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VEHICLE DYNAMICS DATA COLLECTION TO CHARACTERIZE THE DRIVERS' BEHAVIOR

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1. INTRODUCTION

Understanding drivers' behavior is essential to improve road safety. Indeed Singh (2015) reported that, in the National Motor Vehicle Crash Causation Survey conducted in US from 2005 to 2007, on a sample of 5,470 crashes, the critical reason was assigned to the driver in 94 % of the crashes. It was attributed to a vehicle component's failure or degradation in only 2 % of the crashes, and to the environment in another 2 % of the crashes.

The availability of data provided by in-board recorders is a great opportunity to acquire knowledge on drivers' behavior. Event Data Recorders (EDR) are used to collect data on the vehicle's dynamic demands and on driver's actions. Their exploitation enables to improve safety equipment and to better understand and prevent crashes. In particular, Naturalistic Driving Studies (NDS) were conducted in many countries all over the world (Dingus & al., 2006) using EDR and video camera. The collection of large-scale data enabled to identify short time periods of interest, such as crashes, near-crashes and incidents, considered as critical driving situations. As explained by Valero-Mora & al. (2013), the interest of NDS is real, but the huge amount of data requires conspicuous and costly equipment, and a lot of time and resources to be analyzed.

An experiment was carried out in France during one year in 2012-2013 with 51 cars of public fleets equipped with a specific EDR using an automated methodology to detect in real time periods of interest. The data were used to explore the link between incidents and crashes and to improve the safety road diagnosis (Ledoux & al., 2014). Furthermore, in this experiment, the EDRs were used as In-Vehicle Data Recorders (IVDR) to collect continuously data on driving behavior and manoeuvres performed by the vehicles. In the presented experiment "travel trajectories" and "travel syntheses" were collected in real time for all the travels. These travel syntheses aggregate the time spent in every longitudinal and lateral accelerations combination. This approach is based on the principle of "friction circle", developed by Lechner & al. (1993), which experiment aimed at acquiring knowledge on the behavior of the couple driver-vehicle in usual driving situations.

This paper explores the interest of the travel synthesis data to characterize the driving dynamical parameters of drivers. The following studies were undertaken:

- 1) The distribution of acceleration levels is elaborated to estimate the real use of vehicles in the experiment and to compare it with a previous experiment performed in 1992 (Lechner & al., 1993).
- 2) The driver's profile is studied by the comparison of the vehicle dynamic operating area experienced by different drivers, linked to the number of their incidents and by the calculation of "behavior ratios". An illustrative socio-demographic study is presented using these ratios.

2. MATERIAL AND METHODS

2.1. Background

Data was collected during one year from specific Event Data Recorders (EDRs) implemented in 51 light vehicles of five public fleets located in the north of France (Normandie-Centre area), in the center (Auvergne area) and in the south (Salon de Provence). The fleets belonged to the different partners of the project. All these vehicles were company vehicle dedicated or not to one person. The dedicated ones could be only driven by one specific driver while the other could be driven by all the authorized employees of the involved entities. The fleets were composed of various car models from French car makers "Renault", "Peugeot" or "Citroën" (Clio, Megane, Laguna, Twingo, 307, 308...).

All the legal conditions to implement EDR in French public fleets of vehicles were respected, in accordance to the prescriptions of the CNIL (French data protection authority) (Guilbot & al., 2016). These conditions integrate European regulations and the respect of Human Rights. EDR were inactivated by default, and volunteer drivers had to opt-in by pushing a button to start the recording at each itinerary. Moreover their hierarchical managers had no access to their data. 221 drivers agreed to take part to the experiment and 154 were ready to authenticate themselves with a badge and to give their age, year of driving license and gender.

The device was designed in 2007 (Naude & al., 2017) with the aim to detect some critical driving situations, called incidents, in which vehicle is faced to high dynamics demands in longitudinal, lateral or combined directions, and also potential accidents. The device continuously acquires analog data from sensors directly integrated into the EDR (3 axis accelerometers and gyrometers for naturalistic driving, and 2 axis accelerometers for crash), data provided by a GPS (trajectory and speed), and data available on vehicle on-board diagnosis system (CAN bus, information depending on the car model).

2.1. Incidents

The data are analyzed using real-time processing performed by the embedded software, to detect potential situations of interest. The incident criteria were chosen considering previous works (Lechner & Perrin 1993,

Mongeot & al. 2006, Bagdadi & al. 2011, 2013 and Nagai & al. 2006) They take into account longitudinal, lateral and coupled demands, and the jerks (derivative of acceleration) modulated by the influence of speed:

- Speed < 80 km/h, and Acceleration norm > 6 m/s² and Jerk > 2 g/s,
- Speed > 80 km/h and Acceleration norm > 5 m/s² and Jerk > 2 g/s,
- Speed > 100 km/h and Acceleration norm > 4 m/s² and Jerk > 2 g/s.

As soon as the vehicle dynamic parameters exceed one of these three thresholds combinations, it is considered that something “abnormal” happened on the vehicle and consequently an “incident” is stored. The data are recorded during the 30 seconds before and the 15 seconds after the trigger and stored in the device. Then the complete report containing the whole data set at 100 Hz frequency is automatically sent to a server using GSM network, and stored in the global database. In addition the GPS data of all the itineraries are recorded, and stored with 1 position per minute in files called “GPS trajectories”, especially necessary to calculate the traffic of equipped vehicles.

2.2. Travel synthesis

Moreover, data collected comprised a file named “Travel Synthesis”, for every itinerary. This file is written at the end of each travel. It includes some general data such as the travelled distance and duration, or the minimum and maximum values of accelerations and speed. The more elaborate data concerning the dynamic parameters of driving are stored according to the concept of “Travel Synthesis” presented in Lechner & Naude (2011). These data are not stored according to time, but under matrix form, aggregating the time spent at a given longitudinal and lateral acceleration combination, with 0.1 g intervals. All along the travel with data recorded at a 100 Hz frequency, the couples (Lateral Acceleration, Longitudinal Acceleration) are counted up in matrixes and can be positioned on a 2d-representation as shown at the graph of figure 1. These couples are placed on the diagram with the lateral acceleration along the abscissa axis (Left turns in positive part and right turns in negative part) and the longitudinal acceleration along the ordinate axis (accelerations in positive part and braking in negative part). This type of graph is called “friction circle”, and its principle is detailed in Lechner & Perrin (1993). The circles with 0.6 g radius represent the level of acceleration beyond which an incident is triggered. The accelerations put a strain on available grip at the level of the tire-road contact, in both longitudinal and lateral directions, and this grip is usually represented by a circle. These graphical representations enable not only to see the coupling of dynamic demands, but also the assessment of acceleration levels operated in every direction.

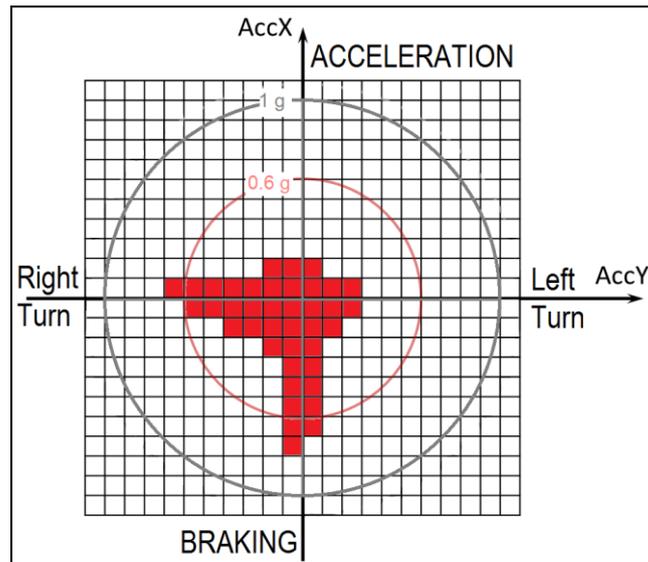


Figure 1: Example of 2D-representation of a travel synthesis.

There are two versions of travel synthesis. The first algorithm takes into account all the periods of the travel. It is called “continuous synthesis” because it enables to have all dynamic demands in proportion of the time spent in every 0.1 g-squares of accelerations. The second algorithm takes only into account the periods where the driver actions are significant, leading to dynamic consequences on the vehicle. Concretely, this second version of travel synthesis, called “simple synthesis”, considers braking, identified when brake lights are on, significant positive longitudinal acceleration, with throttle exceeding 60 %, and lateral acceleration, when the steering angle exceeds $\pm 30^\circ$. These thresholds were determined by past experience and real driving adjustment tests. If none of the conditions is fulfilled the time step is not counted. This version of travel synthesis is useful for 3D-representations with the third dimension representing the time spent in every cell of the diagram. It enables to better see the rarer high dynamic demands. The vehicle speed can also be taken into account in both versions of synthesis, as an additional option, using 10 km/h intervals. Figure 2 illustrates the second version of travel synthesis with the speed levels taken into account (bottom) or not (top). These representations are used to visualize dynamic solicitations of vehicles.

The development of specific software was necessary to exploit these files, to cumulate syntheses for several travels and to link the travel syntheses with the incident files and the GPS trajectory files.

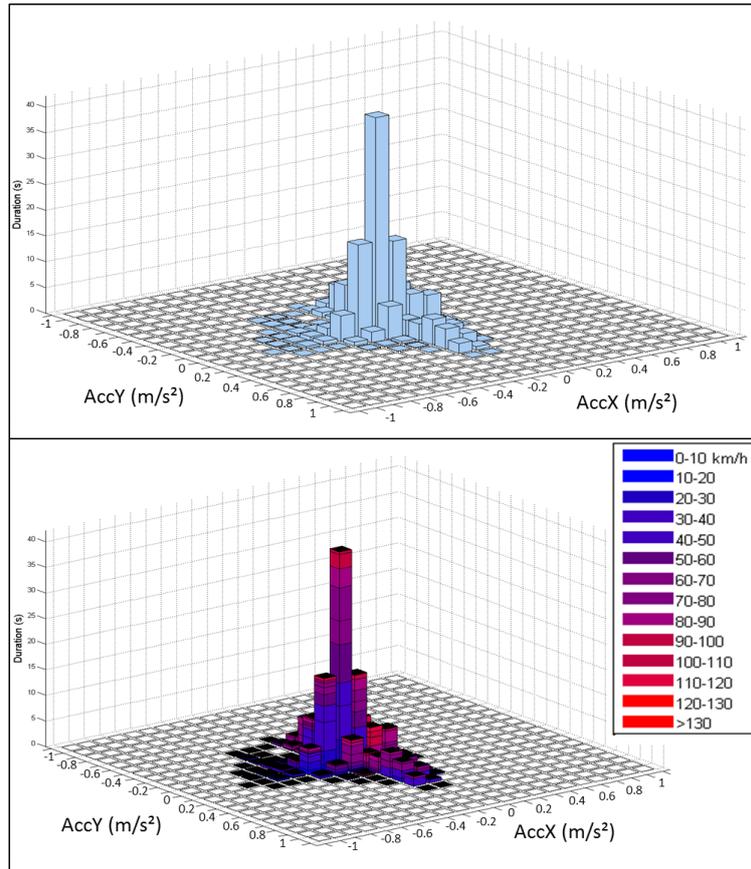


Figure 2: Example of 3D-representation of a travel synthesis with speed taken into account (bottom) and not (top).

3. RESULTS: THE DISTRIBUTION OF ACCELERATION LEVELS

The continuous syntheses, that take into account the entire travels, enable to have a complete overview of the accelerations endured by all the vehicles in all their travels during the experiment. Figure 3 illustrates this distribution of longitudinal and lateral accelerations. It can be noticed that there are more positive longitudinal and lateral accelerations than negative ones, that is, in longitudinal more accelerations than decelerations, and in lateral more left turns than right turns. This last difference between left and right turns was also observed for all the incidents and was analyzed in Lechner & al. (2015).

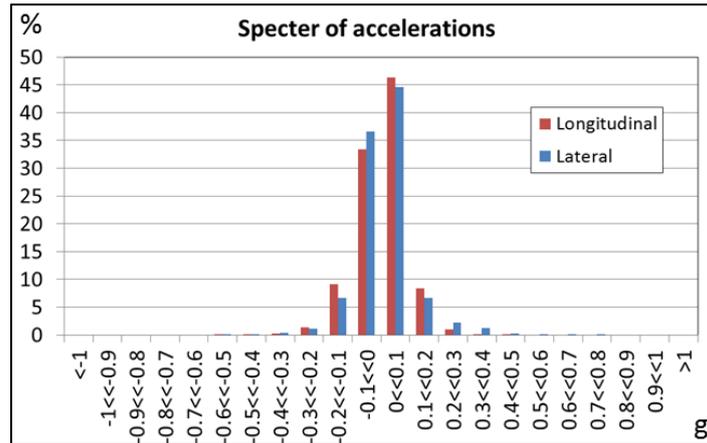


Figure 3: Distribution of longitudinal and lateral accelerations for all the travels of the experiment

This distribution of accelerations was compared to results of the previous experiment already quoted with non-professional drivers on the open road field (Lechner & *al.* 1993, 1996). This study is still a reference in the field of vehicle dynamics although it is more than 20 years old. The objective of this research was to acquire knowledge on the behavior of the couple driver-vehicle in usual driving situations. The experiment carried out in 1992 was based on about sixty drivers who had to make a travel of 85 km with an instrumented car. The itinerary presented a great variety of road infrastructure categories (motorway, crossing of big urban area, national and secondary roads, narrow and sinuous road and crossing of small towns). The sample of drivers included novice, elderly and professional drivers. Nearly 5000 km of data were collected and analyzed. The acceleration levels of this previous experiment were compared to the accelerations of our experiment, which concern 106 600 km travelled during one year by 50 vehicles and numerous drivers on a great variety of roads in 3 regions of France. The Table 1 resumes the comparison, with a similar distribution:

- In both experiments the cars endure longitudinal accelerations superior to 0.2 g nearly 3 % of the time,
- Beyond 0.3 g the time rates for longitudinal solicitations are 0.4 % and 0.5 %, which are close,
- The lateral accelerations are superior to 0.2 g respectively 5.8 % and 5.5 % of the time, and superior to 0.3 g only about 2 % of the time.

Table 1: Comparison of accelerations levels and average speeds between 1992 and 2012-2013 experiments

% of time	1992	2012-2013
Longitudinal Acceleration > 0.2g	3.0 %	2.9 %
Longitudinal Acceleration > 0.3g	0.4 %	0.5 %
Lateral Acceleration > 0.2g	5.8 %	5.5 %
Lateral Acceleration > 0.3g	1.9 %	2.1 %
Average speed	64 km/h	57 km/h

The average speeds were also calculated for both experiments. Yet the precision for our experiment is at least 5 km/h, because the periods passed in square-0.1 g accelerations are associated to a mean speed in a 10 km/h-interval. Moreover beyond 130 km/h the periods are counted in the last speed category, even if the speed is a lot higher. Thus the average speed can be under-estimated. The speed of the first experiment is higher (64 km/h) than the second (57 km/h) but the difference is therefore not significant.

Despite the differences between these experiments, the similar results in term of acceleration levels confirm the awareness that only a few drivers exceed 0.3 g, and this very rarely, mostly in lateral.

4. RESULTS: THE DRIVER'S PROFILE

4.1. Comparison of the vehicle dynamic operating area experienced by different drivers

The 3D dynamic parameters were compared between the 43 authenticated drivers having actually produced travel syntheses during the experiment, among the 154 volunteers to do so. As an example, the cumulate syntheses for all the travels of 4 different drivers are presented in Figure 4. For each driver an identification number, age, years of driving license, number of travels (Iti), total driving time, total distance travelled and number of incidents (Inc) are indicated.

These 4 drivers show very different behaviors: D1, who is only 23 years old, has the widest operating area, experiencing braking and lateral accelerations beyond 1 g, whereas D11 has the smallest one, reaching quite never 0.5 g, whichever direction of demand. D15 accepts higher acceleration in braking (beyond 1 g) than in bends (rarely up to 0.8 g). On the contrary, D17 experiences higher lateral accelerations (beyond 1 g) than braking decelerations (never exceeding 0.8 g).

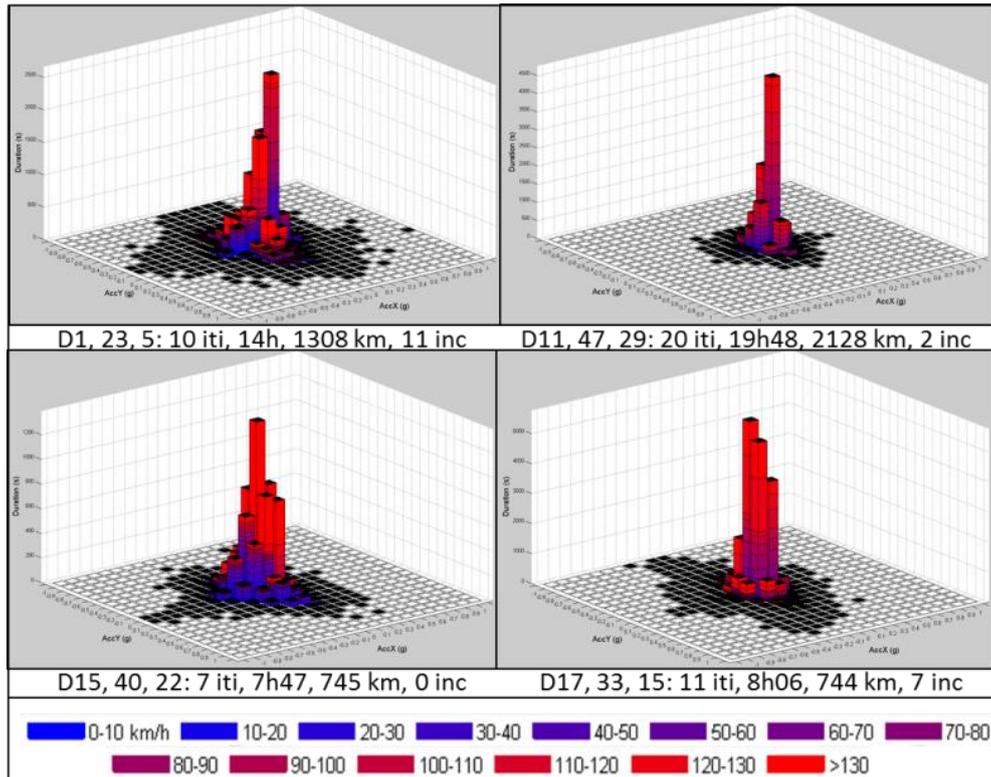


Figure 4: Dynamic parameters for 4 drivers among the 43 self-authenticated in the data collection

4.2. Statistics and “behavior ratios”

The whole database for one year of collection on the French road network represents 3052 itineraries and 106645 km travelled. 1237 simple events, 338 genuine incidents and one material accident were collected.

The exploitation of travel synthesis and GPS trajectories produced statistics on the experiment. For example, the authentication ratios were calculated: 17% of the travels, and 30% of the travelled kilometers. On average, each of the 43 authenticated drivers realized 841 km, but there is a great diversity of situations. Indeed, some drivers travelled a lot, up to 12800 km, whereas some of them travelled very little.

A ratio “R1” for driver’s actions was calculated by the relation between the duration of periods counted in the “simple synthesis” and the total time of the travels. In this way it takes only into account the periods where the driver actions are significant (braking, turning...), with dynamic consequences on the vehicle. This ratio characterizes the proportion of relevant dynamic solicitations of the vehicle during the travels. A low ratio rather corresponds to a calm driving, and a high ratio to a sportier driving. A big travelled distance is required to have a significant ratio, not dependent on the type of roads and environments used (urban area, motorways...). Figure 5 shows this ratio for the 28 authenticated drivers who travelled more than 250 km, in ascending order. The ratio was also calculated for all the travels of the experiment and all the drivers, even those not authenticated. This average value for all the drivers (52%) is considered as a reference for the ratios of the authenticated

drivers. The travelled distances and the number of incidents were also reported on this graph. This action ratio is not directly in relation to the number of incidents.

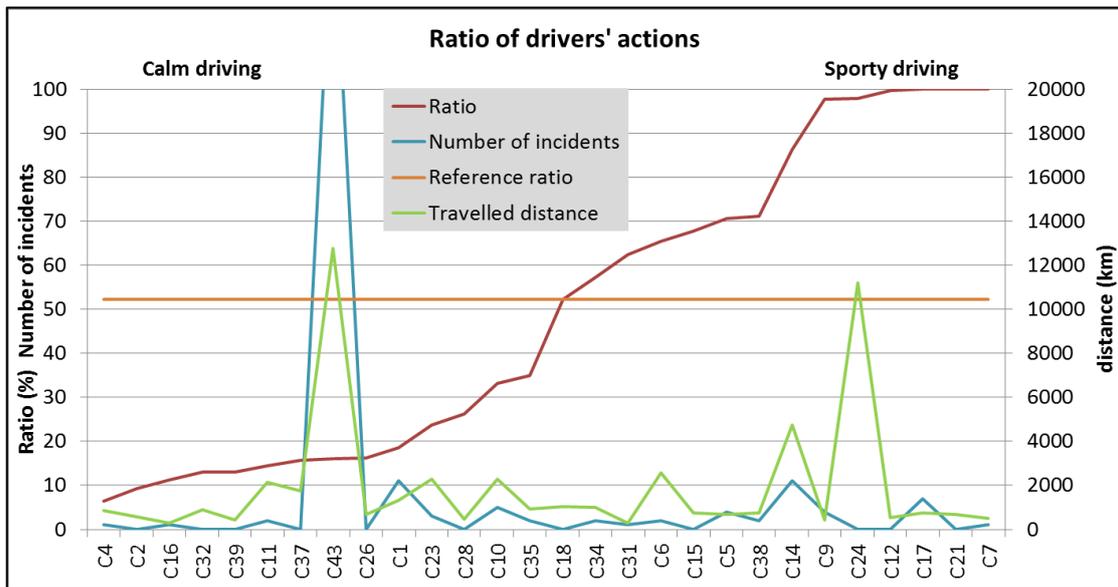


Figure 5: Action ratio for 28 authenticated drivers with a travelled distance higher than 250 km

The travelled distance of every authenticated driver was also compared to his number of incidents, as illustrates Figure 6. The situations are varied, and the ratio "R2" between the numbers of incidents and the travelled distance, for every authenticated driver having experienced at least one incident, can be an indicator of the driving profile, in particular for the most travelling drivers.

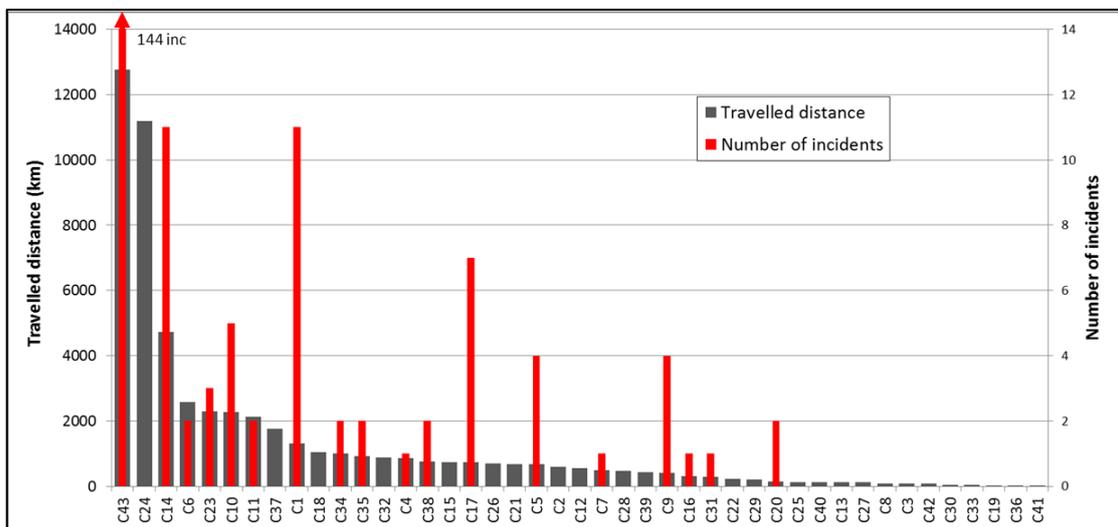


Figure 6: Travelled distances (by decreasing order) and numbers of incidents of the 43 authenticated drivers (The first driver had 144 incidents which are not entirely represented).

It has to be noticed that the driver who had the highest number of incidents, C43, has not the higher incident ratio because he travelled a very long

cumulative distance. In the same way the driver C24, who travelled the second longer distance (11200 km), had no incident, whereas the driver C14 with the third longer distance (4700 km) had 11 incidents.

A third behavior ratio "R3" was calculated taking into account the levels of longitudinal and lateral accelerations and the cumulative time spent in each square 0.1 g interval of accelerations. The Figure 7 shows the crossing of the three behavior ratios: the action ratio on the horizontal axis, the incident ratio along the vertical axis, and the acceleration ratio indicated by the size of the circles. The red lines represent the reference action and incident ratios (52% and 87%) for the whole travels collected in the experiment.

This graphical representation shows that the biggest acceleration ratios correspond to drivers with low action ratios, and varied incident ratios. The driver C43, with the sportier driving according to incident ratio, is also the sportier for the acceleration ratio. The sportier drivers according to action and incident ratios (C9 and C17) have on the contrary a low acceleration ratio.

These three behavior ratios seem to be complementary.

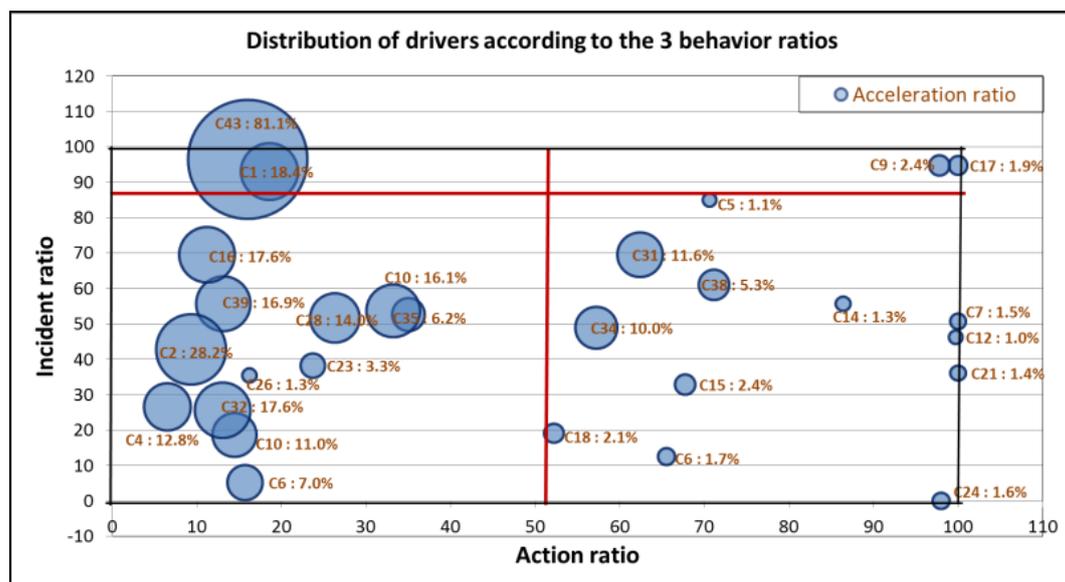


Figure 7: Distribution of the 3 behavior ratios for 28 authenticated drivers (dist. >250 km)

4.3. Differences in types of driving according to the gender, the age and the driving experience

Thanks to the previously described ratios, a socio-demographic study was carried out on the 28 authenticated drivers who travelled more than 250 km. The sample size is very little and the results are only illustrative of the possibility to infer some trends from such data.

First, the averages of the 3 behavior ratios were calculated for the 23 men and the 5 women, and are given by Table 2.

Table 2: Difference between men and women average behavior ratios

	MEN	WOMEN
Number	23	5
Mean age	41 years 5 months	30 years 7 months
Driving experience	22 years 6 months	13 years 2 months
Average speed	82 km/h	85 km/h
R1 (Action ratio) (Calm → sporty)	48.4%	53.5%
R2 (Incident ratio) (Calm → sporty)	48.6%	50.7%
R3 (Acceleration ratio) (Calm → sporty)	12.2%	3.3%

The average speeds are calculated on the basis of travel synthesis, with a precision of at least 5 km/h, thus the difference of 3 km/h between men and women is not significant.

According to the action ratio and the incident ratio, the women driving may be sportier but with a level of acceleration a lot lower. These averages are not significant since the distribution of the men (in blue) and women (in yellow) in the graph crossing the three ratios, at Figure 8, is contrasted. In one hand, it can be noticed that there are only men in the right upper part of the graph, with high action and incident ratios, contrary to what the averages could lead to think. On the other hand, the sportier drivers according to the acceleration ratio are the men, in agreement with the average. These differences are observed with a small sample of women, and could also be due to their lower age and driving experience.

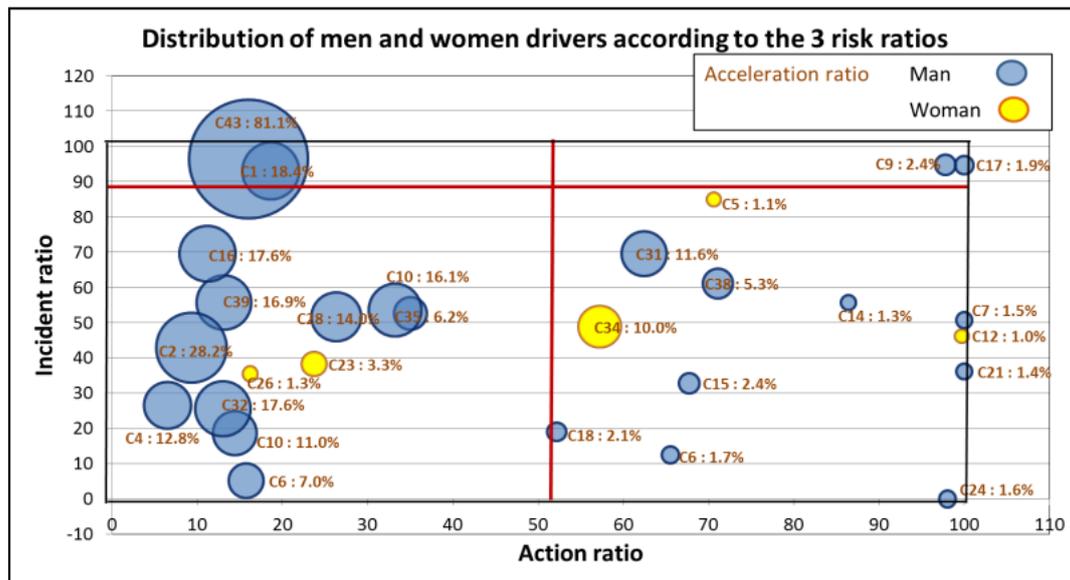


Figure 8: Distribution of behavior ratios for 23 men (blue) and 5 women (yellow) drivers (dist. >250 km)

The graphs of Figure 9 show the 3 behavior ratios according to the age range and the driving experience. Overall, older the drivers are, faster they drive and

more the vehicles endure high dynamic demand, but rarer the drivers' actions are and less incidents they have. These observations should be taken rather as an illustration of exploitation possibilities for such data, especially since some categories in the sample are very small, like the older drivers or the lower driving experience.

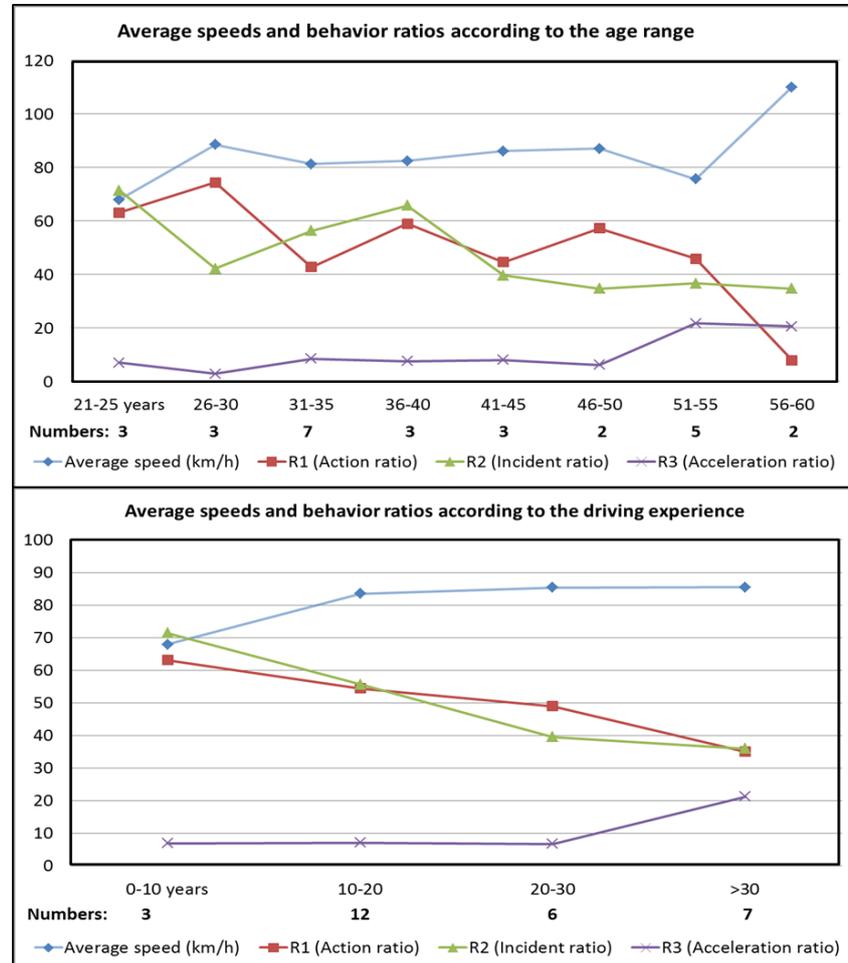


Figure 9: Distribution of average speed and behavior ratios for 28 drivers (dist. >250 km) according to age (top) and driving experience (bottom)

6. CONCLUSIONS

The studies presented in this paper show how EDR can provide relevant information on drivers' behavior. More than 3000 travel synthesis and GPS trajectories files were exploited, representing more than 100000 km/h travelled, in connection with the 338 incidents collected.

The synthesis of all the travels was compared with a previous study aiming at acquiring knowledge on the driver-vehicle behavior in usual driving situations. In spite of the differences between both experiments, the acceleration levels were similar, which confirm the fact that only a few drivers exceed 0.3 g, very rarely, and mostly in lateral. Thus the driver behavior seems not to be modified 20 years later.

To study the driver's profile through the travel synthesis data, the comparison between the 43 authenticated drivers was made, illustrated in this paper by the example of 4 drivers with quite different driving profiles. Moreover, three ratios were calculated to characterize the driver behavior, quantifying respectively the actions of the driver during his travels, the number of incidents per distance travelled, and the levels of accelerations endured by vehicles. These three "behavior ratios" seem to be complementary. A brief socio-demographic study was carried out on the 28 authenticated drivers who travelled more than 250 km. The results, illustrative because of the small size of the sample, show the relevance of using such data and ratios to differentiate the driving behavior between men and women, young and old, novice and experienced drivers.

This work shows that data collection of aggregate accelerations is useful to characterize the drivers' behavior, which is essential to better understand the occurrence of crashes, and to improve road safety. A similar algorithm applied to motorcycles was also developed in another project, based on a dedicated smartphone and using not only accelerations but also angular speeds, in order to study the specific behavior of motorcycle drivers.

7. ACKNOWLEDGEMENTS

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