METHODOLOGY TO INTRODUCE SCENARIOS OF ACCIDENT IN DRIVING SIMULATORS
INTEREST FOR THE ANALYSIS OF DRIVERS' BEHAVIOR

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ABSTRACT

Simulators provide a fairly realistic reproduction of driving environments so that the behavior of drivers immersed in such systems is representative of what can be expected on the road. However, situations and scenarios which are introduced in these simulators are sometimes too approximately defined and not very realistic.

We have thus developed a methodology to simulate accident scenarios. The scenario concept used concerns a group of accidents presenting similarities from the point of view of the chain of events leading to the collision. The sequential analysis method used to group accidents in the form of scenarios is based on a segmentation of their progression. A set of scenarios have been spatio-temporally implemented into the IFSTTAR[1] simulator using data from real accidents collected in the French in-depth accidents investigations program EDA from the research unit,

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[1] The two institutes, LCPC (Central laboratory of roads and bridges) and INRETS (National institute for transport and safety research), merged on the 1st of January 2011 to create IFSTTAR (French institute of science and technology for transport, development and networks).

Accident Mechanism analysis. They have then been validated before being submitted to different populations of drivers.

Methodological aspects of this procedure are described and past use of such scenarios is evoked: for example to study drivers' capacities as a function of driving experience, or the effects of alcohol and medicines. Finally, some examples are given concerning future development, e.g. accident scenarios to be introduced in a powered two-wheeled simulator.

Keywords: methodology, driving simulation, accident scenarios, in-depth accident investigation.

INTRODUCTION

Simulators became indispensable tools for improving our understanding in the field of automobile driving. Investigations carried out with this type of tool concern driver behavior, vehicle design, road infrastructure design and training. Simulators provide many advantages: absence of risk, reproducibility of situations, control of experimental parameters, time saved and reduced costs. Their flexibility also makes it possible to test situations that do not exist in reality or that only rarely and randomly occur. It is indeed the only safe way of exposing drivers to dangerous situations. Simulators are therefore indispensable, notably when studying accident-causing situations. Note however that the absence of risk, which is often considered an advantage, also raises questions when studying objectively risky situations.

Validation of the simulator's characteristics, in another hand, is vital before interpretation. The first level of simulator validity relies on the correspondence of the simulator's layout and dynamics with those of real vehicles and environment, referred to as "physical validity", which supposes that the simulator's dynamics accurately model those of a car. Moreover, their use entails verifying that the trends observed in a virtual setting are identical to those commonly observed on the road, e.g. their "behavioral validity". Studies show that "behavioral validity" can be a "relative". For example, when approaching a curve, drivers' speed profiles, but not values, are similar on a simulator and on the road (Godley et al., 2002), drivers seem in fact to adopt slower speeds on a simulator than on the road (Klee et al., 1999). Also, the classification of intersection dangerousness obtained experimentally was congruent with the crash information for their field counterparts (Yan et al., 2008).

The work presented here is part of the research and development field for scenarios used on driving simulators. Its purpose is to assess the relevance of including scenarios identified as accident-producers in simulation systems. The general hypothesis is that including them makes it possible to confront different populations of subject with difficult situations rarely encountered in natural driving conditions.

First, we will present our work on prototypical accident scenarios and the method used by researchers at IFSTTAR to identify them. We will then present the way in which these scenarios are implemented using objective data from the detailed data gathered on accidents before including them on the driving simulators. Lastly, we will talk about the different studies already carried out with such scenarios and current projects using this method.

METHODOLOGY

Accident scenarios

The concept of scenario, in the widest sense of the term, refers to the implementation of situations in which events occur in order to provoke a behavior (Fischer et al., 2002). In the literature relative to road safety, this concept refers to a category or type of accident. Scenarios reproduce infrastructures and prototypical situations that generate accidents. They correspond to a group of accidents presenting overall similarities from the point of view of the chain of events and causal relationships in the different phases leading up to the collision, and are actually prototypes of accident processes. The term "prototype" is used in reference to cognitive psychology to emphasize the fact that accident scenarios are abstract constructions that demonstrate the main traits of a set of accidents presenting similarities, and not a particular, concrete accident process behind any one of them. In general, the accidents in this set do not have an identical prototypical process, but are more or less similar (Fleury and Brenac, 2001; Brenac et al., 2003).

The procedure for drawing up prototypical scenarios has been largely described by their initiators and we will only go over the principal features (Fleury and Brenac, 2001). Representative samples of bodily-injury accidents for which procedures have been gathered by the police are used to draw up these scenarios. These procedures are rounded out, insofar as possible, by a collection of maps and photographs of the accident sites (Clabaux and Brenac, 2010). The accident is then considered as a series of phases or sequences that are linked chronologically and causally2.

This breakdown takes into account the spatio-temporal evolution of the situation as well as the interactions between the different parties involved. Its application to accident procedures established by the police makes it possible to extract prototypical accident scenarios and to determine all the factors playing a role in accidents (Brenac, 1997).

The researchers at the IFSTTAR Accident Mechanism analysis research unit have therefore listed a certain number of accident scenarios (Brenac et al., 2003), (Brenac & Fleury, 1999), (Brenac et al., 1996). Based on this work, a selection of prototypical scenarios can be made. In order to implement them spatio-temporally with precision, real accident data have to be associated with them. These data are available in the IFSTTAR in-depth accidents study database.

In-depth accidents investigations (EDA in French)

The objective of the in-depth accidents investigations (EDA) carried out at IFSTTAR in Salon de Provence is to increase the understanding of accident-causing mechanisms and dysfunctional processes in the road system. Highly detailed data, gathered in part at accident scenes, are used to reconstruct and describe their process, to explain the chain of causality behind this process,

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[2] The sequential accident analysis method used to aggregate prototypical scenarios is the result of in-depth accidents investigations. It was adapted to the study of police reports and the safety diagnosis context, which makes it possible to make a wider grouping of samples.

and to identify factors among the characteristics of the users, vehicles and infrastructures which, if controlled, could constitute preventive action.

EDA are based on:
- a system approach (interactions between users, travel tools and infrastructures),
- an analysis model (breakdown into phases of the accident process, described above),
- a kinematic model (reconstruction and configuration of the accident dynamic in time and space),
- an operating model of the human operator (data processing system).

These models guide the gathering of data by the team of investigators (a psychologist and a technician) and also their processing and their interpretation. The EDA strategy is based on gathering a maximum of data focusing on the accident process itself. The investigation covers three components which are the driver, the vehicle and the infrastructure (Girard, 1993). Information on bodily injuries and lesions is also gathered. The main objective is to identify, firstly, mechanisms causing the accident, and secondly, the role of the three components of the system in producing the dysfunctional situation. After processing, the case is archived in an electronic format.

Each EDA study thus contains a precise description of the circumstances and spatio-temporal characteristics of the trajectories and the environmental conditions of the accident process, among other information. These data are used to implement the prototypical accident scenarios that we include on the driving simulators.

Example: exploitation and implementation of a prototypical scenario

Description of the prototypical scenario

The scenario presented here was taken from the work by Clabaux and Brenac (2010, prototypical scenario 35, p 234). We will now present a summary description without describing the accident-causing factors identified, as our interest is focused on the general time/space characteristics of the process.

A driver is driving in an urban area in a priority lane at generally high speed (sometimes much faster than authorized by the regulations). Another driver coming from another street, a side access or arriving from the opposite direction, is about to undertake a non-priority maneuver (crossing the priority road or crossing the lane dedicated to traffic from the opposite direction). This driver sees the other vehicle but considers he has enough time to perform his maneuver before the other car reaches him, which is not the case. Only the priority driver undertakes emergency braking, but the collision cannot be avoided.

Real accident case (EDA) representative of this scenario

The situation occured in France (right hand driving). In the daytime, with clear weather, a driver (A) was driving along an urban infrastructure with a straight layout and two-way traffic, footways on both sides, parked vehicles on the carriageway's right side and on the left footway.

There was good forward visibility. Another vehicle (B) arrived from the opposite direction, whose driver wanted to fill his tank at the service station located to the left of his driving path. This driver turned left when he saw the service station, cutting off vehicle A path which was coming toward him. The carriageway was 8-m wide, but only 6 m were dedicated to traffic due to the presence of parking spaces. In the reconstruction of the circumstances of this accident, it appeared that neither driver involved was really attentive to the other's behavior.

Our interest in this accident did not lie in the possible dysfunctions and errors intrinsic to each driver, but rather in the kinematic reconstruction of the situation and in the configuration of the accident site. The reconstruction was carried out in several steps. Using the final position of each vehicle, we determined the collision situation, then the accident situation (rupture). The latter corresponds to the moment when an event created a break in the normal driving situation. In the case presented here, it was vehicle B (Figure 1, t=-1.1 s), by starting its left-turn maneuver toward the service station, that created the rupture and triggered the emergency situation in the system. The two vehicles' positioning in time and space shows that, with the speeds driven in this situation, the accident could not be avoided by vehicle A. In fact, when vehicle B started to cut across the lane on which vehicle A was driving (Figure 1, t=-1.1 s), vehicle A was still moving at approximately 60 km/h and, if we take an average reaction time of 0.8 s into account, even hard braking would not have enabled him to stop his vehicle before impact. As our objective was to include difficult situations on the simulator and not situations that systematically produce accidents, we had to adapt the different values from the accident reconstitution so that drivers on the simulator would be able to develop collision avoidance strategies.

We made the choice to have the driver on the simulator as vehicle A, i.e. the driver who had to react to a sudden situation imposed on him by the action of vehicle B and would have to avoid the collision. The hypothesis is that a driver A whose behavior is taken as a "reference", driving at a speed of 50 km/h as required by the regulations in an urban environment, combined with an average response time of 0.8 s and an average vehicle hard braking capacity (-8 m/s²), will take approximately 25 m to bring his vehicle to a full stop just before the point of collision (Table 1). So, we changed the real accident kinematic to get that when the driver on the simulator is 25 m from the possible point of collision, we confronted him with the accident situation (rupture): the obstacle vehicle B started to cut off his lane (Table 1). This distance remained constant whatever the speed at which the subjects drove, as we dynamically adapted the situation by increasing or decreasing the initial speed of vehicle B.

For a "reference" driver A behavior driving at 50km/h, we chose of assigning vehicle B a reference speed of 32 km/h at -6.8 s before the point of impact identified by the reconstruction; it then slows down to reach a speed of 2 km/h at the time when it moves into vehicle A's lane (i.e. -2.5 s before the point of collision identified by the reconstruction). Vehicle B then accelerates while turning left to reach a speed identical to that identified by the reconstruction at the time and position of impact (8 km/h; cf. t=0 s; Figure 1 and Table 1).
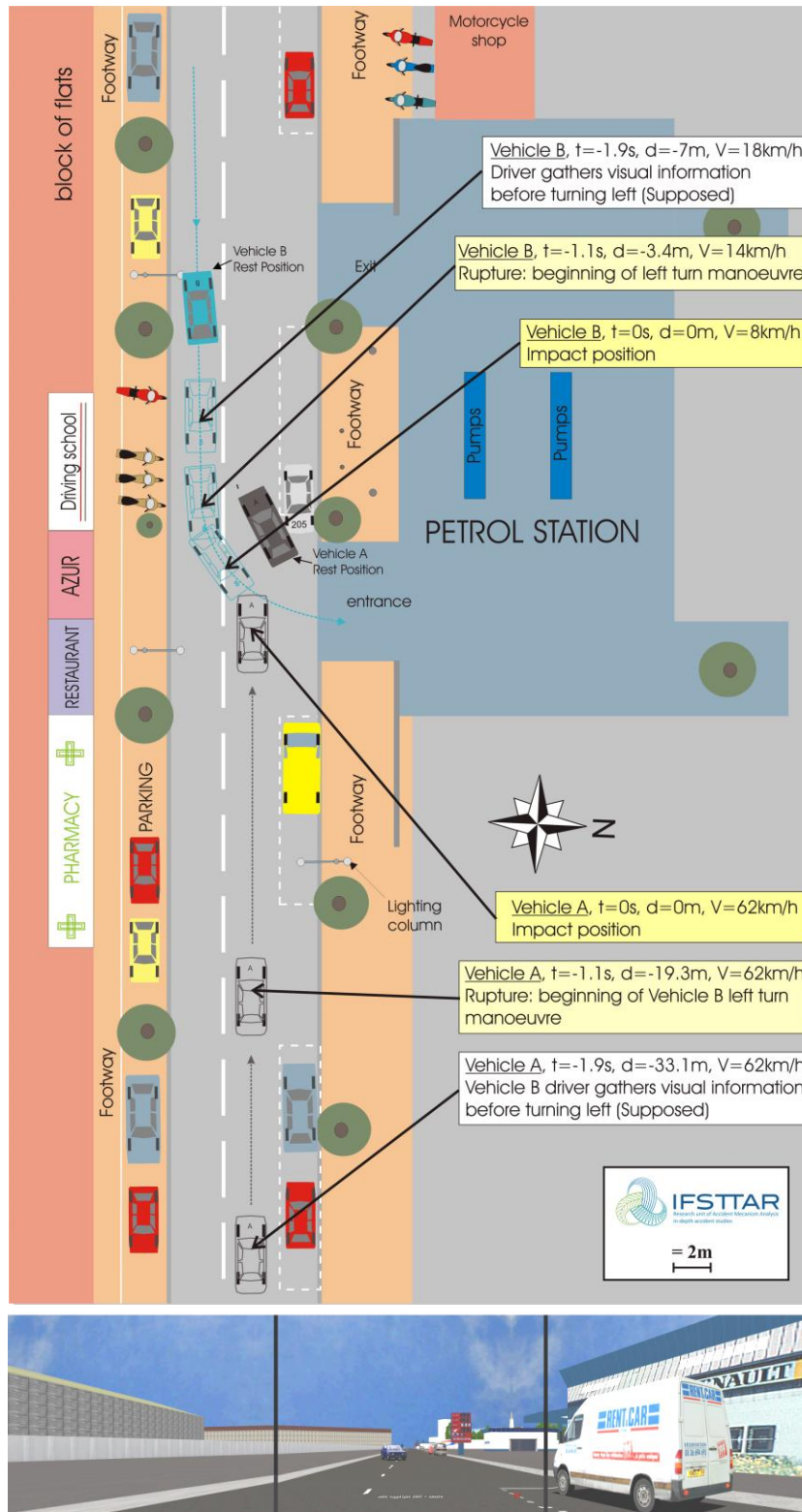
Figure 1 Accident kinematics reconstruction outcome of In-depth investigation and corresponding simulated situation

This example of prototypical scenario implementation, using data from a real accident case whose kinematics is adapted to achieve discriminating results for the studied drivers' population, is a part of a set of scenarios built with the same method. By example, we developed an "overtaking scenario" where the driver is overtaken by another vehicle which starts to pull back in ahead of him while slowing down, a "pedestrian scenario" where a pedestrian hidden by a bus parked on the right-hand side of the carriageway suddenly crosses the road in front of the bus, an "opposite vehicle crossing scenario" where another vehicle cross the subject's lane, a "parked vehicle scenario" where a vehicle parked on the right-hand side pulls out of its parking space, and some "left and right crossroads scenario" with an without visibility.

In the following section, we present an example of our experimentations and discuss future uses.

Table 1 Comparison of real and simulated accident progress

Sequential Analysis	REAL ACCIDENT		Time (s)	SIMULATED ACCIDENT		Sequential Analysis
	Vehicle A	Vehicle B		Vehicle A (Simulator) Reference Behaviour	Vehicle B (Adapted to simulator driver reference behaviour)	
Approaching phase			-6.8	d=-85 m, V=50 km/h	Beginning of slowing down d=-23 m, V=32 km/h	Approaching phase
			-2.5	Synchronisation of movements d=-25 m, V=50 km/h	Beginning of acceleration and left turn d=-3.4 m, V=2 km/h	Accident situation (Rupture)
	d= -33 m, V=62 km/h	Visual information gathering before turning left d=-7 m, V=18 km/h	-1.9			Emergency phase
			-1.7	Beginning of braking d=-12 m, V=50 km/h	d=-2.8 m, V=4 km/h	
Accident situation (Rupture)	d= -19 m, V=62 km/h	Beginning of left turn manoeuvre d=-3.4 m, V=14 km/h	-1.1			
Emergency phase						
Collision	d=0 m, V= 62 km/h	Synchronisation of movements d=0 m, V=8 km/h	0	d=0 m, V=0 km/h	d=0 m, V=8 km/h	Collision

Past and future use of such constructed scenarios

Such accident scenarios have been used to test the effect of driving experience on the ability to manage difficult, accident-causing situations (Berthelon et al., 2008). Two scenarios, out of four we have tested, clearly showed the effect of experience on driving. Faced with a "hidden pedestrian crossing" scenario, all subjects brake in the emergency situation in equivalent timeframes, but only experienced drivers combine braking with swerving toward the right before reaching the pedestrian. Faced with a "vehicle pulling out of parking", beginners take more time than experienced to take their foot off the accelerator; this long response time, combined with high speed, led to more collisions. This probably reflects greater forecasting abilities and greater skill than beginner drivers (Berthelon et al., 2008; Underwood, Chapman, Bowden and Crundall,

2002). Other scenarios could be included in the driving simulators and, with a view to improve driver training, it could be useful to confront young drivers with ranges of difficult situations not commonly encountered in natural driving.

Our accident scenarios have also been used to test any residual effects of hypnotics which have long and short half-life on older middle-aged drivers' capacities (55 to 65 years old) (Meskali et al. 2009). Results showed weak effects of active molecules on drivers' behavior but produced an increase number of collisions (but not significant) after intake of the hypnotics tested and notably with zolpidem, which was generally associated with no residual effect on drivers' behavior. The effects of treatment are therefore different from those usually found in the literature among young participants in monotonous situations such as motorways, although the two types of situations can not been directly compared (see Vermeeren 2004 for a review). The tendencies observed with elderly subjects in urban driving situations are however in agreement with driving performance observed with elderly subjects in monotonous situations (Bocca et al. 2011). Physiological changes that occur with age could indeed to be associated with modified sensitivity to the effects of hypnotic drugs.

Another field in which we have used accident scenarios concerns the effect of different doses of alcohol on driver behavior (Meskali et al., under press). We showed that the number of collisions increases with the level of alcohol, but not participants' responses times. Only one urban scenario involved a sort of increase of participants' reactions with the highest rate of alcohol: the brake pedal was pressed shorter and stronger. However, before the experiment and to avoid any learning effect, participants were trained to the urban scenarios. The scenarios were thus not so unexpected in natural driving.

Insofar as the origin of the real accidents has many factors, of course, a small percentage of drivers actually collided in the situations presented, but the results obtained in these studies thus appear to be discriminating and promising.

We also believe that accident scenarios could be used to design educational training modules for motorcycle drivers, who are particularly vulnerable users. We have the objective to identify prototypical scenarios specific to Powered Two Wheeled (PTW) accidentology (collisions occurring while making left-turn maneuvers or right-turn maneuvers by four-wheeled vehicles at intersections, for example) and to reproduce them on PTW riding simulators. It thus should possible to increase awareness among PTW riders of the risks they take when running up lanes in different situations which could help to reduce mortality among this population.

DISCUSSION AND CONCLUSIONS

Using a driving simulator is the only safe way of exposing drivers to dangerous situations. They do, however, have limits relative to their physical and behavioral fidelity (Espié and al., 2005). Concerning "physical validity", e.g. the simulator's dynamics, the acceleration, braking and steering values of our simulator are those of an average vehicle. However, it is not our aim to study physical characteristics emergency maneuvers. Due to the various limits of driving simulation, this goal is nowadays almost unreachable, even on the largest existing simulators. We focus more on the cognitive aspects of the driving task and on the time when the emergency

maneuvers are engaged. This leads us to search for another level of simulator validity, the so called "behavioral validity", which corresponds to its capacity to induce the same driver response as in a real traffic environment. Exploiting the behavioral data obtained by recording the reactions of drivers confronted with the prototypical accident scenarios has thus a relative ecological value. We observed that the analysis of subjects' behaviors confronted with these difficult situations makes it possible to better pinpoint hypotheses concerning the mechanisms behind the dysfunctional situations demonstrated by accident analyses and could help to the conception of learning simulators.

In this perspective, the methodology presented here contributes to developing and/or validating new preventive actions for the three components in the traffic system (driver training, specific infrastructure layouts, driver assistance systems, etc.).

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