal itself and its capacity varies depending on the pressure on the pedal by the driver.

V. EVALUATION OF THE PROTOTYPE

To assess the functionality of the simulator as to the data input devices, the way of collecting and analyzing data related to economic driving, there was an empirical evaluation with a sample of 14 users, divided into two groups. The first group had six participants and was composed of instructors of practical lessons in economic driving. The second group had 8 participants, who were all truck drivers. In the group of drivers, 75% identified themselves as trainees and 25% as professional drivers.

To organize the evaluation, the following hypotheses were made during the development of the project:

H1) The simulator is capable of capturing the same violations to economic driving techniques that a human expert would identify;

H2) The report generated by the simulator is a tool that helps the instructor assess the driver being trained;

H3) The set of interaction devices has a similar quality to real devices in a truck as to how the user uses them.

Tests that aimed at corroborating hypothesis H3 and evaluating the data input devices were carried out in both groups. Besides these tests, for the first group (instructors), we attempted to corroborate hypothesis H2, with the instructors following the tests with the drivers and comparing their opinions with the final report generated by the prototype. With the group of drivers, we sought to confirm hypothesis H1. In these tests, there was always an instructor who followed the simulation and recorded the perceived violations. At the end of these test sessions, the reports by the system and by the instructor were compared.

A. Tests with instructors

The tests with instructors were carried out in two stages. Firstly, the instructors were divided into two groups and each group watched a driver being tested and then evaluated the report made by the simulator, in order to verify whether it can be used as a tool for analysis of the behavior of the driver that is using the simulator.

In the second stage, the instructors used the simulator themselves, in order to evaluate the physical devices of the simulator and the quality of the simulation as to realism of movements and of images presented. These tests also intended to verify whether the drivers who used the simulator were able to identify violations to Economic Driving Techniques committed during the simulation

B. Tests with drivers

Two economic driving techniques instructors from ISETT were present in the tests with the drivers, who were previously trained to register in the system the violations committed by the driver during the simulation. Subsequently, these data were used to corroborate hypothesis H1. All simulations were videotaped for further analysis and assessment of the weaknesses of the simulator. In the first stage of the testing there was an adaptation of the driver to the physical devices of the prototype and its method of use. In order to do this, the driver drove the truck during 2 or 3 laps on a 2.7 km long track, with similar characteristics to the track where the test would be carried out. Training was finished when the driver believed to be comfortable with the system and its devices.

When the training phase was finished, the test itself began. The first task of the simulation was to ask the driver about the conditions of the truck. In order to answer them, the driver should know the current state of the truck, by observing the instrument panel. Then, the driver started to drive the virtual truck in the test circuit, performing the tasks he was requested. All the drivers performed the same tasks in the same locations. The purpose of these tasks was to cause situations when the driver should use economic driving techniques.

After completing the simulation, the driver filled in a form in which he scored his perception of the physical devices and of the system responsiveness. The driver also could comment, criticize and make suggestions on the devices.

VI. RESULTS

The first evaluation aimed to determine if the simulator was able to perceive the same violations in the use of economic driving techniques that the instructor noticed during the route. For doing this, the number of occurrences perceived by the instructor and by the system and the moment when these events occurred were compared.

To make the comparison between the data in both models (simulator and instructor), ANOVA was used for each item, based on the six valid tests. In this case, the determining factor was the amount of occurrences in each model, so the items without any detection were excluded from the analysis. A significance level of 5% ($\alpha = 0.05$), was considered for all the items in analysis, that is, for the results to be considered statistically equal, the p-value (TABLE I.), which was obtained with ANOVA, should be higher than the value of α .

In the items where the p-value is greater than the significance factor α (#1 to #10), the statistical measure indicates that the difference in the number of violations detected by the system and by the instructor is not significant and can be ignored, so that they can be considered statistically equal. In the items when it does not occur (#11 to #13), it is possible to conclude that the values are very different and cannot be considered random errors that occurred in the test samples, so they cannot be considered statistically equal, which indicates that the results by the instructor and by the system are not the same.

TABLE I. RESULTS OBTAINED IN P-VALUE WITH THE APPLICATION OF ANOVA WITH $\alpha=0,05$

#	Item	p-value
1	Disrespect to speed limit	0,508
2	Driving with low RPMs	0,705
3	Driving with high RPMs	0,147
4	Driving with very high RPMs	0,713
5	Incorrect start or stop	0,165
6	Driving with the foot on the clutch pedal	0,522
7	Incorrect use of stationary brake	0,145
8	Incorrect use of engine-brake	0,713
9	Sudden stop	0,207
10	Driving out of the road	0,780
11	Incorrect use of neutral gear	0,049
12	Changing gears with low RPMs	0,005
13	Changing gears with high RPMs	0,004

In the items where the results were not equal, we made a review of the videos recorded during the simulation by comparing them with occurrences perceived by the instructor and by the system, searching for reasons that explained such a difference. In the items related to changing gears (#12 and #13), the disparity occurs by a difference in how the actions are

identified by the instructor and by the system. The instructor performs his analysis based on his experience in a real truck that causes fluttering, bumps and different sounds in each situation, without focusing specifically in the engine RPM control, which is the parameter used by the simulator, together with the relief of the track. As the fluttering did not occur in the simulator, the instructor could not perceive them.

As to the item "incorrect use of neutral gear" (#11), it was noticed in the review of the videos that the system identified one violation every time the driver made a mistake changing the gears, which made the gearshift stay in neutral, while the instructor did not consider this a driver's mistake. In this case, it is possible to say that the system detected this occurrence incorrectly.

Through the instructor's reports, it was possible to notice by watching the videos that most occurrences related to changing gears detected by the system were correct, except when the vehicle was picking up speed or stopping and when the violations perceived in the use of neutral gear were incorrect. Thus, it is possible to corroborate hypothesis H1, as the system is able to detect the occurrences of infractions to the economic driving rules practiced by the user in most items.

In order to evaluate the physical devices of the prototype and its responsiveness, all the participants (drivers and instructors) answered a questionnaire after performing the tests with the simulator. They were asked to attribute scores between 1 and 5, for each of the physical components, which are accelerator, brake, clutch, gearshift, steering wheel, instrument panel and steering wheel position, and the reactions they perceived within the system as to acceleration, braking, changing gears and steering wheel, as well as the entire set of devices. The scores were accounted on a Likert scale from 1 to 5. The graphs in Figure 6. and Figure 7. , presents the mean and standard deviation obtained from the users' responses.

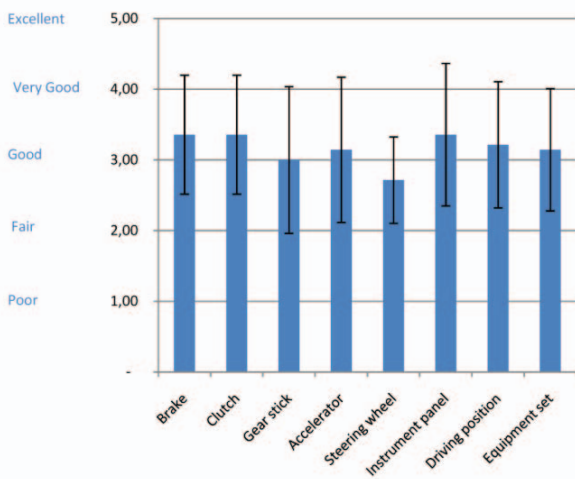


Figure 6. Subjective evaluation of the system devices

By looking at the graph (Figure 6.) we can see that the devices of the brake, clutch, gear stick, accelerator, instrument panel and driving position were classified as "good", and the

steering wheel was classified as "fair." This may have happened because all devices, except the steering wheel, had mechanisms that offered resistance to their activation, so that the user needed to use a similar force to that in a real truck to perform the task. However, the steering wheel did not use force feedback mechanisms, so that the user always used the same force in all situations.

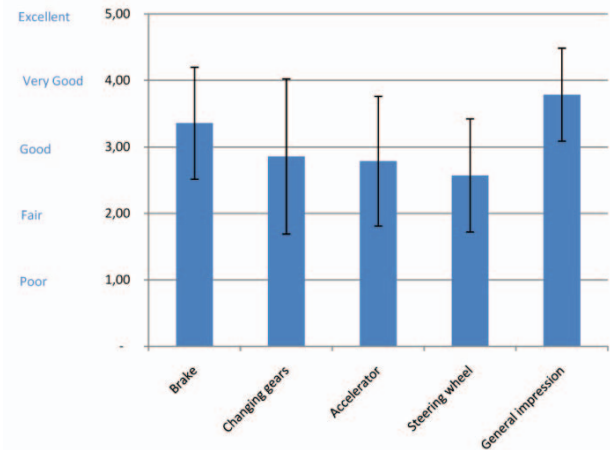


Figure 7. Subjective evaluation of the system devices responsiveness

Regarding the responsiveness of the system, that is, the degree of realism perceived by the user in the system reactions to the execution of real tasks, it was possible to notice (Figure 7.) that there is a need for improvement, since only brake reactions were scored 3,00 and classified as "good." The remaining items related to acceleration, changing gears and steering wheel, were scored below 3,00, and were classified as "fair." One hypothesis for the fact that the reactions of the virtual environment are inconsistent with reality is that the software used as the basis for development (TORCS) has its physical simulation based on cars rather than trucks, which may have affected the interactions of the virtual truck with the virtual environment. When the user was asked to evaluate the prototype as a whole, taking the physical devices and their responsiveness into consideration, an average above 3.00 ("good") was obtained, corroborating the hypothesis H3.

Regarding the final report of the simulation, we asked the instructors who followed the simulation sessions to evaluate the result given by the simulator and compare with their impressions of the driver's performance, and to indicate the usefulness of this report to make a final report about the driver being trained. In this case, 100% of the instructors said that the report would be useful to assess the driver, which corroborates hypothesis H2.

Among the observations made by the instructors, it is possible to see that the system perceives more actions than a human, and that the report allows the instructor to assess the data more objectively and more calmly for expressing a position about the driver, and may even indicate specific trainings to improve the learner's ability, based on data from the report.

VII. CONCLUSIONS AND FUTURE RESEARCHES

The use of simulators for training is growing every day, especially in areas that involve risks for the learners and for those around them or for the environment. In addition, the costs can be very high in trainings in which it is necessary to use equipment and real situations that depend on input to be accomplished, which can be reduced with the use of simulators.

In this research we built the prototype of a truck driving simulator, which is able to monitor economic driving actions practiced by drivers and to record their violations, in addition to defining a methodology to assess the driver's actions. In order to prove the efficiency of the simulator and of the methodology proposed in this paper, tests with truck drivers and economic driving instructors were carried out.

As to the physical devices developed, it was possible to notice that communication between the system and the equipment met the needs of the project, and the system was able to capture the actions performed on the equipment properly. Using real parts helped the users get acquainted with the equipment and facilitated their interaction with them. Aiming to improve the way data are captured, it is possible to use analog sensors with greater precision to capture the actions performed on the pedals and steering wheel more faithfully.

The virtual environment used in this research was efficient as to the level of realism of the roads, which were designed to represent the reality of Brazilian roads, but presented deficiencies in relation to responsiveness of the system. An alternative to improve its responsiveness is to develop an engine that simulates the physical effects based on trucks, since the system used as a basis for development simulated physics with cars.

Although the report made by the system with the results obtained during the assessment of the driver's actions perceived some violations incorrectly, it is a useful tool for instructors who are assessing drivers.

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