ACTIVE SAFETY EXPERIMENTS WITH COMMON DRIVERS FOR THE SPECIFICATION OF ACTIVE SAFETY SYSTEMS

Thierry Perron
Laboratory of Accidentology, Biomechanics and human behavior - PSA Peugeot Citroën - RENAULT (LAB)
Mohamed Kassaagi
Ecole Centrale Paris
Guillaume Brissart
LAB
France
Paper Number 427

ABSTRACT

The design of active safety systems capable of helping avoiding a crash or reducing the collision severity requires data on how drivers behave in accident situations. These systems must be triggered when drivers actually need assistance. They must enhance insufficient reactions and limit unsuitable ones without being in conflict with drivers' natural behavior.

The Laboratory of Accidentology, Biomechanics and human behavior, PSA Peugeot Citroën - Renault (LAB), has conducted experiments on driving simulators and on test tracks to analyze driver's behavior in emergency situations. Two of these experiments concern front-to-rear accident situations, each one involving more than 100 representative common drivers. The first study was carried out on a simulator with different accident scenarios : an adverse vehicle stopped or driving slowly at the top of a hill, a vehicle coming into the driver's lane from a parking area, or a vehicle driving in front of the subject then suddenly braking. The second study was carried out on a test track. The subjects were following a vehicle pulling a trailer that suddenly broke away and strongly braked. In both studies, the drivers' actions on the controls and the vehicle dynamics were recorded along with videos from driver's hands, feet and face and from the scene.

The results show the benefit of such studies for the specification of active safety systems. These experiments revealed the inefficiency of braking actions of common drivers in emergency situations. The results provided a basis for the determination of triggering criteria of emergency brake assist and enabled to give recommendations on control strategies. Moreover, these experiments pointed out the benefit of emergency brake assist in terms of collision avoidance rate and crash speed reduction.

INTRODUCTION

Several studies have been conducted on the limits of secondary safety. They have proved that approximately half of car occupants fatally injured in car accidents could not be saved only by means of passive safety despite the significant improvements made in the field of occupant protection both on car crashworthiness and restraint systems [Thomas 1990].

Technology is now providing a wide range of possibilities for the development of active safety systems capable of helping the driver avoiding a crash or reducing the collision severity : emergency brake assist, stability control systems, global chassis control, anti-collision systems… These systems must be triggered when drivers actually need assistance, but must not interfere in normal situations. It is necessary to avoid any non-required activation to achieve a good acceptability and therefore a good efficiency to reduce the number of accidents. At the same time the system must be triggered in a maximum of critical situations. Moreover, once activated, the system must take into account drivers' common behavior in order to limit unsuitable reactions and enhance insufficient ones without being in conflict with drivers' natural behavior.

The design of active safety systems capable of helping the driver before the crash requires the determination of accident scenarios and data on how drivers actually behave in these scenarios. This knowledge is necessary to define the systems' triggering criterion and their action strategy. The determination of accident scenarios must rely on in-depth analysis of real world accidents. Once the most relevant scenarios have been determined drivers behavior in those scenarios can be studied by experiments conducted in driving simulators and on test tracks.

FROM ACCIDENTOLOGY TO ACTIVE SAFETY EXPERIMENTS

The specification of active safety systems requires knowing the accident scenarios in terms of trajectory and dynamics of the vehicles, and in terms of drivers' cognitive processes. In-depth investigation of real world accidents conducted by trained accidentologists is the only way to have access to this kind of accident reconstruction. In order to get this data the LAB PSA Peugeot Citroën - Renault has engaged a wide research program with CEESAR (European Center for Safety Studies and Risk Analysis). The teams involved are conducting on scene accident studies [Tarrière 96, Damville 97&99, Alleaume 98, Thomas 99&00]. They arrive on the accident spot at the same time as the rescuers in order to collect all the data that disappear rapidly. Each team is made of a vehicle engineer, a road engineer and a psychologist. They are in charge of collecting the data concerning the vehicles (vehicle state, tire pressure, vehicle deformations…), the road infrastructure (brake and skid marks, point of impact, road grip, geometry, mark and signs…) and the drivers (interview concerning their perception, interpretation, decisions and actions).

All this data is then analyzed for the cognitive and cinematic accident reconstruction [Hermitte 00]. Collision speeds are estimated. The pre-collision is broken down into different phases corresponding to certain types of solicitations (acceleration, braking, swerving…). The reconstruction consists in analyzing the pre-collision phases going backward from the point of impact by taking into account the different marks left on the road and the interviews.

In-depth accident investigations provide very important data on the scenarios of real world accidents. However they provide few quantitative data on the actual drivers' reactions. Moreover they cannot provide data on critical situations where drivers reacted efficiently and avoided the crash (near-accidents). Yet these situations must be taken into account in order to be sure that safety systems will not disturb drivers in those cases.

Active safety systems operate from measurements taken by on board sensors. Their design requires knowing the characteristics of these parameters in accident situations with a high level of accuracy. These data can be obtained by experiments artificially reproducing the scenarios identified through the in-depth accident investigations, and by measuring the behavior of drivers and the reactions of the vehicle.

Since 1997 the LAB has developed a research group devoted to the analysis of common drivers' behavior through Active Safety Experiments. These studies are conducted in driving simulators or on test tracks. In order to provide comprehensive results they involve more than 100 common drivers representative in terms of age and sex of actual drivers. In order to keep the subjects behave spontaneously they are not told the aim of the study.

Driving simulator experiments enable the analysis of very severe configurations that are not feasible on real scale, with a very good reproducibility of the experimental conditions [Chevennement 97, Perron 98]. However, in highly dynamic situations, the driving simulators' validity field is difficult to assess without any complementary studies.

Test track experiments are therefore necessary to validate simulator results, although they require adapting the accident configurations for safety reasons. These studies enable a more accurate analysis of some reactions (as the control phase of braking action).

Several experiments have been conducted following this scheme. Two of them concerning front-to-rear accident situations are described hereafter [Perron 99, Kassaagi 99].

EXPERIMENTAL PROTOCOL

Both studies involved 114 common drivers (total of 228 persons). Each test lasts about 3 hours. First a medical examination enables to check the subject's medical state and its compatibility with the test protocol (Figure 1). Visual sharpness tests and morphologic measurements are performed. The subject is then asked to go for a first drive in order to get used to the simulator or to the vehicle. The road track is representative of real road network with road marks, signs and with vehicle traffic on the different lanes and at intersections (both in the simulator and on the test track). In both studies the weather conditions are good (daylight and dry road). Subjects are asked to "drive" comfortably, as they do with their own car, at the speed they would drive on the road.

During the experiment a psychologist (in the simulator) or a pilot (on test track) is seated in the front passenger seat and asks general questions. The passenger stop intervening several kilometers before the critical situation. The driver’s behavior is recorded on the whole track in order to get data on normal driving behavior. The session ends with one of the studied critical situations.

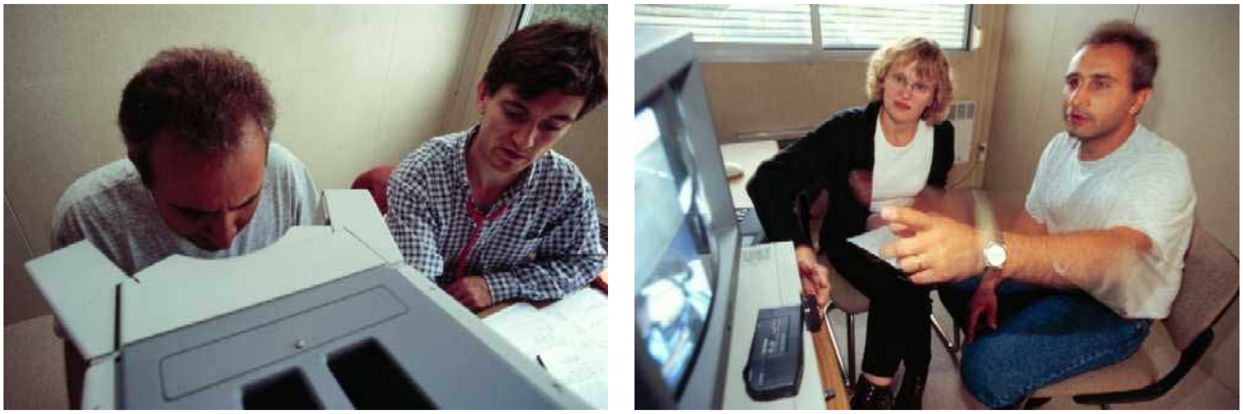

Figure 1. Medical examination and interview with the psychologist.

Each subject is then interviewed by a psychologist to chronologically describe what he perceived of the situation, what he understood, what he intended to do and how he actually reacted (Figure 1). Perceptions, interpretations and actions on the car's controls are then correlated with the video recording.

CRITICAL SITUATIONS

The critical scenarios that were tested were determined from accidentologic studies. However, conducting experiments with unavoidable situations would not provide interesting data on drivers' evasive maneuvers. The most relevant conditions are those which generate roughly 50 % of accidents and 50 % of avoidance. Cinematic parameters of the scenarios were thus tuned in order to obtain this distribution.

Four front-to-rear accident configurations were tested in the simulator (Figure 2) :

- a vehicle coming out of a parking in an urban area into the subject's way (E1) ;
- a vehicle stopped behind the top of a hill on a roadway (E2) ;
- a vehicle driving at reduced speed behind the top of a hill on a roadway (E3) ;
- a vehicle decelerating, then braking strongly after having been followed for 500 m in an urban area (E4).

On the test track the subjects were confronted to several normal traffic situations. In the session, they had to follow a vehicle with a trailer a couple of times. The accident situation was caused by releasing this trailer (Figure 4). The release was triggered from a relative distance of 17 m and at a speed of 70 km/h. The trailer then braked with a deceleration of 7 m/s².

The trailer was designed specifically for this study in order to resist multiple crashes without causing any damage to the instrumented vehicle (honey comb structure, aluminum mechanical parts, crash absorption blocs…). The trailer was fitted with hydraulic brakes and accelerometers with a recording device in order to verify its deceleration (Figure 6).

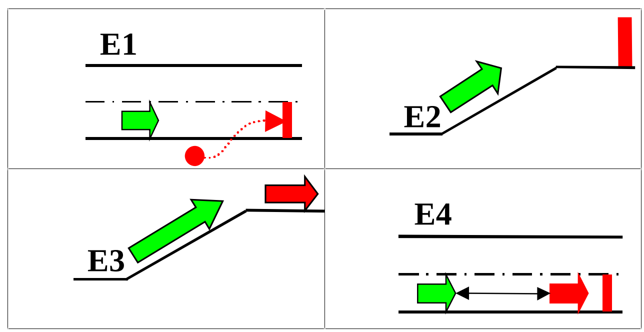

Figure 2. Pictograms of the four emergency configurations tested in the simulator.

Figure 3. View of the SHERPA driving simulator.

Figure 4. Accident scenarios tested on the test track.

MATERIAL AND MEASUREMENTS

The simulator used in the first experiment is the SHERPA fixed-base driving simulator developed by PSA Peugeot Citroën (Figure 3). The cabin is a serial production Citroën ZX, fitted with a steering wheel actuator and a complete brake pedal feedback. The simulator model, fully 3D and non-linear, includes a simulated Anti-lock Braking System (ABS) and the description of the longitudinal/transversal tire behavior. The vision system features one window projection on a cylindrical screen located at 3.5 meters from the driver's eye point and covers a 65° x 30° field. The image is generated at a basic 30 Hz frequency. The environment scene, completely dedicated to the experiment, includes original road and terrain databases and interactive traffic scenario. Engine, aerodynamic and tire noises are reproduced using sound synthesis technology.

For the test track experiment the vehicle was a serial production Peugeot 306 fitted with ABS. For safety reasons the car was equipped with double pedals derived from driving school systems. The car is instrumented with sensors that are not visible to the subjects (Table 1, Figure 5). The measurements are relative to the subjects' actions on the car controls (clutch, gas and brake pedals, steering wheel and gear shift) and to the vehicle response to these solicitations (speed, acceleration and angle velocities). The entire signal conditioning and recording material is located in the trunk.

In both studies the measurements are synchronized with a video of the visual scene, including the face, hands and feet of the subject (Figure 7).

Table 1.
List of recorded parameters

Driver reactions	Dynamic variables
Clutch pedal switch	Distance to the trailer
Gas pedal travel	Longitudinal speed
Brake pedal travel	Lateral speed
Brake pedal force	Longitudinal accel.
Steering wheel angle	Lateral accel.
	Yaw velocity
	Roll velocity
	Brake pressure

Figure 5. Recording material, optical speed sensor, face camera, lidar, instrumented pedals.

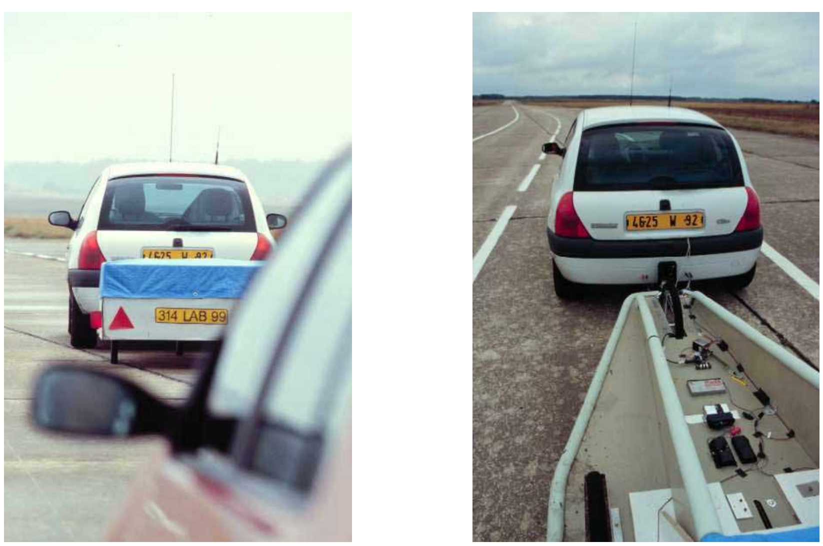

Figure 6. Views of the trailer.

Figure 7. Video recorded in the driving simulator and on test track.

SYNTHESIS OF THE RESULTS

The analysis of drivers' reactions on the vehicle controls in the two experiments provided general results useful to the design of active safety systems. From the synthesis of both studies came the following results :

- all drivers braked, but only 50 % tried to swerve (in rural area) ;
- 85 % of drivers who swerve avoid the crash, compared to 20 % for those who only brake, which shed light on the benefit of swerving ;
- 50 % of drivers do not trigger the ABS, which shows that many drivers do not step strong enough on the brake pedal ;
- 80 % of drivers who activate the ABS do not try to swerve, which shows that drivers do not know how to use it ;
- the median delay between the danger occurrence and the maximum vehicle deceleration is 1.7 s (Figure 8 and Figure 9) ;
- 50 % of drivers do not reach 7 m/s² of mean deceleration, the potential being 9 m/s² ;
- swerving actions are engaged when braking is not sufficient any more to avoid the crash ;
- 65 % of drivers who swerve brake before swerving ;
- all drivers who swerve partially release the brake pedal during the swerving maneuver (86 % during steering action - 14 % during counter-steering) ;
- counter-steering angular velocities are higher than steering velocities ;
- more than 50 % of drivers stepped on the clutch pedal before braking or during the evasive maneuver ;
- men and women have the same performance ;
- gas pedal release speed and brake pedal force increase with driving experience.

APPLICATION TO EMERGENCY BRAKE ASSIST

It was pointed out that 50 % of drivers did not activate the ABS, which means that 50 % of drivers do not step strong enough on the brake pedal. Moreover, the analysis of the brake travel and force signals showed that for 85 % of drivers the braking action is affected by plateaus of force or travel. In other words, for 85 % of drivers the maximum braking is delayed due to a non-efficient brake pedal hit. An emergency brake assist could therefore significantly enhance the drivers' braking action at those two levels, enabling drivers to actually reach the maximum deceleration more rapidly.

The experiments provided data for the specification of such systems. The triggering of some emergency brake assist relies on a threshold value of the brake pedal speed. A combined analysis of the break pedal speed distribution both in critical situations and in normal conditions (Figure 10) provided a basis for the choice of emergency brake assist threshold values.

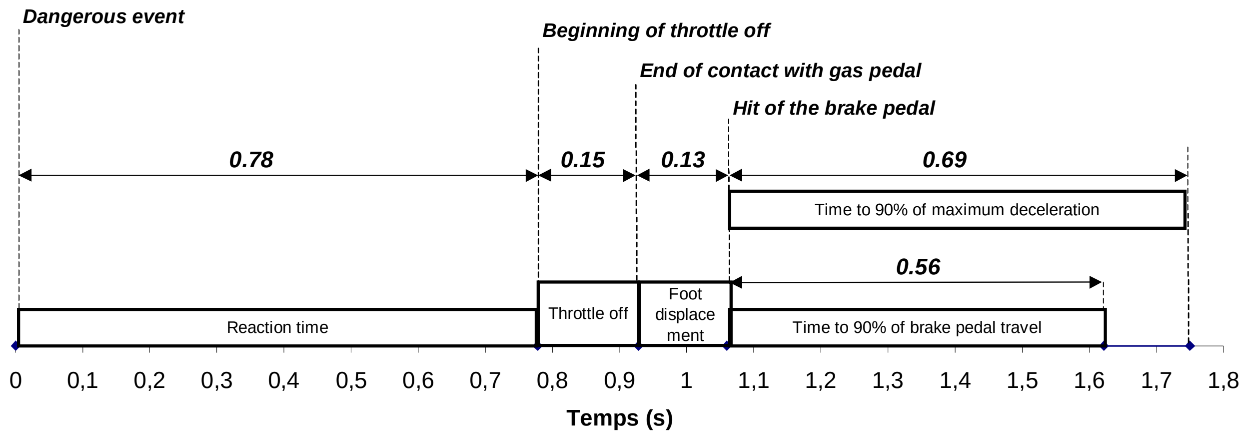

Figure 8. Breakdown of braking maneuvers (median values).

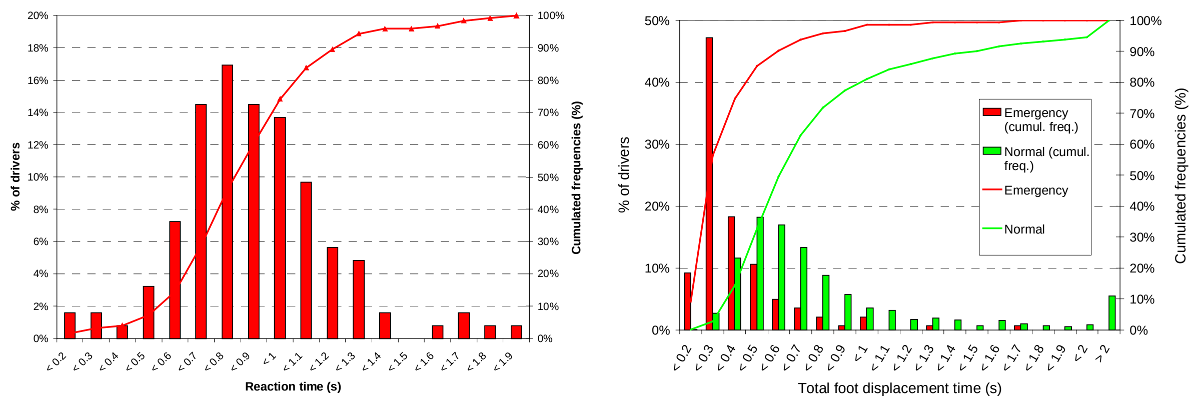

Figure 9. Distributions of Reaction time (from danger event to beginning of throttle-off) and Total foot displacement time (from beginning of throttle-off to brake pedal hit).

More generally, it has been shown that most drivers avoid the obstacle thanks to swerving maneuvers. It has also been pointed out that drivers who swerve release the brake pedal during their swerving maneuver. Despite the fact that most drivers are not aware of it, the release of braking provides more lateral potential. It therefore seems that once activated emergency brake assist should keep the driver in the loop : it should let the driver in control of the deceleration rate by allowing him to reduce the brake power and therefore end the ABS active control phase without totally releasing pressure on the pedal

A simulation showed that if the vehicle was fitted with an emergency brake assist, up to 30 to 40 % of collisions would have been avoided. In another 30 % of cases the impact speed would have been reduced by more than 15 km/h. Beyond the emergency brake assist which is reactive to a driver action, still a greater gain would be reached thanks to proactive systems that anticipate the emergency braking action. Actually other simulations have pointed out that if the brakes were activated at the throttle off moment (approximately 0.3 s sooner than the brake pedal hit), more than 70 % of crashes would have been avoided.

However these figures rely on the hypothesis that the assistance is actually always triggered in emergency situations, which is an ideal case. Actually, due to the significant overlap of braking parameters distributions between normal conditions and emergency situations, triggering criteria based on a single braking parameter cannot both detect all emergency braking actions and never activate the assistance in situations in which it is not absolutely necessary.

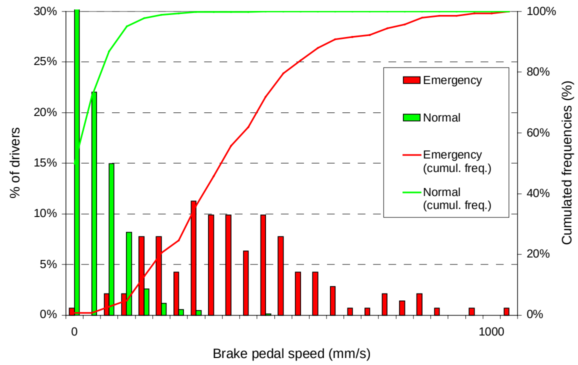

Figure 10. Distribution of brake pedal speed in normal conditions and in critical situations from both experiments.

In order to optimize triggering criteria of those systems, the LAB has engaged a dedicated research program. The optimization work is conducted on the basis of the emergency situations data of the two experiments and representative normal condition data collected by open road experiments. First results show that combining different parameters together enable to build new powerful triggering criteria. These multi-parameter criteria can significantly enhance the detection of emergency braking actions, and therefore increase the number of drivers that will be actually assisted in accident situations.

METHODOLOGICAL ASPECTS

There are two kinds of driving simulators : static simulators (fixed base) and dynamic simulators (moving base). This study proved that static simulators are suited to the study of guidance accidents (due to a problem in the vehicle's trajectory relatively to the infrastructure or to the traffic, [Perron 96&97]). The results show no differences compared to the test track study as long as initial reactions are at stake (Table 2). In emergency situations, drivers operate with a reflex in an open loop mode : the perceptive bias of the simulator has no effect on the initial evasive reactions (reaction time, brake pedal hit…). At this moment the drivers are not yet expecting to feel the effect of their action. The lack of deceleration feedback is therefore not disturbing.

However this is not true any more for the control phase of actions, when drivers are in a close loop mode : typically 500 ms after the beginning of the braking action, the drivers do not feel the deceleration and tend to brake harder. In order to analyze this control phase it is therefore necessary to perform experiments on a test track. The problem is the same for the analysis of control accidents (loss of control), the control driving task being slightly different in a static simulator due to the lack of kinesthesic feedback. This kind of scenarios must therefore be analyzed in a dynamic simulator or on a test track.

More generally experiments carried out in simulators or on a test track seem to be suited to the analysis of maneuverability or sensibility to disturbance accidents (caused by an external element), but not to the analysis of pilotability accidents (due to internal driver errors - these concepts are defined in [Perron 96]). Driver error probabilities are actually not in accordance with the limited duration of any experiment. It is possible to artificially increase the risk of error (asking the driver to over-speed for instance, or with important visibility masks), but then the analysis can only concern the drivers' reactions once the error has occurred (evasive actions) excluding the error mechanism itself.

Table 2.
Simulator / track comparison

Parameters	**Simulator** (median)	**Track** (median)	**Statistical difference**
Reaction time (s)	0.87	0.78	Non signif.
Throttle off speed (mm/s)	283	240	Non signif.
Foot displacement time (s)	0.30	0.28	Non signif.
Brake travel at 100ms (mm)	32.5	29.2	Non signif.
Maximum brake effort (daN)	*33.8*	*21.7*	*Significant*
Maximum steer angle (°)	*43*	*70*	*Significant*

CONCLUSION

The design of active safety systems requires data concerning accident scenarios and the behavior of drivers in these situations. Scenarios can be determined by in-depth accident investigations. Experiments conducted in driving simulators and on test tracks enable to complete this data and to analyze the behavior of common drivers (both those who crash and those who avoid the collision) in the identified scenarios.

Two experiments were conducted for the study of front-to-rear accident scenarios. The results pointed out that :

- 50 % of drivers did not activate the ABS, which shows that drivers do not step strong enough on the brake pedal ;
- 85 % of drivers stepped on the brake pedal with a plateau phase, which means that the maximum deceleration is delayed ;
- an emergency brake assist could have avoided up to 30 % of crashes ;
- all drivers who swerve partially release the brake pedal during their swerving maneuver.

These experiments have therefore demonstrated the potential benefit of emergency brake assist. The analysis of drivers' behavior in accident situations provided data for the determination of triggering criteria and control strategies of such systems.

The LAB is conducting two other experiments concerning loss of control accidents. The first one has been carried out on a dynamic driving simulator in four different road configurations with 124 common drivers. Another campaign is planned on a test track. However the specification of active safety systems cannot rely only on accident data. The knowledge of normal driving situations and driver behavior is necessary in order to be sure that the systems will not assist drivers when they do not need it. This is required for a good acceptability of those systems and consequently for their efficiency to reduce the number and the severity of accidents. In order to meet those requirements the LAB has engaged a new research program for the analysis of driver behavior on open road.

ACKNOWLEGMENTS

The authors wish to extend their acknowledgments to B. Mansaud (test pilot from PSA Peugeot Citroën), to J.-M. Bersac, J.-F. Lydie, H. Guillemot, A. Damville and C. Mautuit (CEESAR), for their deep involvement in the experiments. This research has been carried with a sponsorship of the French PREDIT program.

REFERENCES

Alleaume S., Thomas C., Perron T., Le Coz J.-Y., Emergency Braking Patterns prior to Real World-Crashes, FISITA World Automotive Congress, 27 septembre - 1er octobre 1998, Paris

Chevennement J., Perron T., Le Coz J.-Y., Contribution of a Motionless Driving Simulator to the Analysis of Driver's Behavior in "Potential Accident" Situations, EAEC international congress, july 2-4 1997, Cernobbio

Damville A., Perron T., Thomas C., Le Coz J.-Y., Apport de l'accidentologie en sécurité primaire pour l'analyse des facteurs de risque, 1er congrès transversal Sécurité Automobile de la SIA, 8 et 9 octobre 1997, Rouen

Damville A., Mautuit C., Perron T., Thomas C., Défaillance des conducteurs en fonction de l'infrastructure routière au travers des Etudes Détaillées d'Accidents, Assises Européennes de Psychologie Appliquée aux transports, 16-19 juin 1999, Angers

Hermitte T., Thomas C., Page Y., Perron T., Real-World Car Accident Reconstruction Methods for Crash Avoidance System Research, FISITA World Automotive Congress, june 12-15 2000, Seoul

Kassaagi M., Perron T., Péan E., Guillemot H., Bocquet J.-C., Study of drivers' behavior in rear-end accident situations on a driving simulator, Driving Simulator Conference, 7-8 juillet 1999, Paris

Mautuit C., Damville A., Perron T., Thomas C., Le Coz J.-Y., Reliability of Drivers' Statements on a Driving Simulator, Xie CMRSC Conference, may 9-12 1999, Halifax

Perron T., Thomas C., Le Coz J.-Y., Bocquet J.-C., Methodological Framework for Primary Automotive Safety, 15th ESV International Technical Conference, may 13-17 1996, Melbourne

Perron T., Méthodologie d'analyse de sécurité primaire automobile pour la spécification fonctionnelle et l'évaluation prévisionnelle d'efficacité de systèmes d'évitement d'accidents, Thèse de doctorat, 1997, Ecole Centrale Paris

Perron T., Chevennement J., Damville A., Mautuit C., Thomas C., Le Coz J.-Y., Pilot Study of Accident Scenarios on a Driving Simulator, 16th ESV International Technical Conference, june 1-4 1998, Windsor

Perron T., Brutel G., Le Coz J.-Y., Kassaagi M., Bocquet J.-C., Etudes expérimentales de scénarios accidentogènes - Second Carrefour PREDIT, 23-25 mars 1999, Lille

Tarrière C., Brutel G., Perron T., Chenisbest B., Thomas C., Driscoll R., European Accident Causation Survey, ATA International Conference, october 10-11 1996, Capri

Thomas C., Koltchakian S., Tarrière C., Tarrière B., Got C., Patel A., Primary Safety Priorities in View to Technical Feasibility Limits to Secondary Automotive Safety, FISITA World Automotive Congress, may 7-11 1990, Torino

Thomas C., Perron T., Le Coz J.-Y., Aguadé V., What Happens on the Road before Fatal Car Crashes ?, 40th AAAM Conference, octobre 7-9 1996, Vancouver

Thomas C., Hermitte T., Perron T., Le Coz J.-Y., Drivers Actions during Real-World Pre-crash Phases, JSAE Spring Convention, may 19-21 1999, Yokohama

Thomas C., Damville A., Perron T., Mautuit C., Le Coz J.-Y., Comportement humain en accidents corporels, 2ème congrès transversal Sécurité Automobile de la SIA, 23-24 mai 2000, Rouen