A STUDY ON DRIVER BEHAVIOR DURING BRAKING ON OPEN ROAD

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ABSTRACT

Thanks to new advances in automotive technology, active safety systems (*emergency brake assist* or EBA, ESP…) are designed to avoid accidents or reduce their severity. Their triggering are often based on drivers' behavior. Their efficiency depends, on the experimental or real data representativeness, and on the triggering criteria definition. According to the literature, a few experiments have been carried out with "normal" drivers in "natural" or emergency situations in order to search for variables correlated to the intention and the needs of drivers. These data are necessary to define a "borderline" between emergency and natural driving to ensure that the system will be activated only if drivers need it.

An experiment was conducted on open road. A hundred volunteers drove approximately 100 km. Traffic parameters and subjects' actions on the car's controls were recorded and synchronized with the video recordings. 14000 braking actions were analyzed.

The results are useful for the design of active safety systems. For example, in some "natural" brakings, a fast accelerator pedal release, close to emergency situation actions, is relatively frequent on the road. A few of these actions are effectively linked to potentially dangerous situations. Taking into account other parameters, such as car's speed, distance to precedent car or drivers driving style, may increase the emergency braking recognition.

INTRODUCTION

State of the art on the LAB accidents studies

Two experiments were conducted by the LAB on a driving simulator and on a test track to study the behavior of drivers during obstacle avoidance situations (or front-to-rear accident scenarios, [1]). For these tests, the drivers were recruited in the general public. They were told they were participating in a test concerning vehicle "ergonomics".

At the end of the test, the driver was surprised by the triggering of the accident situation. His (or her) actions on the car's controls are recorded and synchronized with dynamic parameters and video recordings. He is then interviewed by a psychologist who tries to identify his the intentions, his perception of the danger and the elements which motivated his behaviors during the experiment.

Five critical scenarios (4 on simulator and one on test track), according to accidentologic studies, were tested. The four front-to-rear accident configurations tested in the simulator (Figure 1 - [2]) were :

- a vehicle leaving a parking in an urban area and inserting into the subject's lane ;
- a vehicle stopped behind the top of a hill on a roadway (visible lately) ;
- a vehicle driving at reduced speed behind the top of a hill on a roadway ;
- a vehicle decelerating, then braking strongly after having been followed for 500 m in an urban area.

On the test track the subjects had to follow for some times a vehicle pulling a trailer [3]. The accident situation was caused by releasing the trailer decelerating at 7 m/s² (Figure 2). This release is triggered from a relative distance of 17 m and at a speed of 70 km/h.

The first study proved that static simulators are suited to the study of guidance accidents (i.e. due to a problem in the vehicle's trajectory relatively to the infrastructure or to the traffic [4]). The results in driving simulator show no differences compared to the test track as far as initial reactions are concerned [3]. In emergency situations, drivers operate with a reflex behavior in an open loop mode : the perceptive bias in the simulator has no effects on the initial avoidance reactions (reaction time, brake pedal hit…). At this time the drivers are not yet expecting to feel the effect of their action. The lack of deceleration feedback is therefore not disturbing. This is no more true during the control phase, when drivers are in a close loop mode : generally 500 ms after the braking action beginning. The drivers tend to brake harder because they do not feel the deceleration in simulator. In order to analyze this control phase it is necessary to perform experiments on a test track. This phenomenon becomes a source of bias when studying "normal" braking. In this case, the control phase could take many seconds, and significant differences (Table 1) may be observed on the test track compared to the static simulator. This lack of kinesthesic feedback and the quality of projected road view in the simulator may be responsible of strong differences in drivers behaviors.

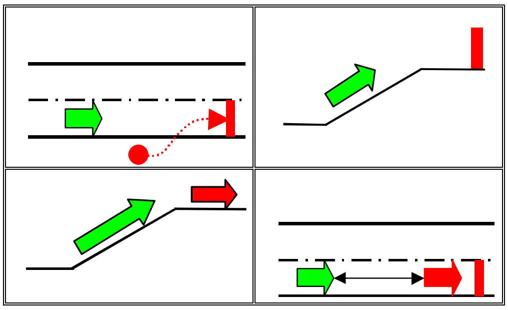

Figure 1. Pictograms of the 4 emergency situations tested in the simulator

Figure 2. Accident situation tested on the test track

Table 1.
Simulator / track "normal" braking comparison (Median values)

	Simulator	Track
Accelerator pedal release (mm/s)	102	121
Foot displacement time (s)	0,61	0,66
Brake travel at 100 ms (mm)	8,1	1,9
Maximum brake speed (mm/s)	138	50
Maximum brake effort (daN)	16,4	5,5

These two studies allowed to build a data base on the behavior of "normal" drivers in emergency situations. This database is very interesting to search performance specifications for active safety systems which intervene, at the latest, some tenth of second after the beginning of braking (brake pedal hit) : the data on tracks and on simulator were thus explored. For example, the maximum brake speed is obtained in the 80 ms after the beginning of the braking in 90 % of emergency brakings. On the other hand, only the "normal" braking data obtained on track were kept for the later applications. The study on track demonstrates the effect of the environment on the braking behavior, even at the very beginning of the brake pedal hit.
But on the test track, it is very difficult to put the drivers exactly in the same conditions as on open road. The traffic is relatively weak. There is no pedestrians nor motorcycles. The only "critical" brakings took place during situations in which the driver was surprised by an event which he had not anticipated as for example a vehicle parked on the verge of the road and seen at the last moment. The low frequency of this type of event also may explain the relatively low values of the medians on the track and let us suppose that recordings on open road would give different results. Finally, some drivers on the track drove at high speeds and take risks. Their behavior is maybe usual, but how to know if it is not induced by the perceived safety of some test tracks or by the search for sensations or speed exhilaration ?

Requirements to an open road study

To make these data more general and more representative of realistic braking situations met on real road, a supplementary study was carried out : a richer environment, more complex for the driver, is thus necessary to obtain "natural" brakings close to those observed in emergency situation. As no study in the literature was able to indicate at the same time the type of the requests to be implemented to obtain this kind of behavior and their frequency on real road, the experimental study has been realized on open road. The aim of this work was to :

- characterize the drivers' actions while braking ;
- study the influence of human factors (sex, age…) ;
- analyze the effects of environmental conditions ;
- improve the efficiency of active braking based on drivers' actions.

Behavior in emergency situations

Various studies ([3], [5] and [7]) showed that the drivers in emergency situations were far from using the maximal capacities of their vehicle, particularly in braking. For example, during an emergency braking (on track), 52 % of the drivers have not reached the ABS regulation. In 57 % of the cases, the hit on brake pedal contains a fall of brake pedal speed, with possibly a bearing in travel (Figure 3). For these reasons, it seems that if an *emergency brake assistance* (EBA) was activated in all these cases, it would allow to improve in a significant way the performance of the braking. The principle of such a system is to detect brakings corresponding to critical situations and to amplify the assistance ratio of the braking system to help the driver to obtain earlier the maximal deceleration of the vehicle. Within the framework of this study, the system was considered perfect, that is to say able to discriminate perfectly between the emergency and the normal situations. The evaluation of a help (by simulation) to the EBA shows that such a system would allow to avoid 30 to 40 % of the front-to-rear collisions taking place during the experiments, for a response time of 100 ms and a mean deceleration of 8 m/s². In still 30 % of the cases, the reduction of the hit speeds would be superior to 15 km/h. By taking into account current improvements of the EBA which can achieve until 1.1 m/s² on dry road, these percentages can reach more than 90 %.

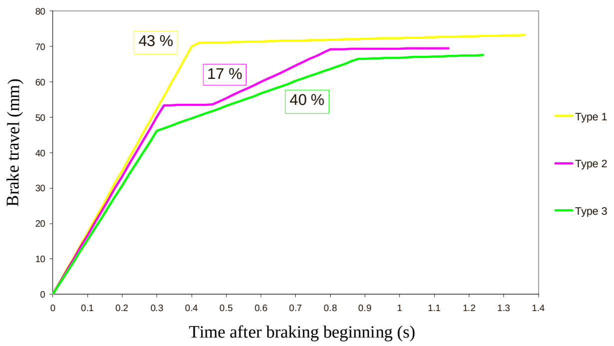

Figure 3. Typologies of brake pedal travel during emergency situations

Additional analysis of emergency braking

To study in a global way various interactions and influences of the starting conditions in emergency situation on the performance and the behavior of the drivers, an MCA (Multiple Correspondence Analysis, [9] and [10], Figure 4) was applied. The quantitative variables were transformed by means of a fuzzy membership coding.

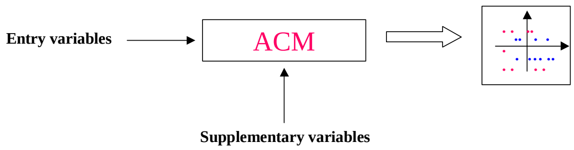

Figure 4. MCA principle

The results of the MCA notably show that :

- A "good" steering wheel maneuver could be an interesting alternative to avoid collisions. The action on the steering wheel is not associated to a specific behavior at the pedals (accelerator release and brake hit), but the regulation of the braking is different. Generally, the driver releases more or less the brake pedal, whereas when he is only braking, he tends to brake more and more hardly until the collision (and\or the complete stop of the vehicle) ;
- The "distracted" drivers (11 cases from 90 didn't look at the road at the moment of trailer dropping) reacted significantly later and had faster duration of foot displacement and higher brake pedal speeds than the others. Their accelerator release speeds are not significantly different. The video recordings allow to notice that several drivers take off their foot from gas pedal automatically by turning eyes to the trailer. It is only when they perceive the danger that they accelerate the movement of the foot. On the other hand, the "distracted" drivers are not more implied in accidents than the other drivers and don't differ in steering wheel maneuver.

These results, as those of [8] emphasized that the slightest modification of the initial conditions of the accident scenario (like driver's attention or obstacle kinematics), has a strong hit on the driver behavior during emergency situation : the driver is thus extremely sensitive to the parameters of the situation, and can act fast according to these totally different operations. Paradoxically, at first sight the reaction of the driver in emergency braking does not seem to have influence on its result (avoidance/accident). In fact, the consequences of the good reactions of the drivers are masked by the effects of the initial parameters (distance to obstacle and speed of the vehicle), of the steering wheel maneuver, as well as by the compensation of the long reaction times (often linked to an error of attention) by more energetic actions.

Conclusion of the studies on test track and simulator

The occurrence of out of standards behavior being relatively rare (on track, only a few brakings over more than 1300), the duration of the open road test was long enough to allow the calculation of the probability of bad braking recognition (of the order of 1/1000). The number of brakings to be analyzed were thus very important.

MATERIALS AND METHODS

Open road driving

To be able to compare the behavior of the various drivers, the circuit was the same for all of them. The road has a length of 94 km. It contains portions in urban areas, on main and secondary roads and on highway. The duration of the test is about 2 hours (according to the traffic and the driver) so as to obtain enough information about the driving style of the subject. The schedules of the tests were chosen in order to minimize the differences in traffic. The simplicity of the guidance (by the experimenter) was privileged so as to limit the incomprehension between the driver and the experimenter sitting next to him. The circuit contains 74 traffic lights, 4 stops, 3 give in the access, 13 roundabouts, 12 priorities to the right, 4 hogback, as well as a hundred intersections where the driver has priority. The road contains mainly 6 types of infrastructures :

- Urban (29,8 km) : main streets with a relatively dense traffic as well as small ways in the almost absent traffic (maximum legal speed : 50 km/h) ;
- Secondary road (18,3 km) : straight main lines and very sinuous parts ;
- Main road (10,5 km) : sections of 2*2 ways (Figure 5 - speed : 70 to 110 km/h) ;

- Highway (16 km) : (Figure 8, speed : 110 km/h) ;
- Suburban (17,6 km) : speed : 70 km/h ;
- Mountain road (50 km/h) : the way is quite narrow and sinuous, with low traffic.

Figure 5. Main road

Figure 6. Narrow and frequented road

Figure 7. Secondary road

Figure 8. Highway

Test vehicle

The vehicle chosen for the experiment was a Peugeot 306, already used during the experiment of accident scenarios on track, so that we can compare directly the measures on track and on open road. The main measures concerned :

- Drivers actions (steering wheel and pedals) ;
- Vehicle Dynamics (speed, accelerations…) ;
- Vehicle location in the environment (GPS, laser-meter, radar).

In addition, 5 cameras synchronized with other measures (Figure 9), record events taking place inside and on the road (Figure 10).

Radar On board Acquisition

Figure 9. Test vehicle instrumentation

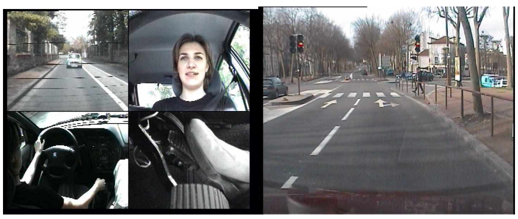

Figure 10. Video recording

Drivers

97 volunteer drivers participated in this experiment. They were recruited according to age and sex criteria so as to be representative of the drivers involved in real front-to-rear accidents in France. The sample is composed of 67 % men (and 33 % women), between 21 and 68 years old (Table 2). The license years vary between 2 and 50 years (median of 14 years), and their annual mileage is between 1000 and 70000 km a year (average of 17000).

Table 2.
Drivers characteristics

	Age (year)		Driving License (year)	
	Male	**Female**	**Male**	**Female**
Minimum	21	21	3	2
Maximum	68	64	50	37
Medium	36	33	15	14

Experimental protocol

As the experiment was conducted on open road, inducing artificial variations of the driver's motivation, of his level of stress, of his fatigue … would have been dangerous. After a familiarization phase with the controls of the car, the subject is asked to drive on the road, as he usually does with his own vehicle, by respecting the directions indicated by the experimenter. No particular instruction concerning the speed was given. The subject took a break of 10 mn in the middle of the test. At the end of the test, he answered a questionnaire related to his driving experience.

RESULTS

A preliminary analysis was realized on the data recorded on open road. At first, the results concern the characteristics of the studied population (sex, age, driving experience…). The aim of this analysis is to improve our knowledge concerning the studied population and the experimental conditions (not completely mastered). The results of this study concern two items :

- The dynamic use of the vehicle (analysis of speeds and accelerations among to the type of infrastructures) ;
- The braking action and specifically the hit of the brake pedal. Typologies of "brakers" will be presented and the braking comparable to those in emergency situations will particularly be studied.

The experience of the drivers could be defined through the study of 4 variables: the number of years of license, the annual mileage, the frequency of driving on the road infrastructure and the knowledge of the test road.

Questionnaire analysis

<u>**Self-evaluation**</u>

51 % of the drivers consider themselves as "good" drivers, and 84 % judge that the other drivers are "bad" drivers. Besides, generally the subjects judge the driving as an easy activity during which they

feel relaxed. These results are homogeneous with the literature ([6], [8]) concerning the overestimation of the competence and the underestimation of the road risks.

Perceived realism

90 % of the drivers think that the equipment of the vehicle had no major influence on their behavior. 64 % (resp. 60 %) think that the presence of an experimenter (resp. the guidance during the circuit) had no effect on the way they drive. A high correlation is observed between the *self-evaluation of his driving abilities* and eventual difficulties due to the guidance (p = 0.007) : the drivers who say themselves bothered by the guidance rather consider themselves as "good" drivers, while the others are self classified in the category "average". Would the drivers who consider themselves as "good" be afraid that their capacities are not recognized ?

Dynamic use of the vehicle

Dynamic variables such as speed or accelerations are interesting indicators of the subjects driving style. The study of [6] showed that there is a big variety of use of vehicles according to sex and to the infrastructure type. The same study, on a road relatively sinuous points out the very different behavior between drivers. Those who adopt a "sport" driving behavior don't hesitate to get closer to limits of the dynamic capacities and reach higher transversal accelerations (about 0.7 g). In this paper, the study is then focused on the influence of infrastructures.

Mono-variable approach

- Vehicle speed and infrastructures : The median speeds were close to legal speed limits : for example, 70 % of the subjects exceeded at least once the speed limit on the highway and 60 % on the road.
- Longitudinal accelerations : recorded values are comparable to those obtained in [6]. The drivers take rarely advantage of the longitudinal capacities of their vehicle. While the longitudinal potential of cars is more important in deceleration than in acceleration, histograms remain relatively symmetric around -0,5 m/s² and 0 m/s². Histograms are slight different on all the infrastructures, except for highway where the accelerations and the deceleration are lower.
- Transversal accelerations : The results are compatible with those obtained in the literature. They are similar for urban areas and for open countryside, lower for highway and higher for sinuous road (Figure 11).

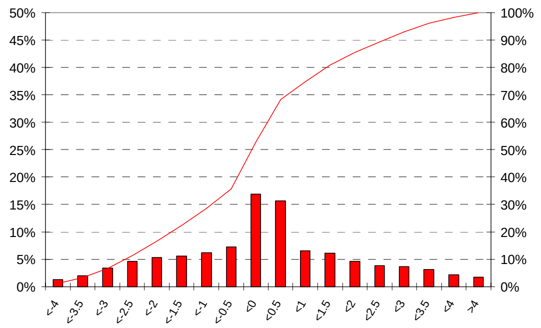

Figure 11. Transversal accelerations on sinuous road (m/s²)

Multi-variable approach

To conduct a multi-variable study, by subject and by type of infrastructure, an MCA was applied to the dynamics (as entry variables). The driving experience and the "qualitative" characteristics of the subjects were considered as supplementary variables. The results of the MCA reveal that it is possible to distinguish two groups of drivers :

- The "sports" drivers who often drive faster than the others (> 90 km/h on road of open country, > 110 km/h, even 130 km/h on highways, between 70 and 90 km/h on sinuous roads, > 50 km/h in urban areas). They have higher transversal accelerations superior to 3 m/s² (sinuous road), and in a lesser measure have higher longitudinal accelerations and decelerations. On the other hand, these subjects know very well the highways of the circuit, drive on highway several times a week and several times a day on road, and are mainly men ;
- The "slower" drivers : drive more often than the others at speeds between 50 and 90 km/h on highways, between 50 and 70 km/h on roads, and between 20 and 50 km/h on sinuous roads. They drive on highway several times a year or never and several times a month on road.

Synthesis of the results

This study highlights big differences between drivers' behavior, which could be classified in "sports" and "slower". The drivers who have a "sports" behavior are characterized by:

- higher speeds, close or over the speed limits on all infrastructures ;
- higher transversal accelerations on any infrastructures except on highways ;
- higher accelerations and decelerations in urban areas and on sinuous roads.

To refine the analysis of these data, supplementary variables were used for the analysis : the sex, the knowledge of the test road, the driving experience, the age and the weather conditions during the test :

- Sex : Men take place rather in the category of the "sports" drivers on open country road and on highways, while women have generally a more careful driving on these infrastructures. No significant differences are observed on sinuous road ;
- Knowledge of the circuit : drivers who know very well the highways of the test rather take place in the category of the "sports" drivers on highways ;
- Driving experience : drivers who drive several times a week on highway, or several times a day on road, take place rather in the category of the "sports" drivers on the whole test road except in urban area. On the other hand, the drivers who drive several times a month or never on highway are rather "slower" drivers in urban area ;
- No influence of the annual mileage and the number of years of license were observed on the dynamic variables ;
- Weather conditions : no correlation was observed between the dynamic variables (including driving speeds) and the weather conditions.

<u>Conclusion about the dynamic use of the vehicle on open road</u>

Different behaviors were observed between the drivers on all the infrastructures. To the "sports" drivers who drive relatively fast, have more important dynamic accelerations, which are rather men, often drive on highways and road and know very well the express ways, oppose the "slower" drivers who are rather women and drive little on highway and on road. The driving experience has no lead significant influence on the dynamic use of the vehicle.

Study of the braking on open road

<u>Mono-variable analysis of the braking</u>

The analysis of emergency situations on test track and simulator [3], as well as the results of various studies conducted on real accidents show that when the driver perceived the danger, his first reaction is the braking which only allows to reduce significantly the speed of the car. Furthermore, the analysis of the actions on the controls during these emergency situations puts in evidence that the characteristic variables of the first moments of actions on the brake pedal discriminates the detection of emergency situations. This research work (on open road) thus concerns the driving situations containing the use of the brake pedal. Therefore, the brake pedal hit phase was more particularly studied.

In front-to-rear accident scenarios, several variables were defined to characterize the situation, as the emergency degree, the time to the obstacle and the reaction time of the driver. However, on open road, these parameters are more complex to define. For example, the braking is not always induced by an obstacle, but by a necessity of regulating the speed according to the context (approach of a bend or an intersection for example). On the other hand, these criteria don't take into account the probability of the situation evolution while the driving task is made by successive anticipations. The observation of the video recordings shows for example that regularly the drivers slow down even before the car who precede them : they deducted from the situation the others' reactions. Finally, the current limits concerning the detection of the environment don't allow to automate the determination of the complex driving situations characteristics met on open road, even if remarkable progresses have been realized these last years.

An active safety system, as the EBA, has to be activated as soon as possible after the braking beginning so as to have a real efficiency in emergency situation. The most interesting period in this context begins before the braking and ends 100 or 200 ms later. The analysis is thus focused on this period.

Every braking is led by a particular situation which requires a control of the speed of the vehicle. In emergency situation, the reaction time is the time between the appearance of the initiator event and the beginning of the accelerator release. On open road, this measure could not technically be realized in an automatic way given the number and the variety of the situations. The analysis of the braking thus starts with the beginning of the accelerator release and finishes at the end of the brake pedal action. Figure 12 offers a "natural" braking example on open road. Every braking was decomposed according to the following 5 phases:

1. Accelerator release ;
2. Foot displacement from gas pedal to the brake pedal ;
3. Hit of the brake pedal (generally in the 100 to 200 first ms) ;
4. Regulation of the braking ;
5. Brake pedal throttle off.

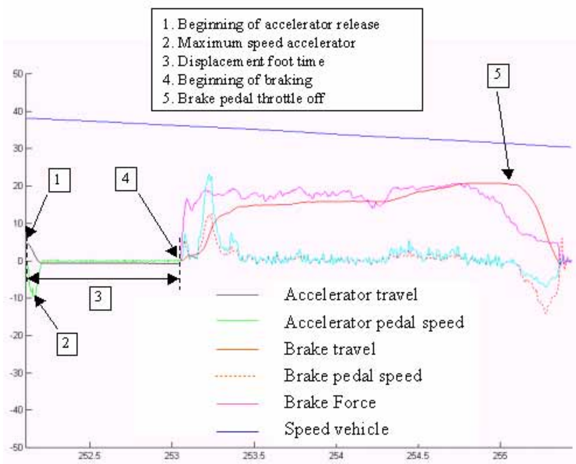

Figure 12. Example of "normal" braking

- Phases 1 and 2 : The accelerator release : 86 % of the brakings are preceded by an accelerator release. Several parameters were retained to characterize the actions before the beginning of the actions on the brake pedal, as the maximum accelerator speed, or the duration of foot displacement from the accelerator to the brake (Figure 13). Various parameters allow to characterize the beginning of braking, as the maximal brake pedal speed or the travel of the brake pedal (in 100 or 200 ms after the braking beginning, Figure 14). It is interesting to notice that the brakings analyzed on road were recorded on a wide panel of speeds (from 0 to more than 110 km/h, Figure 15).

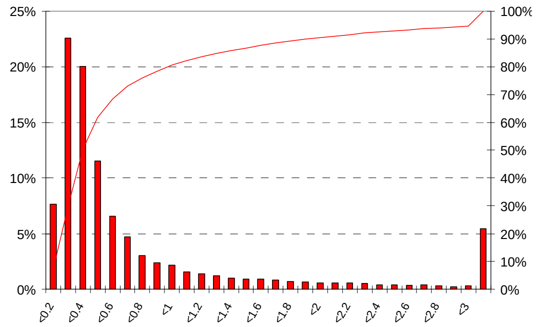

Figure 13. Duration of foot displacement between pedals on the road (s)

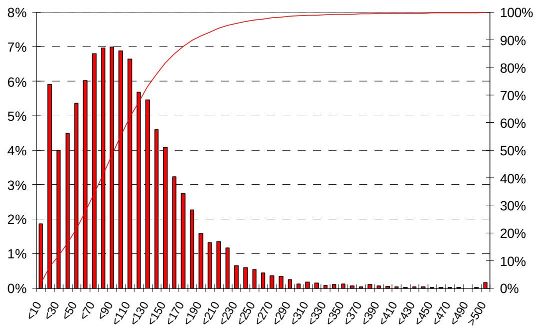

Figure 14. Maximum brake pedal speed on the road (mm/s)

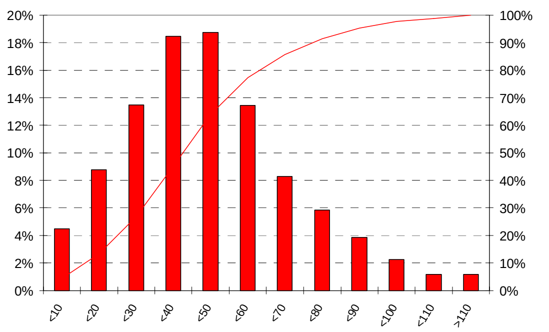

Figure 15. Vehicle speed at the braking beginning on the road (km/h)

- Phase 3 : Regulation of the braking : The study of the braking regulation is relatively complex because it depends on the evolution of the driving situation. Within the framework of this analysis, the objective was to find possible links between the actions at the beginning of brake pedal hit, the specific behavior of regulation, and specific driving environments (sloping street, bend…). Several parameters can be used to characterize this phase : the mean brake travel, the duration of the braking, the mean car' s deceleration. For example, Figure 16 shows that the range of use of the brake pedal is relatively narrow because in 98 % of the cases the mean travel of the brake pedal is lower than 30 mm. 70 % of the brakings last less than 5 s. Besides, certain analyses put forward that the objective of the braking is not only to stop the vehicle, but also to reduce its speed to prepare a progressive possible stop or to regulate the distance to the previous traffic (more than 50 % of the brakings reduce the vehicle's speed less than 10 km/h).

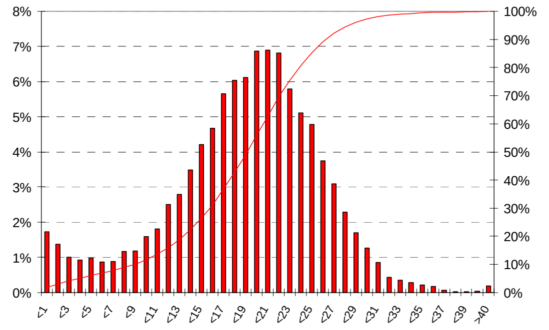

Figure 16. Mean of the brake pedal travel (mm)

<u>Multi-variable analysis of the braking</u>

- Analysis of the braking : After this brakings characterization phase, a preparatory multi-variable analysis was conducted thanks to an MCA, with as entry the behavioral variables and other dynamic ones. Figure 17 is the result of this MCA. Figure 18 shows a zoom of the central part of the previous graph :

❖ The first group of variables (on the right of Figure 17) collects the modalities corresponding to the smallest values of the braking regulation variables. The associated brakings are thus small contacts on the brake pedal ;

❖ A second group of variables (on the right and close to the first axis), collects the slow hits of the brake pedal ;

❖ The third group of variables (on the left and close to the first axis) collects modalities corresponding to the fastest values of the braking regulation variables (higher brake force and deceleration). These variables are correlated ;

- ❖ Finally the last group relatively far from the others (left top of the graph) corresponds to more energetic brake pedal hits. The density of points is much lower than in the central part. Points located in its extreme part correspond to the most atypical brakings. The brakings in this area have characteristics close to emergency situations in term of brake pedal speed or brake travel in 100 ms.

No correlation is observed between, on the one hand, variables connected to the accelerator release or to the duration of foot displacement, and on the other hand, variables related to the brake pedal hit. This result is also valid in emergency situation [1]. The position of the modality longitudinal acceleration, “ALmax of -inf to –4 m/s²”, close to the group of the brakings with fast hits of the brake pedal, is interesting because it shows that these brakings look like the emergency ones, not only in terms of hit of the brake pedal but also in terms of deceleration.

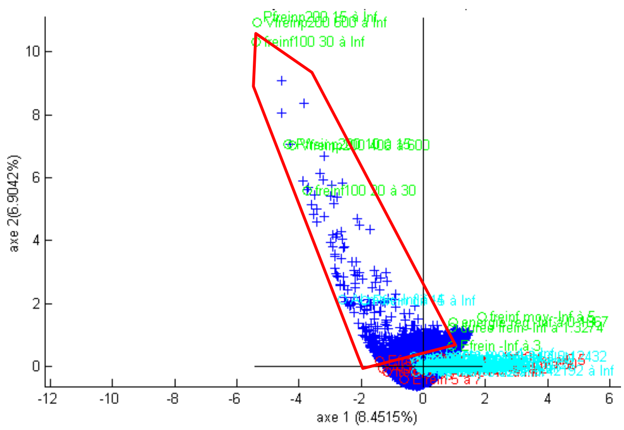

Figure 17. MCA on the braking data, axes 1 & 2

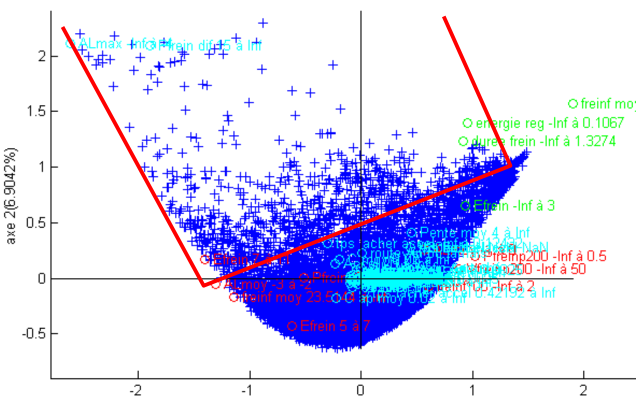

Figure 18. MCA on the braking data (zoom)

- Video analysis of particular braking behaviors : The MCA puts forward one group of brakings with characteristics closer to emergency brakings both in terms of hit of the brake pedal and braking regulation. To complete this analysis, a detailed study of the “non standard” actions on pedals was led. This analysis is based on the fine investigation of all the experimental data, notably the video data analysis which are extremely rich. Thanks to the observation of the drivers’ faces many indexes (opening of the mouth, increase of eyes opening or their very fast movement towards an object of the environment) participate largely to the understanding of the scene. Furthermore, the sound recording is often an interesting element. Certain drivers comment a posteriori some driving situations. Finally the data from the telemeter or the speed of the car allow to appreciate better the objective danger of the situation.

The display of these brakings on the graphs of the MCA shows that they well correspond to the group of the atypical brakings put in evidence by the MCA. The brakings corresponding to the “normal” situations, drawn in cyan blue, are for the greater part closer than other brakings, while the potentially dangerous or dangerous brakings are rather more taken away from it. At first, the analysis of the driving situations was successively led on each of the characteristic variables by respecting the chronological order of the actions during braking. In a second time, it concerns the relations between these variables.

- ❖ Accelerator release (atypical brakings) : The analysis concerned firstly the brakings with quick accelerator release. 36 brakings were thus selected and analyzed. It is interesting to note that a single atypical driver realizes about 22 % of these brakings. The analysis of these situations puts in evidence two types of situations: “Normal” situations, where the fast accelerator release rather seems to be characteristic of a “sports” driving ; “Unusual” situations which could require from the drivers a corrective action. These actions are not necessarily followed by a fast duration of foot displacement or by a fast brake pedal hit. This could be explained by the evolution of the situation or its estimation by the driver. The accelerator release action seems thus not necessarily always a good indicator of the objective emergency of the situation.
- ❖ Duration of foot displacement between pedals (atypical brakings) : This analysis was followed by the observation of 42 brakings. These situations correspond to reactions during disruptive events of the driving as for example when the driver is surprised by a priority to the right, or he perceives another vehicle coming opposite on his way, or he avoids a cyclist … These very fast actions could be explained by an anticipative or reactive reaction in front of a disruptive situation. The duration of foot displacement is, below certain duration, a good

indicator of the danger perceived by the driver during the situation.

- Braking pedal behavior (atypical brakings) : On the whole, 58 brakings were observed in the video and selected following certain criteria, as the high brake force or the pedals' speed, as well as the perception of the experimenter (sat next to the subject). All the "atypical" braking situations were classified into 3 categories :
  - The normal situations (25/14000) : the subject seems to master the vehicle and not to be surprised. For example : arriving to a stop sign or a give up the access or a roundabout, parking maneuvers, driving in row at low speed in an urban area, navigation, insertion in row, arriving very fast at traffic lights, braking in a bend ;
  - The potentially dangerous situations (16/14000) : the subject is surprised but the ambiguity of the situation or its evolution makes the emergency braking not forcedly necessary. For example : traffic lights perceived at the last moment or pass into red, no-entry sign seen late, a stop sign seen late, in bend…;
  - The objectively dangerous situations (17/14000) : the subject is surprised and a reaction of the driver is necessary because the situation is objectively dangerous at the moment of the braking beginning. For example : priorities to the right or vehicle in opposite direction … The analysis of these situations shows that a fast action on the brake pedal is connected most of the time to the perception of a potential danger, notably when the speed of the car is superior to about 20 km/h. This explains the will of the driver at the moment of the brake pedal hit : he might want to stop or to be able to make it quickly. However any fast hit of the brake pedal does not lead inevitably to a braking with an important deceleration. This is explained during potentially dangerous and dangerous situations, by the favorable evolution of the situation or by the better interpretation of the situation by the driver. To illustrate this result, let us quote as an example a driver approaching a priority to the right where another vehicle appears suddenly. The driver generally deeply reacts by perceiving it (from the accelerator release to the hit of the brake pedal). If this vehicle stops, the driver re-estimates the situation, stops braking and takes his road normally.

The relations between variables describing the braking and the intentions (presumed) of the drivers on open road are largely based on the diagnosis which seems to him the most appropriate. The hypothesis according to which the action of the driver during time would be purely reflex in potentially dangerous or dangerous situation, is not confirmed by the observation of the driving situations on open road. Indeed, while the situations evolves, the driver quickly modifies the speed of his foot (whether he is at the accelerator release phase, or the foot displacement one, or the brake pedal hit or even in the braking regulation phase) according to the evolution of the situation or his diagnosis.

Typologies of "brakers"

One of the research ways for the driving assistants improvement is the determination of driving typologies. Indeed, they should allow to refine the assistant systems by proposing several laws of functioning following the drivers (or their driving style). Other performances (functions) of the vehicle evolve in this direction. For example, certain transmissions or suspensions systems adapt themselves to the sportsmanship of the driver.

An MCA was thus realized on behavioral data before and during braking. Every statistical individual (subject) is characterized by a fuzzy histogram of each of the characteristic variables of the braking (including the braking number realized by subject on the road because of the big inter-individual differences). The supplementary variables consist of dynamic data vehicle and population characteristics (age, sex, experience).

This analysis puts in evidence 2 sets of "brakers" :

- The drivers who have an important number of brakings, often short foot displacement duration and in a lesser measure which quick accelerator release ;
- The drivers who have more often their foot between the accelerator and the brake and a lower braking number. The mean brake travel is generally more important.

This typology seems independent from the dynamic use of the vehicle (not significant values-test) and from weather conditions. The MCA brings to the fore the relative differences between brake pedal hits from a driver to another. Some drivers hit often quickly the pedal while the others on the contrary put slowly the foot on the brake pedal. However no link is observable with both groups previously put in evidence, or with dynamic use of the vehicle.

Conclusion and application to the detection of emergency brakings

The observation of these brakings puts in evidence the link between some typical situations and the drivers' reactions. A fast accelerator release or short time of foot displacement, similar to what is observed in emergency situation is a relatively

frequent action which generally has no influence on the comfort of the driver. Some of these actions are effectively linked to potentially dangerous situations, but in some cases, the situations in which these brakings are realized, seem to be "normal". This result must be taken into account for the design of active safety systems (as EBA). The analysis of driver typology underlines two different groups which have not the same management of the foot movement from a pedal to the other one on open road. Taking into account this typology may increase the contribution of the foot displacement duration and, in a lesser measure, the accelerator release speed for the detection of emergency brakings.
Regarding the brake pedal hit, a fast action on the brake is most of the time synonymous of a potentially dangerous or dangerous situation for the driver when the car's speed is superior to about 20 km/h. This fast action at the moment of the brake pedal hit denotes the will of the driver to stop or at least to be ready to stop quickly (notably in case of surprise after "distraction", or in case of bad interpretation of the situation). Variables describing the brake pedal hit are, without surprise, the most efficient variable to trig an EBA (Table 3). When they are combined with a threshold on vehicle speed, the result is even better and reach 67 %. Fast hits of the brake pedal are not inevitably followed by important brakings when the potentially dangerous and dangerous situations evolve favorably. In spite of the relatively fast evolution of driving situations, the diagnostic and the actions of the drivers evolve as fast as those situations.
Some driving situations, as traffic lights which become in the orange or the arrival to a hogback, are considered as potentially dangerous by some drivers who reach decelerations superior to 5 m/s², whereas the objective danger could be relatively low. The question is what would they think of an activation of the EBA in this kind of situation ?
This considerations lead us to make a new database with the objectively dangerous situations on open road classified in the group of emergency situations. This new classification shows that 74 % of emergency situations could be detected.

Table 3.
Probability of "emergency" braking Detection

	Emergency Brakings well detected		
	First database	Brakings at V>25 km/h (first database)	Brakings at V>25 km/h (second database)
accelerator release	8 %	9 %	9 %
Foot displacement Duration	5 %	7 %	7 %
Braking pedal behavior	60 %	67 %	**74 %**

CONCLUSION

Data of three experiments, two concerned accidents scenarios and one on open road, were analyzed in order to study driver's behavior when braking and to find the better means to trig active safety devices. Being given the complexity, the cost and the availability of the trial means, the accident situations studied concerned only front-to-rear accidents (unexpected appearance of an obstacle on the way of the subject). Regarding open road experiments, about a hundred of volunteers, women and men of various ages drove around 100 km (60 miles) in the Paris area for 2 hours. More than 14000 brakings were recorded and studied. The analysis of the brakings allowed to underline of the links between the actions of the drivers and the potentially dangerous or dangerous driving situations.
The study of the driving on open road showed that in an "unpredictable" environment, certain "critical" brakings can take place (approximately 60 case on 14000 on the whole). By means of the video analysis, these brakings were classified in 3 categories: "normal" situations, potentially dangerous situations, and objectively dangerous situations. Some critical brakings have characteristics close to emergency ones. So, two databases were used to evaluate characteristic variables of actions on the car's pedals for trigging EBA. In the first one, all brakings on open road were considered like normal brakings. In the second one, objectively dangerous situations ones were classified in emergency situations. In spite of the number relatively reduced of emergency brakings (145 cases) recorded in front-to-rear accidents studies, the current results of discrimination are very encouraging, especially the combination of behavioral variables related to braking pedal hit and the threshold on vehicle speed. The use of supplementary variables as accelerator release behavior and duration of foot displacement between pedals would even improve this result [1].
The measures of the drivers' behavior thus constitute an interesting way for the diagnosis of the will of the driver to brake in emergency, but do not enable us to detect all the emergency situations. First of all, because drivers have specific typologies of accelerator release behavior and of foot displacement between pedals. The use of these typologies should enable to improve the efficiency of these variables to trig active safety devices. Secondly, because drivers' actions are based on their perception and their understanding of the situation which are not necessarily objective. In emergency situations, some drivers perceive really the danger after the beginning of braking. So in this kind of situation, an EBA must be triggered after the braking beginning, or better, by adding

objective data like distance to earlier obstacles (by a radar or a laser). Simulations showed that environment information close to the vehicle enable to improve significantly the recognition of the braking type. The real benefits from active safety systems to avoid (or at least to decrease the real accident severity) must be studied in the future in order to estimate their contribution among other safety systems.

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