Driving Simulator Use for Pre-Crash Tests

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Abstract

This paper presents the first experiment managed as part of the Sciences and Technologies for Safety in Transport (ST2) program, a French national research project. In this program, human physical reactions are studied in order to adapt primary and secondary safety systems to driver behavior. The objective of the present study was to examine how car drivers modify their posture just prior to a frontal impact (pre-crash) and to use the resulting data to model possible anticipatory postural changes using a digital human model. The experiment was conducted with 35 subjects using SHERPA, the driving simulator at the LAMIH research lab. After a short training session, during which the subjects were allowed to familiarize themselves with the simulator, all subjects were asked to complete a 50-kilometer run, in which the last traffic situation was a pre-crash situation. Reactions to this pre-crash situation show that the simulated crash was realistic: all subjects swerved immediately, and then experienced feelings of nervous agitation. Further data shows that none of the subjects was in the standard driving position at the time of the crash, and that the movements made to control the situation put the subjects into risky positions.
Introduction

Many studies have dealt with the communication between drivers and driver support systems in three crash states: pre-crash, crash and post-crash. These supports aim to mitigate crash severity by first informing drivers when a collision is imminent in hopes of avoiding the crash, and if this is not possible, protecting them during the crash by triggering such secondary safety systems as pre-tensioning seatbelts and airbags; tertiary safety systems can then initiate automatic telephony in order to inform the proper authorities. Analyzing the transitional periods between each type of safety system is not easy because drivers must experience an accident situation in order to evaluate the new support systems. One way to make this task easier is to use simulation.

One approach to studying crashes is to analyze accidents as they "occur" by reproducing the actions of both drivers and vehicles in the period leading up to a crash. Wood et al. have proposed a vehicle and traffic simulation methodology that allows this to be done [12]. These technologies use both national-level and in-depth accident data that can provide a relatively unambiguous description of the circumstances surrounding an accident and the nature and cause of any injuries. These authors try to understand the events occurring before and during a crash by using physical evidence from the scene, and from the vehicles. The objective is to simulate vehicle movement and the final resting positions of the crash victims. Expert investigators arrive at the scene of an accident within 10 minutes of its occurrence to gather information, including trace marks on the road, pedestrian contact marks on vehicles, the final resting position of the vehicles involved, witness interviews, weather, visibility and traffic conditions.

Another approach is to simulate crashes using a driving simulator. One previous simulation experiment studied driver responses when faced with imminent collision [8]. Drivers situated in two adjacent, full-vehicle simulators acting within a single shared virtual driving world were asked to respond to two ambiguous traffic situations: one at an intersection and one at the top of a hill. The initial results demonstrated that it was possible to provoke realistic avoidance behaviors in such an interactive simulation environment. These results also underlined the importance of drivers being able to see one another clearly and in time. For drivers who have “enough time to see and react”, a warning system may be effective, but without "enough time to see and react”, the result is random-patterned “panic” avoidance reactions. The authors of this study interpret the observed swerving tactic as a result of the roadway characteristics.

Another experiment, which studied subject reaction time during impact, showed that the driving simulator can reproduce the real situation quite well [7]. This experiment verified that drivers do try to avoid accidents by reflex reaction, and that these reactions are the same in a virtual driving situation as in a real one. In fact, in an emergency situation, drivers operate with their reflexes in an open-loop mode, thus the perceptive bias of the simulator seems to have no effect on the initial evasive reactions.
A more recent experiment has highlighted the value of using a driving simulator to analyze driver behavior during critical events [6]. The author wanted to find out if different critical events could be designed that would all elicit the same driver response and if the effect of secondary tasks on driver responses to the events could be measured. The conclusion was that it is easier to define critical situations than to design several events that provoke the same driver response. When designing critical events, certain precautions must be taken. For example, the predictability of the event must be low in order to avoid an anticipation effect. In addition, the event must be critical enough to obligate the driver to produce a collision-avoidance maneuver.

A fourth experiment, conducted in 2005 by the Mercedes Car Group, used the DaimlerChrysler Berlin driving simulator to demonstrate the benefits of braking assistance systems for emergency braking [9]. In this experiment, subjects driving on a city street at approximately 50 km/h had to react to the sudden appearance of a child in the road. In this situation, the possibilities for avoiding an accident were limited.

Method

Because designing and setting up an experiment can take at least 6 months, it was decided that three LAMIH research teams (Crash Worthiness Modeling and Testing, Cognitive Psychology and Ergonomics in Technological Environments, and Human-Machine Systems) would work on the same experiment. The road databases were built with the software tool, EVARISTE NETWORK©, by the Oktal company [10]. Many different traffic situations were defined and then calibrated to make them both appropriate for different types of drivers and as realistic as possible. The first part of the experiment dealt with human error, specifically violation [1]. This paper presents and analyzes the second part of the experiment, related to the pre-crash test.

A total of 52 subjects took part in the experiment. Because each team has different objectives for their part of the experiment and because a counterbalance for the effect of scenario order and type of scenario was needed, this subject population was divided into four groups, which completed different combinations of the experimental runs: 1) one run with collision and one run without, 2) one run with no collision and one run with, 3) a single run with collision, and 4) a single run with no collision. For this reason, only 35 randomly-selected subjects participated in the crash runs. Most of the 35 subjects (85.7%) were between 22 and 30 years old, with more men than women: 26 compared to 9. Half of the population had had their driving license for less than 7 years, and the other half had had it for between 8 and 27 years. The scenario was constructed so that the subject would understand that incidents might be triggered.

Experimental protocol

Driving simulator

The experiment was carried out using the LAMIH driving simulator, SHERPA, which is a full-scale driving simulator used for studying driver/vehicle/environment interactions (Figure 1 and Figure 2). SHERPA (the French acronym for “Simulateur Hybride d’Etude
et de Recherche de PSA Peugeot Citroën pour l'Automobile”) is a fixed-base simulator derived from a fully instrumented Citroën Xantia mock-up, including a dashboard, a gear lever, and a steering wheel with force feedback, as well as accelerator, brake and clutch pedals. A sound feedback generator reproduces the sound of the engine, as well as any aerodynamic noise and Doppler effects for the traffic. The driving environment is defined as the combination of road infrastructure, meteorology, and the traffic situation.

SHERPA is powered by a Onyx 2 workstation that allows the road environment to be generated at up to a 60 Hz refresh rate. The same workstation does the calculations necessary for generating the traffic and the dynamic model of the vehicle. A PC handles the I/Os for the car mock-up and the computations for the steering model that operates the steering wheel force feedback. The PCs, which are connected to an optic fiber ring, obtain information about the simulator through a "reflexive memory" card that manages the principal simulation variables, such as data relative to the subject vehicle (e.g. acceleration, speed, position, driver actions) and data relative to the other vehicles on the road. Three BARCO 6400i LCD projectors (1280 x 1024 pixels) project the front scene onto three 3m80 x 2m70 flat screens set in a 3m50-radius circle centered on the driver's head, thus providing a 180° front visual field. A single rear scene is projected by a BARCO 6300 LCD projector (1024 x 768 pixels), providing a rear visual field of 50°.
A command cabin (cf. Figure 3) allows the supervisor to act on the virtual environment at any moment of the simulation. Figure 4 shows the recorded video feedback.

**Experiment**

After a short training session designed to familiarize the subjects with the simulator, each subject was asked to drive a 50-kilometer run (35 to 40 minutes). The run was mainly composed of main roads, with a small section of motorway. Throughout the trip, regular traffic was reproduced so that subjects would respect the Highway Code and adapt their driving to the presence of other cars. Five minutes before the end of the experiment, a stress situation occurred to make the driver attentive: a car approaching a crossroad from the right runs the stop sign, which could provoke an accident with the subject vehicle. This situation was designed to remind subjects that unpredictable events may happen at any time. After a few minutes, an unavoidable crash situation was introduced. A truck pass a tractor, heading straight towards the subject vehicle. The presence of trees along the side of the road coupled with the trucks makes the crash unavoidable (cf. Figure 5).

To increase the level of reality, a real physical impact was added. At the moment of the virtual crash, a substantial foam rubber block fell from the ceiling of the experimental room, impacting with the windscreen of the car, and the sound of a truck horn was emitted.

Figure 5 : Scenario of the unavoidable crash situation, with the sequence of the falling foam in the thumbnail pictures

Videos of the front and back screen (cf. Figure 4) as well as driver views were recorded during the experiments. The driver-vehicle-environment interaction parameters were measured, such as steering wheel position, state of the pedals, gear lever position, and the arrangement of the vehicles on the road. Spontaneous verbalizations were also recorded. Driver comments on the critical situations and their state of mind during these situations were recorded during the video replay of the experiment.
At the end of the run, drivers were asked to report on the quality of task execution after viewing the video record of the run ("self-confrontation"). They were also asked to fill out questionnaires evaluating their driving characteristics (behavior patterns) and their reactions to each separate situation.

**Results**

The results were obtained by analyzing the subjective and objective data. Subjective data include both the drivers' verbalizations during the self-confrontation phase and their answers to the questionnaires. Objective data include the time needed to release the accelerator, to brake, to engage the clutch, and to change gears, as well as the amplitude of the braking and swerving maneuvers provoked by the trucks' overtaking maneuver.

**Realism**

Subjects had to drive for nearly 40 minutes. After about 20 minutes, drivers were comfortably settled in the seat, generally with only one hand on the steering wheel, and the left elbow resting on the door. Some drivers mentioned that they experienced the same driving pleasure as in the real world. The mean speed, just before the accident, was 70.18 km/h (standard deviation: 12.8 km/h). This seems realistic, considering the type of road, which is the beginning of a wide turn.

Only 3 of the 35 subjects said they were expecting something because of the unusual amount of farm equipment and trucks on the road. Of the 30 subjects who verbalized about the collision, 6 said they were conscious of being in a simulator during the situation, and so, found the experiment amusing instead of stressful. In contrast, 8 drivers said they were quite nervous. For 18 drivers, the situation happened too quickly for them to be able to do something to avoid the collision, and 8 said that it happened so quickly that they had no time to even be afraid. Only 3 drivers thought they could have avoided the collision. It is interesting to see that 10 drivers expressed opinions about the truck driver's driving, either remarking that the driver didn't obey the Highway Code or that he/she should have reacted to the presence of another vehicle and aborted the overtaking maneuver. In addition, 8 subjects could imagine the accident in the real world, or connected it to a past accident in which they had been involved.

**Driver behavior and vehicle trajectories**

All drivers tried to control the situation by swerving to avoid the truck in front of them. Surprisingly, 20% of the subjects tried to avoid the truck by turning to the left. Still, 51.4% of the subjects returned to the right lane quite rapidly.

A few of the subjects (22.8%) clutched but did not change gears, and 34.28% actually changed gears during the 3 minutes following the trucks' overtaking maneuver. Only one subject didn’t brake at all.

**Driver pre-crash positions**

Injury to the upper body is the main risk in a frontal crash. To verify the position of the upper body, i.e., hands, head and chest movements (rotation, translation) just prior to the
crash were analyzed. Left hand pre-crash positions: The results showed that 30% of the subjects had their left hand in a risky position, which means that the left arm was just in front of the airbag at the time of crash.

Right hand pre-crash positions:
- 37% of the subjects had their right hand on the gearshift,
- more than 52% kept their hand on the steering wheel,
- less than 3% kept their hand on the handbrake, and
- less than 8% had their hand in another position (e.g. on the thigh).

Chest positions:
- more than 67% of the subjects moved back in anticipation of the crash, with the majority (57% of those moving back) rotating the chest,
- 8% moved towards the steering wheel,
- less than 3% rotated the chest without moving back,
- 22% had no postural change.

These results clearly show that none of the subjects adopted a "standard" driving position during the collision; all were out of position with regard to the standard posture imposed on crash test dummies. This standard requires the driver's back be set against the seat back, with the hands in the “10h10” position, the right foot on the accelerator pedal, and the left foot close to the clutch. Our next step was to measure the posture of the subjects to try to discover how much of a risk drivers run with an “Out-Of-Position” (OOP) stance.

**Pre-crash posture measuring**

In order to make the driving simulation as realistic as possible, no intrusive element, such as motion markers, was used. Instead, we employed the method proposed by Mickaël Hetier [2], which uses a digital model to deduce motion data.

This method was performed in three steps. First, a digital model of the subject was created by superimposing a mannequin into at least two photos of the different images taken in a calibrated space, using the software MAN3D developed by INRETS [11][2]. Second, the standard "crash test dummy" driving posture described above was used as a reference for positioning the digital model created in step 1. Third, the subject's pre-crash posture was analyzed and modeled using a numerical model.

A 3D scanner was used to record the geometry of the vehicle cabin. This scan showed the coordinates of all the necessary points for the calibration, and the realistic digital model was inserted into the calibrated picture and adjusted to the subject's driving position (cf. Figure 6).
Figure 6: Estimation of the driver’s standard driving position by inserting the subject’s digital model in the calibrated area.

The foot position was analyzed for the case in which the driver did not touch the clutch more than 10 seconds before impact. The right foot was situated on the brake pedal and left foot was deduced to be very close to the clutch.

Once the seat adjustments, the subject’s anthropometry, and the positions of the hands and feet were known, the driver’s posture at the time of impact could be estimated by using the inverse kinematics method. As stated earlier, 30% of drivers had their left hand to the right of the steering wheel, thus placing it just in front of the airbag at the time of crash. At the same time, 37% of drivers had their right hand on the gearshift. In addition, 67% of the drivers moved back in anticipation of the collision, with a majority of them rotating the chest.

The most representative of the OOP posture was modeled with Madymo®, and compared to a normalized situation (cf. Figure 7).

The load applied to the virtual dummy corresponded to the deceleration undergone by a car during a head-on collision at about 50km/h. The linear head acceleration, for the standard and OOP postures, shows that the maximum head acceleration value is 60g for the standard position, whereas it reaches to 180g for the chosen OOP posture. This is due to the impact caused when the airbag projects the arm into the head, and corresponds to a critical situation which could lead to a mortal traumatism.
Conclusion and perspectives

This paper focused on frontal pre-crash driving postures. In terms of the realism of driver actions, according to the drivers’ category, the subjective and objective data indicate that most of the subjects reacted as they would do in a real situation. In terms of pre-crash posture measurements, the most striking result is that none of the subjects adopted the standard driving position used in crash experimentations. About a third of the drivers had their left hand placed in front of the steering wheel, which is a rather risky position, especially given that airbags are usually mounted on the steering wheel. The Madymo simulation confirmed this danger. The next step will be to integrate these observations into a predictive postural model that can be used, with the method proposed by Hetier et al. [2], to optimize protection systems (e.g. airbags, seat belts) in order to minimize crash-related injuries. In addition to the data presented in this paper, we would like to use data related to driving styles and morphological characteristics in order to perform a multiple correspondence analysis. Driver typologies could be constructed and used to predict which behavior a driver will adopt in a certain kind of situation. Because of the well-known inter-individual differences, physiological measurements will need to be recorded in order to distinguish the cognitive part of the activity from the sensorimotor activity. New experiments will be done at the beginning of the next year using the new dynamic version of the driving simulator (6 DOF motion platform), with part of the tested population fitted with physiological sensors [4].

References


