A System for Driver Behavioral Indicators Processing and Archiving

Olivier Bezet, Véronique Cherfaoui, Philippe Bonnifait

Heudiasyc UMR 6599, University of Technology of Compiègne,
BP 20529, 60205 Compiègne cedex, France.
E-mail: *firstname.surname@hds.utc.fr*

Abstract - **This paper presents the DBITE (Driver Behavior Interface Test Equipment) system developed in the RoadSense (ROad Awareness for Driving via a Strategy that Evaluates Numerous SystEms) European project (5th PCRD) to implement an evaluation methodology of the driver behavior based on human factors indicators calculation. The DBITE is a distributed architecture embedded in a vehicle, dedicated to the data collection and to the calculation of metrics. The technical feasibility of this methodology was proven on a case study with an ADAS (Advanced Driver Assistance Systems) of a car manufacturer.**

Keywords: Behavioral indicators, advanced driver assistance systems, Embedded system, Data collection.

I. INTRODUCTION

WHATSOEVER the design mode of the ADAS, an experimental phase and tests in real situation or using a simulator is necessary before the decision of production. Part of these tests is carried out by the driving psychologists and ergonomists in order to study the driver behavior confronted to these assistances.

To succeed the study of the driver behavior, it is necessary to observe and question him/ her. The methodology defended by the RoadSense [1] ergonomists consists on the calculation of behavioral indicators (for example, the glance frequency, the driver reaction time or the variance of its lateral variation compared to the right roadside). In this project, about forty indicators were proposed, standardized and studied. Most of these indicators calculation can be automated if the vehicle is equipped with means of perception and/or if ADAS functions transmit information. The developed DBITE system offers this calculation possibility, in real-time or post-processing, and makes it possible the ergonomist to inform uneasily measurable or unobservable indicators with embedded systems. The DBITE has, by nature, a distributed hardware architecture owing to the fact that it includes various systems and records data flows incompatible with the capacities of a single calculator. So data dating in a common reference frame represents the key point for which we found a new invention, entirely distributed and symmetric.

Several other studies from the National Highway Traffic Safety Administration (NHTSA, USA) have been embedded in vehicles and compute and store metrics. E.g. the Crash Avoidance Metrics Partnership (CAMP) [2] has developed practical and repeatable driver workload performance metrics and test procedures that can be used to assess which in-vehicle tasks a driver might reasonably be allowed to access and perform while driving. The data collection effort spanned a six and one-half month period with testing conducted in three venues. Another projects have been leaded, e.g. Collision Avoidance System (CAS) [3], Road Departure Crash Warning (RDCW) system [4], 100-car study [5] or SAfety VEhicle using adaptive Interface Technology (SAVE-IT) [6]. All these studies have led to very heavy experimentations and data recording systems, so that dedicated systems have been implemented for each of them. However, in our case, we wanted to implement a flexible and scalable system, with common computers. We also wanted to be able to add external systems as black boxes (here, an eye tracker). So we had to implement a robust system tolerant to computers or sensor failures: a failure had not to lead to the lost of all previous acquired data. Instead, we had to be able to reboot the system and continue the data acquisition.

The paper is organized as follows. In section 2, we present the behavioral indicators and their classification. In part 3, the DBITE system architecture for the behavioral indicators elaboration is described. We will insist on the key technical concepts which are a component based architecture and a common dating system. Part 4 illustrates the use of the DBITE for the study of the driver behavior confronted to a time warning ADAS with haptic return.

II. BEHAVIORAL INDICATORS DEFINITION

In this study, the driver behavior is evaluated with indicators on the driver vehicle interactions. These indicators measure the driver performance, its mental effects and its comfort. They are evaluated with so called metric measurements, Human Factors (HF) *metrics*. RoadSense partners (ergonomists and psychologists) focused themselves on the driver behavior study in the presence of an ADAS having an interaction with the driver, on a simulator and in real situation. The studies related to the use of navigation systems (45 studies [7], [8], [9]), of alarm and information systems (49 studies including [10], [11]). The goal was to index the most relevant metrics, the target values, and these measurements collection and calculation specifications [12], [13].

The state of the art enables to identify 82 metrics among which 52 were retained for the RoadSense project, knowing that physiological indicators were rejected from the study [14].

System response time
Number of brake pedal actuation
Brake pedal actuation errors
Number of accelerator actuation
Number of situations where the driver is ready to brake
Brake pedal "cover" frequency

A. Indicators classification

The indicators can be gathered in 2 principal classes: objective indicators and subjective indicators.

The objective indicators are evaluated from the driver observation and its driving activity and can be gathered in 6 categories:

- *Lateral control:* describes the driver actions to control its trajectory on the road;
- *Visual management:* informs about the driver capacity to manage visual information relating to the driving task;
- *Speed adaptation:* indicates what are the driver actions to adapt the speed according to the traffic conditions;
- *Interactions with other vehicles:* indicates the driver response to the other vehicles behavior;
- *Situation awareness:* estimates the driver conscience on the dynamics of the surrounding traffic;
- *System usability / suitability:* debriefs the interaction quality between the driver and the ADAS.

Table I describes all the metrics associated to the selected indicators of the project.

TABLE I

METRICS SELECTED FOR THE OBJECTIVE INDICATORS EVALUATION

Indicators	Metrics
Lateral control	Number of major lane deviations Steering wheel position variance Standard deviation of steering wheel angle Behavioural entropy of steering wheel angle Standard deviation of the lateral position Steering wheel reversals rate (SRR) Steering wheel action rate Yaw rate
Visual management	Time on road perception information inside the vehicle Time on driving information inside the vehicle Time on any other areas Visual demand (percentage of total time spent looking at an object or an area) Decrease in glance frequency to mirror
Speed adaptation	Mean speed, Variance in longitudinal speed
Interactions with other vehicles	Time headway Relative distance with other lateral vehicles Relative speed with other vehicles Following distance Duration of close following situations Time on the road / lane occupied Time to collision (TTC) Number of lane changing
Situation awareness	Reaction time Braking reaction time Reaction time in peripheral detection task Number of misses in peripheral detection task Number of emergency braking Braking distance Speed variation Actions on pedals Foot position Speed of accelerator pedal
System usability / suitability	Number of driver actions on the system Number of system responses to the driver's actions Dwell time (sum of consecutive individual fixation and saccade times to a target in a single glance) Number of eye fixations in an area Glance duration Glance frequency Length of eye fixation Task time Number of failures Reading time Reading time for auditory information Action time

Subjective indicators result from the driver opinion on his/ her mental charge and on the use of the assistance system. A microphone and a camera records and films the driver during the driving process and during interviews between driving sequences. They are not subjected to an automatic data collection.

B. Metric calculation specifications

The state of the art carried out within the framework of this project enables to list a number of target values for some metrics. These target values correspond to acceptable bounds or thresholds. When they exist, the target values are criteria either for the evaluation indicators or for calculation triggers for other metric. It is thus interesting to evaluate the metrics during experimentations when it is possible.

As described in the following paragraph, the metric calculation is carried out with the DBITE. An object oriented approach was planned in order to homogenize the data representation and to facilitate the exchanges between components. So each metric and, more generally, each datum is an object. Specific attributes are defined enabling various calculations distributed on various machines composing the DBITE: data fusion, data analyzes, statistics, etc…

In addition to the data value, object's attributes are time reference and quality attributes. The time reference is the datation (with a precise date or an interval time), and the quality is described by the imprecision with which the data was estimated and the attached degree of uncertainty. Indeed, in a fine analysis of the driver behavior preoccupation, psychologists need certainty information for the concerned data. As an example, there is not the same confidence in a mean velocity calculated in a window of time with two samples as from 10 samples.

Quality attributes computation depends on sensors and algorithms used for the metrics calculation. The time reference attribute (datation) depends on the in-vehicle system architecture. The next part describes the D-Bite architecture and the time stamping principle.

III. EMBEDDED COMPONENT FOR INDICATORS CALCULATION

A. The DBITE

DBITE is a tool for driver ergonomists and psychologists to have an adapted sight of:

- The motoring environment;
- The system state during the tests (including the vehicle and the ADAS being analyzed);
- The driver behavior.

This device must be able to record a great large bandwidth data quantity and to timestamp them, while carrying out calculations in real-time. Software platforms as RT-MAPs [15] have been considered attentively at the begin-

ning of the project but were not retained to carry out the system architecture because of their centralized design.

DBITE relates to experimental vehicles equipped with an ADAS to study. In this case, the approach consists of:

- Defining the relevant indicators;

- Equipping the vehicle with a DBITE system adapted to the calculation of these indicators;

- Carrying out tests with drivers and recording data;

- Analyzing data in post-processing and drawing the conclusions.

DBITE is not used alone. There is always an operator in the vehicle to launch the applications, to give instructions to the driver and to supervise the correct system operation.

Its data-processing architecture relies on components or modules constituting an application network distributed on the basis of the *SCOOT-R* (Server Client Object Oriented for the Real-Time) middleware [16]. *SCOOT-R* enables to distribute tasks on several processing units, while communications and synchronization services are managed. It also checks the real-time constraints and proposes strategies of failures management.

Components exchange data according to a transactional model (client-server or consuming-producer) with time constraints. The considered network is the *FireWire* (*IEEE 1394*). This architecture enables to obtain a great modularity, because the interfaces between components are perfectly specified. For example, according to the necessary resources, the architecture of Figure 1 can be deployed on one or more computers.
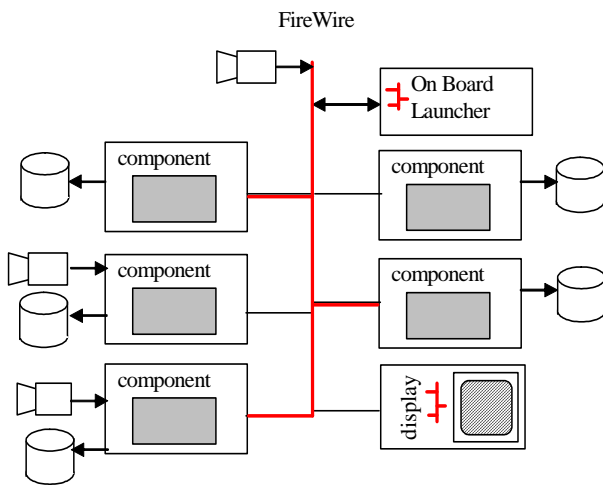

Fig. 1. Example of DBITE architecture.

DBITE enables to acquire and compute data on a distributed system. Thanks to *SCOOT-R*, the components exchange data in real-time to compute indicators. It is interesting to remark that a same data producing component (server) can provide data to several processing components (clients). For example, the speed is a measure involved in several calculations. *SCOOT-R* thus offers an abstraction mechanism of the information sources, making easier the development of data fusion applications.

All components are built in the same way. This is possible, because all components have the same specifications: a component requires input data, processes them and makes them available for other components. Sensors are not synchronous, i.e. they do not produce data at the same time.

Figure 2 shows the general organization of a component needing two objects *a* and *b* to produce *c*.
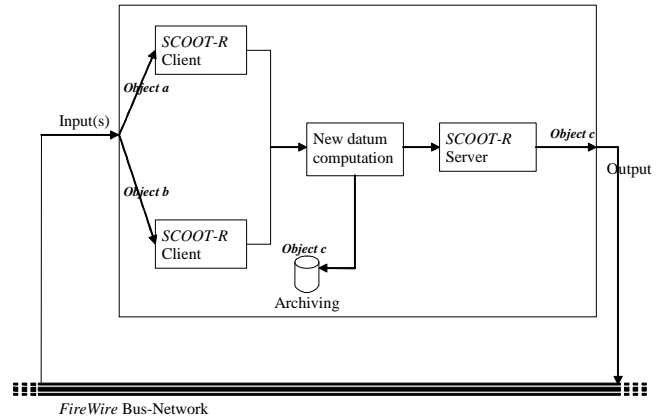

Fig. 2. General organization of a component calculating object C.

The component illustrated on Figure 2 has 2 inputs (*a* and *b*), and one output giving *c*. So this component has two clients *SCOOT-R*, one for each input, and a server *SCOOT-R* for the output. Data are available for possible client components; this method makes the architecture completely scalable for future developments. All data are recorded on the local hard disk so that post-processing analysis is possible. The number of inputs and outputs is variable, depending on the component.

For data recording, a binary format has been developed, enabling a compact and effective recording of great data flows. Each file contains a heading enabling to describe the data format and to check the recording process integrity. All data are timestamped with the local date of the machine having acquired the data.

Starting a distributed application being always complicated and delicate, a mechanism called "launcher" has been developed so that a machine can manage the experiments by defining the name of the test in progress, by starting all the required applications and by loading and transfering data by *ftp* at the end of the experiment.

B. Common dating of distributed data

As we have just seen, the DBITE architecture is distributed on several calculators. During the dynamic data acquisition phase, this architecture implies a time management problem. Indeed, data are timestamped with local computer clocks, physically different for each computer. A clock is seen here as a generator of periodic impulses associated with a counter.

We have designed a mechanism of dating able to take into account a certain structure variability of the system during its phase of recording [17], [18] because:

- It is possible that during an already started recording, it might be necessary to record new data with a new calculator;

- A system component can have a failure and induce a reboot. It would be a pity if all experiments in progress were lost or at least in danger.

Let us suppose that the recording calculators are connected through a synchronous bus, whose clock is used as common time. In this case, it can be noticed that the common time can change at each reconfiguration.

The process initially records, with each produced datum, the local time. This time is an interval containing in a guaranteed way the data production time in the local reference time. We suppose that the local clock parameters are not modified during a test. In parallel of the data recording and timestamping, a process records the correspondences of the local time with the common time. This mapping is carried out in a guaranteed way as follows: the local time is first read (at a time $t1$), then the common time is read (at a time $t2$) and finally the local time is read again (at a time $t3$). Thus, it is certain that $t1<t2<t3$ (in any reference time). This process can be low priority and low frequency (typically 1 Hz), the global result being insensitive to great differences between $t3$ and $t1$ as long as they are occasional. Thus, the minimum possible disturbance is done on the real-time data acquisition and timestamping system.

Consider a system of N units having recorded data according to the previously exposed method. The restamping principle consists in choosing a unit as reference time and in restamping the $N-1$ other data units relatively to this one. The used methods are based on the interval analysis [19] in order to guarantee the result. We exploit anteriority relations to decrease the interval width with constraints propagation techniques.

The presented system has been implemented for a case study involving the evaluation of an ADAS function. The work is presented in the next part.

IV. CASE STUDY

4 case studies have been carried out, each one with a different ADAS and implementation of the DBITE, and with a car manufacturer.

- Control of a 2s time headway (Renault);
- Night vision (PSA);
- Advanced information traffic systems (Jaguar);
- Intelligent communication systems management (FIAT).

A. Case study presentation

This paper describes the first one: the control of the 2 s time headway, imposed by the French legislation. There was a system composed by an ultra high frequency radar detecting the previous vehicle and calculating the time headway. If this last was under the 2 s legislation, various devices warned the driver. This system had to be tested.

17 metrics were chosen to test the system, computed by the DBITE. The configuration was the one shown in Figure 3:

- 3 video streams (driver, scene and feet) at a rate of 15 images/s (320x240 pixels resolution);
- One audio entry recording the driver talk;
- One CAN interface;
- One eye tracker (FaceLab - Figure 4);
- Two industrial PCs;
- One extractable hard disk, to transfer easily the data from the car to the laboratory;
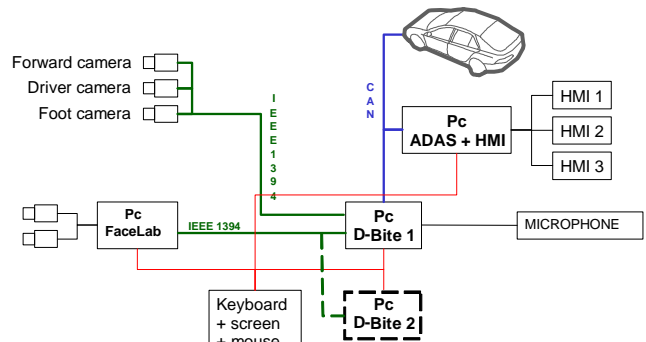- One screen, keyboard and mouse for the experiment monitoring.

Fig. 3. Embedded part of the DBITE.

Fig. 4. Overview of the stereo pair cameras of FaceLab in the experimental car.

B. Experimental protocol

The DBITE was made profitable for the behavioral study of 20 drivers on 100 km long tests, according to a particularly detailed test procedure: presentation of the ADAS, drive with various ADAS operating modes (visual, sound or haptic return of the accelerator pedal). At the end of every test, a questionnaire was filmed and recorded by the DBITE.

During the tests, the experimenter could control the correct test operation, thanks to the screen display of videos and some indicators: mean velocity, time headway, distance and relative speed (see Figure 5). It was also possible to enter comments which were timestamped.
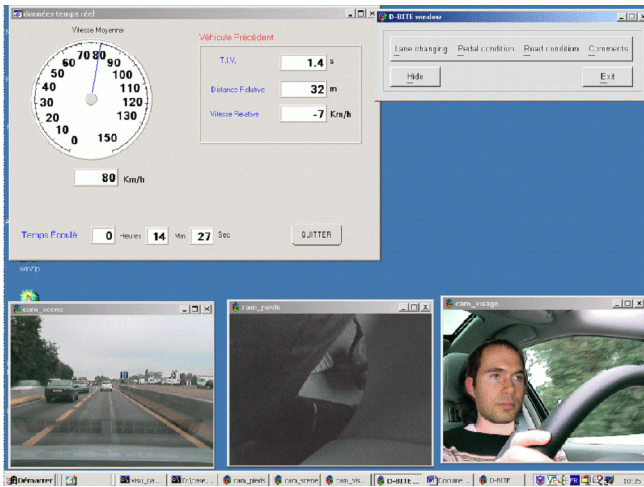
Fig. 5. Control screen during experimentations.

C. Indicators calculation

17 metrics were calculated on-line or during post-processing (see Figure 6): covered distance; mean speed over 0.5 second; variance in longitudinal speed; following speed; time headway; classification and duration of time headway (very safe, safe, dangerous, very dangerous); time to collision; accelerator lift; footbrake pedal pressure: beginning and end; indicators (left and right); steering wheel angle; HMI state: display, sound, accelerator pedal vibrations, recovery; accelerator pedal position mean; accelerator pedal position variance; following vehicle change; accelerator pedal lift reaction time; braking reaction time; glance reaction time.

Figure 6 shows the different calculated and recorded metrics and data, and their dependences. Some data were indeed elaborated with the result of other ones. There were three principal sources of information: the *CAN* bus where the majority of the information provided by the vehicle are, the eye tracker and the cameras. Thanks to these sources, data were calculated on line and others were calculated automatically or manually during post-processing.

The indicators calculation within the distributed environment uses a process of interval restamping, using the synchronous bus-network clock to estimate the drift between the various clocks [20]. This makes it possible to have lower error when data timestampings are far away from the data exchange date.

With the DBITE, on-line indicators calculation is distributed in components: each one of them is devoted to the calculation and recording of an indicator. It enables, at the beginning of each experimentation, to select the indicators to calculate. The calculation choice of an indicator implies, of course, that those of which it depends are also calculated.

Finally, it can be noticed that the DBITE is regularly used for everyday experimentations with the experimental car.

D. Play back and analyzes

A data playback tool was developed in collaboration with the user ergonomists. It enables to play back sounds and videos (play forward, backward or accelerated) while dis-

playing the behavioral indicators. One of its specificities comes from its aptitude to play back asynchronous data expressed in a common time scale. If the machine resources are saturated or in case of accelerated play, it is able to jump data to respect the play back instruction speed.

At the user request, a link to *Microsoft Excel* was developed so that highlighted data in *Excel* sheet are always in synchronism with the video. Likewise, from the *Excel* sheet, it is possible to find the data and images at the corresponding time.

V. CONCLUSION AND DISCUSSIONS

This paper presented a system implementation for the behavioral indicators elaboration of an automobile driver confronted to an ADAS. A system to implement it has been presented and implemented on a consequent case study requiring the installation of complex numerical devices.

The DBITE system has proved its feasibility and was evaluated by Renault. The principal criticism was the lack of simplicity of implementation by a non-specialist for another case study. Indeed, a technician must intervene to integrate the sensors, to develop their interfaces with the DBITE and to develop adequate software components.

However, the open and distributed architecture of DBITE is particularly well adapted to embedded constraints, where the network and the components are not safe, and where it is possible to add new components without loss of time precision during the post processing process. It should be noted its great flexibility with respect to the addition of sensors and data-processing calculation not well defined at the project beginning. This would make it possible to integrate other calculations not carried out in the case study, like image processing (lane position or feet follow-up) which would have avoided the ergonomist making his/ her own calculations.

REFERENCES

[1] http://www.its.leeds.ac.uk/projects/haste/roadsense.pdf

[2] Third Annual Report of the Crash Avoidance Metrics Partnership, April 2003 - March 2004, http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/CAMP3/images/CAMP-IVIThirdAnnualReport.pdf

[3] Final Program Report of the Automotive Collision Avoidance System (CAS) Field Operational Test, June 2004 – May 2005, http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/acas/ACAS_FOT_Final_Program_Report_DOT_HS_809_886.pdf

[4] Interim Report on Road Departure Crash Warning Subsystems(RDCW), September 5, 2003, http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/FINALINTER9-03.pdf

[5] Vicki L. Neale et al., "An Overview of The 100-Car Naturalistic Study and Findings", in proceedings of the 19th ESV Conference, Washington D.C., 2005

[6] Final Report of SAfety VEhicles using adaptive Interface Technology (SAVE-IT), November 2004, http://www.volpe.dot.gov/opsad/saveit/docs.html

[7] Green, P. "Measures and Methods Used to Assess the Safety and Usability of Driver Information Systems" (Technical Report UMTRI-93-12). Ann Arbor, MI: University of Michigan Transportation Research Institute, April 1993. (Also published as FHWA-RD-94-088. McLean, VA: U.S. Department of Transportation, Federal Highway Administration, August, 1995.)

[8] Green, P. "Crashes Induced by Driver Information Systems and What Can Be Done to Reduce Them" (SAE paper 2000-01-C008). Convergence 2000 Conference Proceedings (SAE publication P-360). Warrendale, PA: Society of Automotive Engineers, 26-36, 2000

[9] Ben-Yaacov, A., Maltz, M., & Shinar, D. (2002). Effects of an in-vehicle collision avoidance warning system on short- and long-term driving performance. Human Factors, 44, 2, 335-342

[10] Pattern, C., Kircher, A., Östlund, J., Nilsson, L. "Using mobile telephones: cognitive workload and attention resource allocation. Accident Analysis and Prevention." Vol 36, Issue 3, pp 341-350, 2004

[11] Nunes, L., and Recarte, M. A.. "Cognitive demands of hands-free-phone conversation while driving." Transportation Research Part F, 5, 133-144, 2002

[12] Tijerina L., Parmer E., Goodman M.J. "Driver workload assessment of route guidance system destination entry while driving: a test track study." Proceedings of the 5th ITS World Congress, Seoul, Korea, October 12-16, 1998

[13] Olsson, S. and Burns, P.C. "Measuring Driver Visual Distraction with a Peripheral Detection Task." Obtained from August 2000 The National Highway Traffic Safety Administration Driver Distraction Internet Forum on the World Wide Web, 2000

[14] Chin, & Nathan, F. "State of the art on HMI metrics and target values." RoadSense Deliverable D2.1 [WP2.1/PSA/D2.1/Part1/R1.0]. 29 April 2004

[15] Nashashibi, F., "RTm@ps: a framework for prototyping automotive multi-sensor applications", Proceedings of the IEEE Intelligent Vehicles Symposium, Dearborn, MI, USA, Oct 3-5, 2000.

[16] Chaaban, K., Crubillé, P., and Shawky, M. "Scoot-r: a framework for distributed real-time applications." In Proc. of the 7th int. conf. on princ. of dist. syst., La Martinique, France, 2003.

[17] Bezet, O. and Cherfaoui, V. "Timestamping uncertainties in distributed data acquisition systems." In Proceedings of the 22nd IEEE Instrumentation and Measurement Technology Conference (IMTC 2005), OTTAWA, ONTARIO, CANADA, May 17-19, 2005.

[18] Bonnifait, Ph., Crubille, P., Cherfaoui, V., Gning, El H., Shawky, M, Bezet, O., Brissot, G. "Method for the synchronization of data, such as distributed data, taking account of clock drifts and inaccuracies" Patent CNRS/UTC PCT WO 2005 096123 published: October 13th, 2005. INPI, 2005.

[19] Jaulin L., Kieffer M., Didrit O. and Walter É. "Applied Interval Analysis" Springer Verlag, London (2001).

[20] Bezet O., and Cherfaoui, V. "On-line timestamping synchronization in distributed sensor architectures." In Proceedings of the 11th IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS 2005), pages 396-404. IEEE Computer Society, March 7-10, 2005.
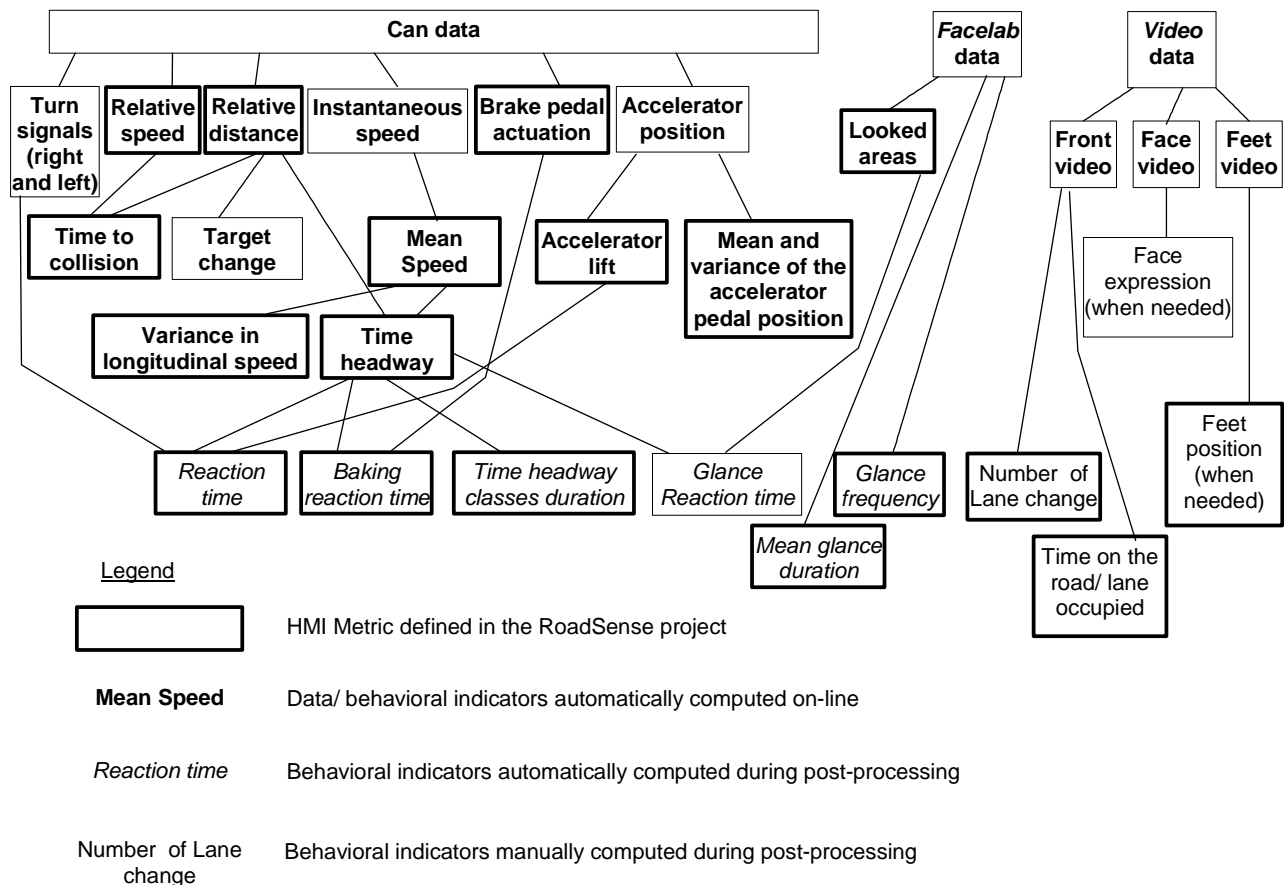
Fig. 6. Case study Metrics.