ADAS DESIGN METHOD BASED ON REAL WORLD DRIVING

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ABSTRACT

Recent cars are more and more equipped with *advanced driver assistance systems* (ADAS). The design of useful and safe ADAS requires real driving behavior data in particular for their specification and their tune-up. Our study is focused on the improvement of *adaptive cruise control* (ACC) design. The specification of such a system requires drivers' profiles using driver's actions and vehicle dynamic data (speed, acceleration…) as well as information about close traffic in longitudinal regulation situations. An experiment on real road is currently carried out with 120 common subjects driving an instrumented car. To ensure that representative road situations are taken into account, data are recorded in ecological conditions, with common drivers using a non-ACC equipped car on a 250 km real road. Four data types are recorded: drivers' actions and comments, car dynamic and road environment characteristics. Drivers' profiles presented in this paper are based on objective data like headways or speed choices in some relevant driving situations. This experimental method has the advantage to allow understanding both the driver's real need (and not what the technology enables) and his/her real dynamic use of the car. As for any experimental procedure, it is essential to be aware of some biases which could impact the study conclusions. The data collected from this study and also from other ones should enable building an "intelligent" driving algorithm able to classify any driver in a pre-defined category of profile in order to configure automatically the best ACC functioning mode.

INTRODUCTION

Over the past 15 years major technological changes emerged in the field of automotive industry. New advanced driver assistance systems (route planning, obstacle detection, speed control…) equip more and more recent cars.

Most of the time, in the development of some of these systems, only technological capacities are taken into account. Seldom, human factor aspects are gone into detail. The use of these assistances can have adverse effects if the behavior of the driver does not correspond to the one anticipated by designers [8].

In this paper, we focus on the improvement of *adaptive cruise control* (ACC) design. ACC system uses sensor to detect the presence of a preceding vehicle and to determine its distance and speed. If a preceding vehicle is detected, the speed of the ACC-equipped vehicle is adjusted to maintain a preset safe distance or time headway.

This kind of systems has not to disturb the driver in his driving task. That is why the specification of such a system requires driver's actions and vehicle data as well as information about close traffic in longitudinal regulation situations. To build a real world database, our laboratory is conducting a large scale experiment on drivers' behavior on real road with 120 subjects driving an instrumented car. This experimental method has the advantage to allow understanding both the driver's real need (and not what the technology enables) and his/her real dynamic use of the car. Collected database helps driving assistance designers to take into account simultaneously what the technology allows and also drivers' profiles.

EXPERIMENTAL DESIGN

Participants

Our objective is to constitute a knowledge database of drivers' real behavior. Only healthy subjects were selected in order to avoid biases due to pathologies. The study includes 120 participants (60 women and 60 men). They were recruited via a local paper and then distributed in three age groups: 20 to 35, 40 to 55 and more than 60 years. Only persons, who drove more than 5000 km/year and had a driving license for more than 2 years, were chosen. As of January 2007, 36 (among 120 foreseen) persons took part in the experiment.

Vehicle

In the study of real drivers' behavior, two approaches at least are generally used: directly using his/her own car or using one or a few instrumented cars. As the first approach is difficult to carry out and does not permit us to instrument the vehicle as we desire, we have chosen the second method in which all interesting measures can be recorded.
Since most people in our sample drive superminis to small family cars, a large family car such as the *Renault Laguna* (See Figure 1) we used may have interfered with drivers' habitudes. However it seems mandatory to use a car in the range corresponding to the primary target market of ACC systems, and subjects had a period to get accustomed to driving a bigger car, which should reduce a potential bias.

Figure 1: Test vehicle instrumentation

Environment

ACC systems have been designed to be used essentially on motorway or highway. Our 250 km route (See Figure 2) is composed of 80% of these two kinds of road. The first 30 minutes of driving allow the drivers to adapt themselves to the vehicle. For the remaining route, we consider that the driver has a natural behavior. The experiment takes place in daytime during the same hours to limit the bias due to the traffic. We have to take into account that all the subjects did not have the same meteorological conditions.

Figure 2: Road route of 250 km

Experimental schedule

The experiment takes place on three meetings. During the first meeting, the participants are interviewed by a psychologist and some questionnaires have to be filled before a medical examination. Driving on a real road is realized during the second meeting. The subjects are accompanied by an experimenter (a psychologist). They drive between 11 a.m. and 6 p.m. including breaks among one of about 2 hours. During the last meeting, another interview is organized. The subjects view parts of the video recordings and have to explain their actions in very specific driving scenarios. Other neuropsychological and personality tests are also realized.

Acquisition of subjective and objective data

For the data acquisition four methods were used in the study: questionnaires, interview, behavioral and dynamic measurements, and video recordings.
During the second meeting, the instrumented car was designed in order to measure at a frequency of 100Hz some indicators of the drivers' actions (use of the brake, accelerator…), car dynamics (speed, acceleration…) and close vehicles thanks to radars used for ACC systems (relative velocity, headway…). A video recording (See Figure 3) of 4 views (visual scene, rear scene, the face and the hands of the driver) encountered along the route was made simultaneously with drivers' comments. This observation technique, combining a video recording of the driving scene with the simultaneous recording of different indicators, allows an "exhaustive" analysis of drivers' behavior in all met real driving situations.

Figure 3: Video recording

RESULTS

Only results based on objective data will be presented in this paper.

Descriptive statistics

Some descriptive statistics on time headways were realized (See Table 1).

Table 1.
Descriptive statistics on observed time headways (THW) on highways limited to 110 kph

Variable	Mean	Std
Mean THW	2.72	1.34
Min THW	1.72	1.32

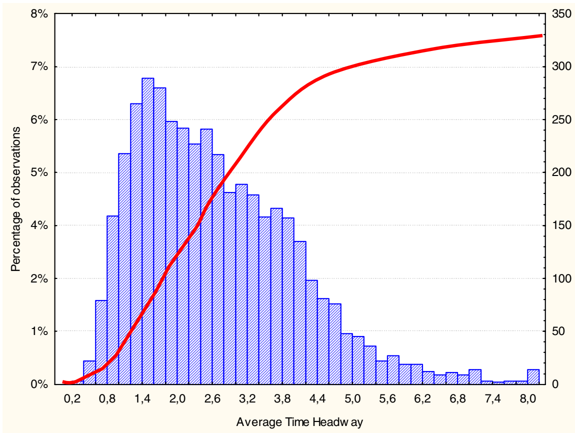

Figure 4. Histogram representing the distribution of the mean time headways in the phases of follow-up on highway limited at 110 kph

In 41% of follow-ups, the mean time headway is under the legal limitation of 2 seconds in France. They are 11% to have a mean time headway lower than 1 second (see Figure 4).
Compared to a study made on the roads of Normandy [1], in 23% of cases, the drivers have time headways lower than 2 seconds. They are 9% to have headways lower than 1second on all types of road.
Another study, published by the ONISR [6], presented the following results: 28% of time headways are lower than 2 seconds and in 7% of follows-ups, the mean time headway is lower than 1 second on dual-lane sections.
In our study, more people have small time headway compared to those obtained in the two other studies probably due to our limited sample, but also because of the difference between infrastructures' types in the three studies.

Typologies of drivers

The research of drivers' typologies is useful for many reasons. Indeed, they can help road safety organisms to develop targeted information campaigns or improve the driving learning. For car manufactures and suppliers, these kinds of information could be used in the specification of ADAS.
Using objective data collected in our experiment, data analysis was performed by a principal components analysis (*PCA*) in order to search for drivers' behavior typologies.

Data analysis method: principal components analysis

In statistics, principal components analysis (PCA) is a technique for simplifying a dataset, by reducing multidimensional datasets to lower dimensions for analysis [5]. Technically speaking, PCA is a linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. PCA can be used for dimensionality reduction in a dataset while retaining those characteristics of the dataset that contribute most to its variance, by keeping lower-order principal components and ignoring higher-order ones. Such low-order components often contain the "most important" aspects of the data. But this is not necessarily the case, depending on the application.

Variables' choice

To characterize driver's behavior, we chose 47 variables taking into account :

- dynamic use of the vehicle : longitudinal regulation (speed, time headways, acceleration, deceleration…) and lateral control (lateral acceleration…);
- drivers' actions on the controls (fuel consumption, braking…).

With such a number of variables, it is too difficult to give a meaning to the axes (See Figure 5). So the number of variables is reduced by studying correlations and contributions to the construction of principal axes. At the end of the process (See Figure 6) only ten variables were kept (see Table 2).

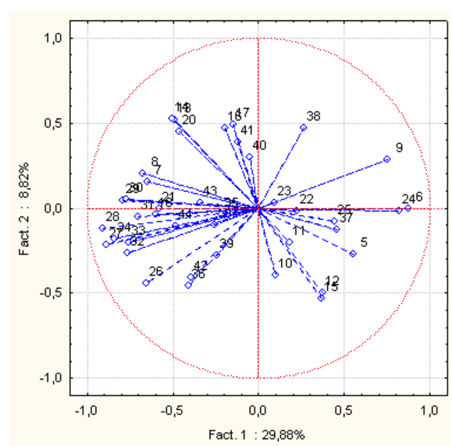

Figure 5. Projection of variables on factorial plane 1x2.

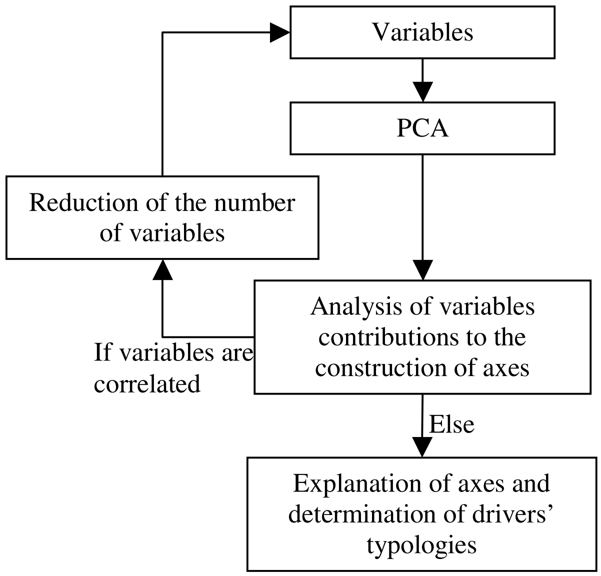

Figure 6. Pattern of the process of variables' selection

Significance of axes

The three first principal components explain 60% of informations included in the data. To determine the most important aspects of the data contained in these components, we studied the contribution of each variable to their construction.

Table 2.
Listing of variables

Mean time headway
Maximal lateral acceleration in bend
Minimum time headway before overtaking
Mean Speed in roundabouts
Maximal lateral acceleration at the end of overtakings
Mean main road speed
Passed time over the speed limitation
Number of brakings
Mean fuel consumption
Maximal longitudinal acceleration

The mean speed on main roads allows to determine if the driver has a "slow", a "moderate" or a "fast" driving. The mean fuel consumption shows if the driver is thrifty. Time headways and time spent over the speed limit allows to determine if the driver respects the driving rules.
The figure 7 show that 5 variables (mean time headway, mean speed on main road, passed time over the limitation, lateral acceleration in bends and mean consumption) are strongly correlated to the first axis (See Table 2). We can group the last four variables. This cluster opposes to the mean time headway (See Figure 7), which could let think that the first factor represents the "risk taking" of the driver. Indeed, the faster the driving is, the smaller time headways are. We can assume that a driver, with a fast drive and small time headways, takes risks and conversely.
The maximal lateral acceleration in curves, the lateral acceleration during overtaking, minimum time headway before overtaking and the speed in roundabouts allows to determine the driving "sportivity".
The minimum time headway before overtaking, the lateral acceleration at the end of overtaking and the speed practised in roundabouts have the strongest contributions for the construction of the second axis. Our study aims at discribing longitudinal regulation and not lateral control. Altough distribution within sinuous road and straight main lines is not equal, the second axe could explain the lateral control and thus if the subject is a "sporty" driver in lateral control.
Indeed, the higher the lateral acceleration is, the smaller time headways before overtaking are. A subject, with small transerve acceleration and big time headway before overtaking, is not considered as a "sporty" driver.

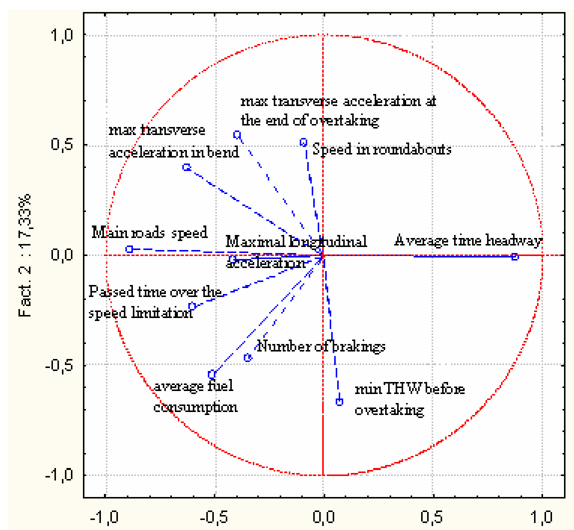

Figure 7. Projection of variables on factorial plane 1x2.

An important number of brakings allows to characterize a nervous driving.
The longitudinal acceleration and the number of brakings are correlated in the third axis (See Figure 8). This one could then allow to characterize a nervous driving. A driver that often brakes and has high longitudinal accelerations has a nervous driving. On the contrary, a driver, with a small longitudinal accelerations and few number of brakings, has a relaxed driving.

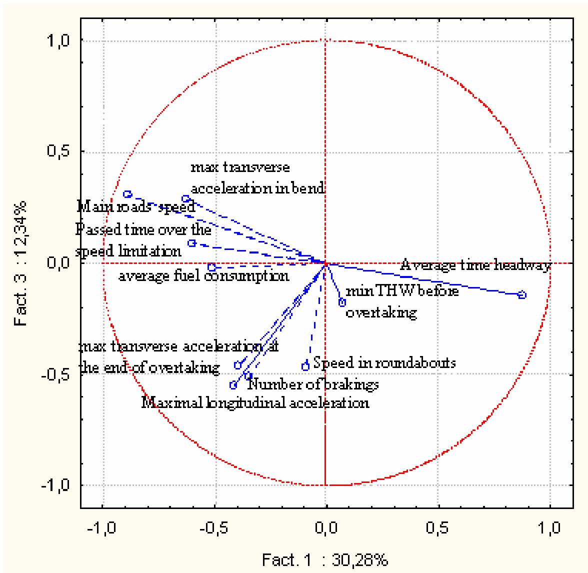

Figure 8. Projection of variables on plane 1x3.

Determination of drivers' typologies

To determine typologies of drivers, we formed clusters of subjects from their projection on the factorial axes.

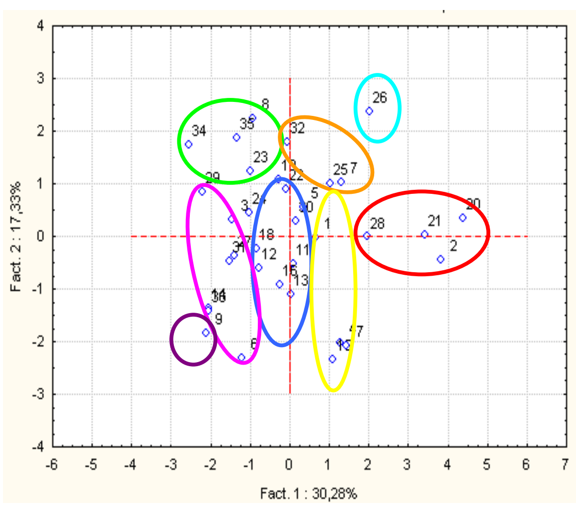

Figure 9. Projection of subjects on factorial plane 1x2

The analysis of the subjects' projections on factorial axes allows us to difference eight driver's behavior (see Figures 9 and 10):

➢ Cluster 1 (surrounded in red): slow, "not sportive" and relaxed driving

Four drivers have a rather slow driving and keep important safety distances with the other vehicles. They have no "sportive" driving because they have low transversal accelerations on road and during overtaking and they anticipate their overtakings. Their driving is relaxed. Indeed they do not press completely on the accelerator and do not often brake.

➢ Cluster 2 (surrounded in blue): moderate, "not sportive" and relaxed driving

Eight drivers have a moderate driving in terms of speed and THW. As the previous class, they have no "sportive" driving because they have low transversal accelerations on road and during overtaking and they anticipate their overtakings. Their driving is relaxed. Indeed they do not press completely on the accelerator and do not often brake.

➢ Cluster 3 (surrounded in cyan): moderate, "sportive" and nervous driving

One driver has a moderate driving in terms of speed and THW. He has a "sportive" driving because he has high transversal accelerations on road and during overtaking and he has small time headway before overtakings. He presses completely on the accelerator and he often brakes, what lets think that he has a rather nervous driving.

➢ Cluster 4 (surrounded in rose): fast, "not sportive", and relaxed driving

Eight subjects have a fast driving and small THW. They have no "sportive" driving because they have low transversal accelerations on road and during overtaking and they anticipate their overtakings. Their driving is relaxed. Indeed they do not press completely on the accelerator and do not often brake.

➢ Cluster 5 (surrounded in green): fast, sportive and relaxed driving

Four subjects have a fast driving and small THW. They have a "sportive" driving because they have high transversal accelerations on road and during overtaking and they have small time headway before overtakings. Their driving is relaxed; they do not press completely on the accelerator and do not often brake.

➢ Cluster 6 (surrounded in purple): fast, "not sportive" and nervous

One subject has a fast driving and small THW. He has no "sportive" driving because he has low transversal accelerations on road and during overtaking and he anticipates his overtakings. He presses completely on the accelerator and he often brakes, what lets think that he has a rather nervous driving.

➢ Cluster 7 (surrounded in yellow): moderate, "not sportive" and nervous

Five drivers have a moderate driving in terms of speed and THW. They have no "sportive" driving because they have low transversal accelerations on road and during overtaking and they anticipate their overtakings. They press completely on the accelerator and they often brake, what lets think that they have a rather nervous driving.

➢ Cluster 8 (surrounded in orange): moderate, sportive and relaxed driving.

Three drivers have a moderate driving in terms of speed and THW. They have a "sportive" driving because they have high transversal accelerations on road and during overtaking and they have small time headway before overtakings. Their driving is relaxed; they do not press "profoundly" on the accelerator and do not often brake.

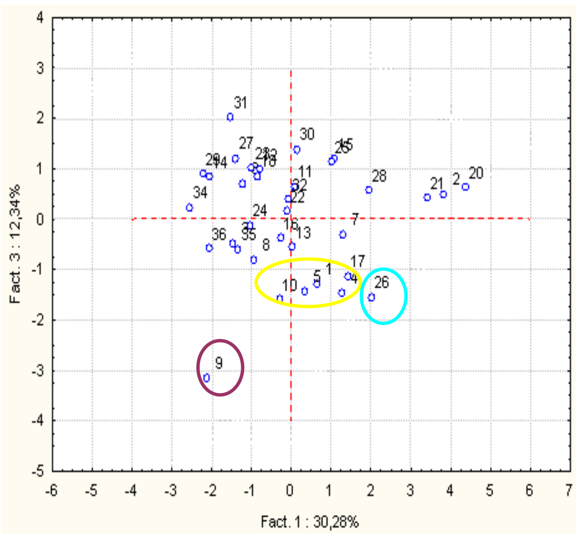

Figure 10. Projection of subjects on factorial plane 1x3

Table 3.
Typologies of drivers

Cluster	Slow, Moderate or Fast driving?	Sportivity of the driving	Nervous or relaxed driving?	Number of subjects
1	Slow	Not sportive	Relaxed	4
2	Moderate	Not sportive	Relaxed	8
3	Moderate	Not sportive	Nervous	1
4	Moderate	Sportive	Relaxed	8
5	Moderate	Sportive	Nervous	4
6	Fast	Not sportive	Relaxed	1
7	Fast	Not sportive	Nervous	5
8	Fast	Sportive	Relaxed	3

Comparison with others typologies

All precedent studies related to driving typologies found in the literature use only subjective data. These data is gathered through questionnaires and interviews. For example, [2] proposes a typology based on drivers' errors in order to improve their behavior. [9] bases his typology on drivers' feelings during the driving. These two typologies are based on parameters that we did not include in our present study, so we can't compare them directly with our results. [4] is interested in drivers' behavior and their actions. He proposes a typology of drivers in five clusters:

- (1) Slow, disciplined and thrifty drivers (26%)
- (2) Moderate and rather thrifty drivers (28%)
- (3) Fast but far-sighted drivers (23%)
- (4) Fast, "sports" and not thrifty drivers (15%)
- (5) Very fast, aggressive and high roller drivers (8%)

This typology is based on three different axes: speed, discipline and fuel thrifty. Some of our variables describe these axes. We wanted to verify if we found the same typology with our data.

For the first axe, the average speed in main roads characterizes the first parameter "speed", according to 3 modalities: slow, moderate or fast driving.

To characterize the discipline, four variables can be used: the average time headway, the time over the limitation, the occurrence of another vehicle cuting in front of the subject's vehicle and the longitudinal acceleration. The study of these four variables allows us to determine if the subject is "disciplined".

We can determine if the subject is fuel thrifty thanks to the fuel consumption.

If we combine all the possibilities for these three parameters, we obtain 12 possible clusters of drivers, but only 6 are actually found (see Table 4):

- (a) Slow, disciplined and fuel thrifty drivers (32%)
- (b) Slow, disciplined and not fuel thrifty drivers (9%)
- (c) Moderate, sportive and fuel thrifty drivers (14%)
- (d) Moderate, sportive and not fuel thrifty drivers (12%)
- (e) Fast, sportive and fuel thrifty drivers (9%)
- (f) Fast, sportive and not fuel thrifty drivers (23%)

Table 4.
Repartition of our subjects according to the three principal indicators of Labiale's typology [4]

Speed	Disciplined	Fuel thrifty	Nb of subjects
Slow	Yes	Yes	11
		No	3
	No	Yes	0
		No	0
Moderate	Yes	Yes	0
		No	0
	No	Yes	5
		No	4
Fast	Yes	Yes	0
		No	0
	No	Yes	3
		No	8

Table 5.
Association and comparison of our clusters and Labiale's clusters

Our clusters	[Labiale] Clusters
(a) 32%	(1) 26%
(b) 9%	
(c) 14%	(2) 28%
(d) 12%	(3) 23%
(e) 9%	(4) +(5) 23%
(f) 23%	

The repartition is slightly different but the same tendencies are observed (see Table 5). The differences must be due to a differential number of subjects (1006 vs. 34) and a different methodology of data acquisition (questionnaires vs. objective data).

DISCUSSION

Our experiment allows us to build a knowledge database of driver's real behavior. However, we are aware of some biases which could impact the study conclusions.
Concerning the drivers' sample, we have only chosen 120 healthy drivers. A bigger sample with some people presenting any pathologies would have been more representative of the drivers' population.
Being observed in a experimental setup can modify the driver's behavior. [2] found that the behavior of moped riders did not change when they knew that they were being observed. On the other hand, [6] found that subjects, driving an instrumented car with an experimenter, had a 1-2kph lower mean speed when the experiment leader was present. They further found that acceleration and deceleration smoothed down and lateral acceleration was reduced. We found no differences in the drivers' behavior with or without an experiment leader in a precedent study conducted by the LAB in 2006.
Different meteorological conditions can pull different behaviors. It is slight easy to control the potential effect of this parameter as the weather is coded in this study. It is also possible to make separate analysis.
The density of traffic influences speeds and headways. Here, the traffic was fluid, so headway could be larger than in a dense traffic. In order to improve the representativeness of the database, we are currently studying the drivers' behavior on the Parisian ring road to obtain headways in a dense traffic.
As a data analysis method, we used the *PCA* in this study. Other methods such as multiple correspondence analysis or classification methods will be also tested.

CONCLUSIONS

Our experimental study is complementary to statistical studies from "road safety" agencies. Indeed, these organisms record only one data per driver but for thousand vehicles. In this experiment, we chose to have much more data per driver in order to characterize the behavior of the driver in longitudinal regulation.
Concerning the research of drivers' typologies, most of studies are based on questionnaires and interviews. A few published studies use "objective data" to determine typologies. Our approach allows us to find eight clusters of drivers. These results based on only 34 drivers are not representative but they allow validating the used method. At the end of the experimentation, we will have to validate our drivers' typologies with the data of 120 subjects. It is difficult to compare our results with the others, because we do not study the same aspects of the driving. But by using our data and clusters constructed thanks to Labiale's criteria [4] we observe the same tendencies. We aim to combine "objectives data" and intentions of drivers collected thanks to verbalization to propose the most drivers adapted ADAS.
The results can be used in the specification of driving assistances taking into account the real use and need of drivers, like helping them to better estimate safety distances, using information systems (safety distance warning) or dynamic ones (ACC for example).

ACKNOWLEDGMENT

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