COMPARISON BETWEEN ADAPTIVE AND BASIC MODEL METRICS IN LANE CHANGE TEST TO ASSESS IN-VEHICLE SECONDARY TASK DEMAND

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Paper Number 09-0252

ABSTRACT

The evaluation of driver's distraction due to driving assistance use requires the development of methods, which allow measuring the driving performance degradation. This paper aims to describe and discuss the metrics utilized in the Lane Change Test, which is developed to become a standard within the ISO framework.

The LCT consists in driving on a three lane road and performing lane changes according to signs displayed on each side of the road. The main metrics are based on deviation measures between a reference trajectory and the current driver trajectory. Two types of reference trajectories can be calculated following an adaptive or a basic model. The adaptive model calculates a reference trajectory different for each participant, while the basic one utilizes an identical one for all participants.

The differences between the two measures have been investigated through an experiment carried out with thirty participants, performing LCT in single and dual task conditions (using auditory and visual manual tasks).

Qualitative analyses of trajectories show the advantage of the adaptive model which better fits to the diversity of real driver's behaviour. Data analyses also show divergent results according to the models, especially in terms of correctness of lane changes. A greater number of correct lane changes is obtained with the adaptive model than with the basic one. These differences are mainly induced by trajectories classified as loss of control errors using the basic model due to usual positions in the lanes of the driver (tendency to drive on the right or left part of the lanes), that are considered as correct ones using the adaptive model.

The adaptive model allows a better description of lane change errors due to secondary task demand. Such a method is now used by different laboratories involved in ISO group.

INTRODUCTION

As described by Mattes and Hallen (2008), the LCT allows evaluating driver's demand while performing a secondary task, such as operating an in-vehicle system. This method is currently being discussed in ISO working group TC22/SC13/WG8 as the basis of a standard to assess driver demand (ISO, 2008).

A simulated driving task is performed, which is based on lane change trials. The distractive impact of the secondary task on the driving is evaluated by analysing the lateral positioning on the simulated route with respect to a reference lateral position. Then, a mean deviation of the driver's trajectory is processed, and used to give the driving performance and the impact of the secondary task on it. The percent of correct Lane Changes is also of interest to better explain this performance.

Two types of reference trajectories can be calculated following an adaptive or a basic model. The adaptive model calculates a reference trajectory for each participant, while the basic one utilizes an identical one for all participants. This paper aims to describe and to compare the two measurement methods. Experimental results are then given both in terms of mean deviation and in terms of correctness of the lane changes according to the way they have been computed.

LANE CHANGE TEST

The primary task is a simulated driving task, which consists in driving along a straight 3 lane road at a system-limited speed of 60 km/h. Participants are asked to use a steering wheel to maintain the vehicle position in the centre of the indicated lane.

Lane change signs appear on both side of the simulated road to inform the driver which lane to drive. The signs are always visible but blank, until the lane change instruction is given at a distance of 40 meters before the sign position. For each task under investigation a driver has to perform a 3 000 meter run composed of 18 lane changes, each lane change sign being spaced approximately with 150 meters.

A lane change is characterized by the lateral displacement of the vehicle from one lane to another one (across one or two lanes). The impact of the secondary task on the driving is evaluated in terms of degradation of the lane change trajectory. For each run, a mean deviation is calculated between the trajectory of a participant (dotted line) and a reference model (solid line), which corresponds to the area between the two curves (Figure 1).

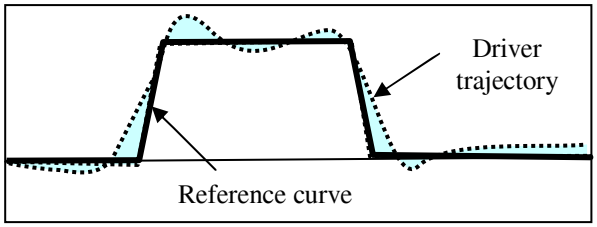

Figure 1. Mean deviation calculation.

Two methods are used to calculate the reference trajectory:

- a *Basic Method*
- an *Adaptive Method*

Basic method

Using a *basic measurement* (Figure 2), the current driver's trajectory is compared to a reference one, which is the same for each driver. Such a curve is defined according two variables:

- The *Start Lane Change distance,* which corresponds to the distance between the lane change sign and the beginning of the reference lane change.
- *The Lane Change Length* corresponds to the distance needed to perform the lane change.

Each basic reference lane change starts 30 meters before the lane change sign and lasts for 10 meters.

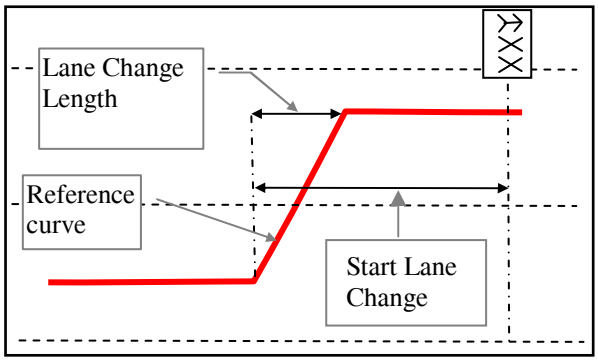

Figure 2. Variables used to calculate the basic reference curve

Adaptive method

Using the adaptive method, the same two variables are used as for the above basic model, namely the *Start Lane Change distance and the Lane Change Length*. However, new variables are now added: the *Average Distance* and the $AdaptedPosXlane_i$ (Figure 3).

- The *Average distance* corresponds to the distance between the lane change sign and the middle of the lane change.
- The $AdaptedPosXlane_1$ corresponds to the mean lateral position calculated for the first lane, the $AdaptedPosXlane_2$ for the second one and the $AdaptedPosXlane_3$ for the third one.

All these parameters are then adjusted to obtain a curve the closest as possible to the driver's trajectory.

Only baseline runs, which are performed without any added task, are used to calculate the adapted reference.

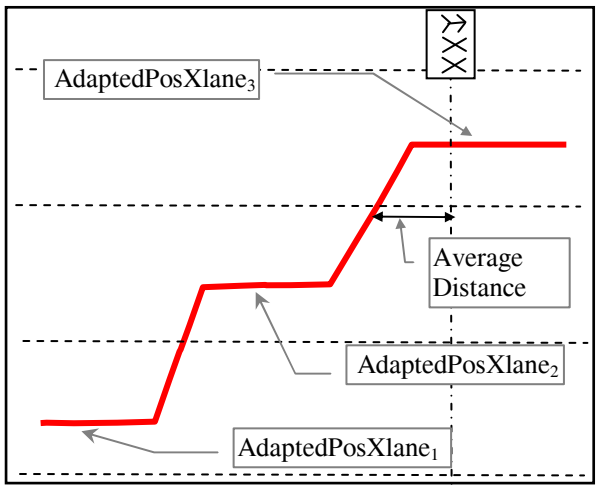

Figure 3. Variables used to calculate the adapted curve

ADAPTED METHOD DEVELOPMENT

The *Adapted reference curve* is obtained in two steps. First, the *Average Distance*, which is the distance from the lane change sign to the middle of the performed lane change, is calculated. This distance being calculated, the *Lane Change Length* and the $AdaptedPosX_i$ (mean position on each lane) can be computed.

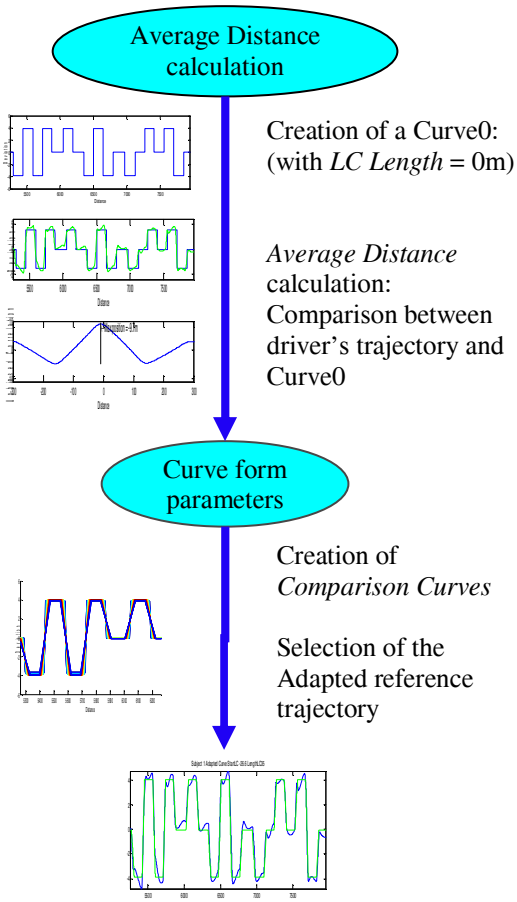

Figure 4. Method steps

Average distance calculation

A curve with a 0 meter *Lane Change Length* is calculated for each lane change sign. This curve, the *Curve0*, corresponds to the attended position on each lane (Figure 5).

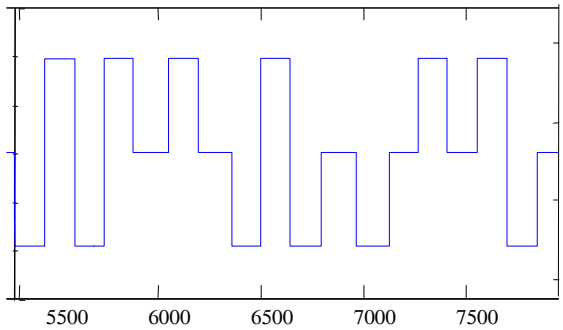

Figure 5. Curve with *Lane Change Lengths=0m*

Then, the participant's trajectory is compared with this curve using correlation metrics (Figures 6 & 7).

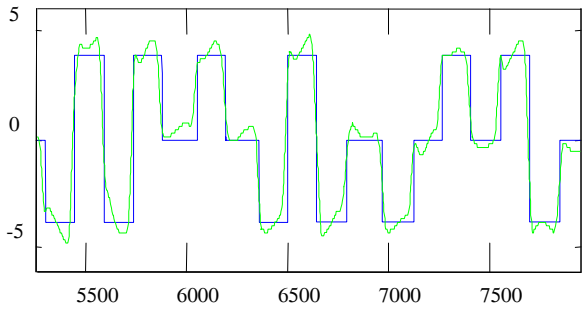

Figure 6. Comparison between driver's trajectory and *Curve0*

To precisely evaluate the *Average Distance*, a high precision of the peak position of the correlation is needed. This precision is obtained by unbiased correlation, which is calculated between the two curves using the formula:

$$\begin{aligned} &\forall m \in [0 : N-1] \\ &R(m) = \frac{1}{N-|m|} \sum_{n=0}^{N-m-1} baseline_{x,n+m} curve0_{x,n} \\ &\forall m \in [-N+1 : -1] \\ &R(m) = \frac{1}{N-|m|} \sum_{n=0}^{N-|m|-1} baseline_{x,n} curve0_{x,n-m} \end{aligned} \quad \textbf{(1)}$$

The correlation obtained by this method presents a peak around 0. The position of this peak gives the distance shift, which has to be applied to the *Curve0* to make it the closest to the driver's trajectory. This distance shift corresponds to the participant's *Average Distance*.

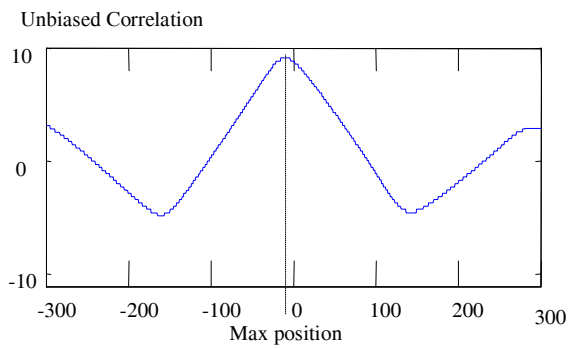

Figure 7: Correlation between driver's trajectory and *Curve0*

Shape variables of the adapted curve

Various curves, the *Comparison Curves*, are calculated using the *Average Distance* defined above and *Lane Change Lengths* (Figure 8). These *Lane Change Lengths* are comprised between 10 meters and 80 meters, and a different $LaneChangeLength_k$ is assigned to each curve. Then, for each of these *Comparison Curves*, three positions are calculated, which correspond to the lateral position of the driver on the three lane road: left, centre and right lanes.

Segments of the driver's trajectory obtained for each lane (lane changes being excluded of these segments) are added and averaged, for each *Comparison Curve*. This allows obtaining the $AdaptedPosXlane_i$.

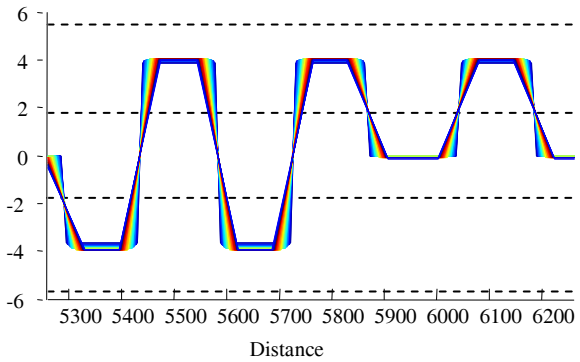

Figure 8. Set of comparison curves

Each of the *Comparison Curves* is then compared with the driver's trajectory. At this step, the peak value is more important than its position. Then, the correlations are normalized by the norms of the two curves using the following formulas:

$$\forall m \in [0 : N-1]$$
$$R_k(m) = \frac{1}{|curve_k|}\frac{1}{|baseline|}\sum_{n=0}^{N-m-1} baseline_{x,n+m}\, curve_{x,k,n}$$
$$\forall m \in [-N+1 : -1]$$
$$R_k(m) = \frac{1}{|curve_k|}\frac{1}{|baseline|}\sum_{n=0}^{N-|m|-1} baseline_{x,n}\, curve_{x,k,n-m}$$
$$|baseline| = \sqrt{\sum_{n=0}^{N-1} baseline_{x,n}^2}$$
$$|curve_k| = \sqrt{\sum_{n=0}^{N-1} curve_{x,k,n}^2}$$

(2)

The curve obtaining the maximum peak value is then selected to become the *Adapted Reference Trajectory* of the driver.

EXPERIMENT

An experiment was conducted with 16 drivers (8 males and 8 females) aged between 26 and 45 years (mean = 34; SD = 5.8). The experiment was run on the INRETS fixed-base simulator in Lyon, which has a front screen with a horizontal visual field of 50°. The car body is a Renault Espace with a manual gearbox and all the standard passenger compartment features, displays and controls. Software, conforming to the ISO draft standard, was developed by the INRETS-MSIS team.

Prior to the experiment itself, all participants performed a learning phase consisting of four runs without any added task to enable them to become familiar with the LCT. The experiment then always began and ended with a run without an added task. Such a run was also performed in the middle. These three runs provided the baseline data.
Four added tasks were performed in four different orders to limit potential task order effects. Each task was first executed without the LCT during about 90 seconds, to let participants get acquainted with it. They were then invited to perform the task with the LCT.

Secondary tasks

Two types of secondary tasks were performed: 2 auditory ones and 2 visual manual ones.

<u>Auditory tasks:</u>

- The first one (AT1) consisted of a series of statements pronounced by an experimenter. The participants had to listen to each statement, to repeat it, and to answer "Yes" if it was true, and "No" if it was false. Each assertion was randomly presented so that each driver had a single series.

- The second task (AT2) involved inventing sentences by creating a chain. To begin with, the participants were given a first sentence comparing animals. They then used the last word of the sentence to create the following one. For example: "A horse is taller than a rat", "a rat is smaller than an elephant"...

Visual manual tasks:
To perform the visual-manual tasks a screen was placed on the dashboard. Position and size recommended by the ISO draft standard were respected. A numeric keypad was laid out under the screen so that the driver could carry out the commands related to the two tasks.

- The first visual-manual task (VM1) was the Surrogate Reference Task (SuRT). The objective was to look at a screen and to locate a circle among distractors (smaller circles). To select the target, the participants moved a cursor to the relevant zone by using right and left arrows. Then a button allowed them to validate the choice and a new configuration was given by the system. Three levels of difficulty could be activated. All drivers performed the "Intermediate" level.
- The second task (VM2) was the Critical Tracking Test (CTT) designed by Dynamic Research. Participants were faced with a moving black line. To begin with, this line was displayed in the centre of the screen but then went up and down. The objective was to keep it as close as possible to the centre part of the screen, by using the up and down arrows of a keypad. Various difficulty levels could be activated. All drivers performed an easy level (lambda = 1, gain = 20).

Performances measures

Two measures of performance have been used:

- The Mean Deviations: as specified in the LCT ISO draft, the driving performance is mainly evaluated by the driver's mean deviation. Two mean deviations were obtained for each run as compared with the two reference trajectories (basic and adapted): the *Basic Mean Deviation* and the *Adapted Mean Deviation*.
- The *Percent of Correct Lane Changes (LC)* indicated the correctness of the responses to lane change signs. Between two lane change signs an observational zone was defined to determine the lane where the vehicle was most frequently positioned. If this lane corresponded to the sign indication, the LC was considered as correct (Engström and Markkula, 2007; ISO, 2008)

Most of the data that will be presented here consisted in data obtained during baseline conditions (without any added task). Results obtained for the different added tasks will be given mainly in terms of *Percent of Correct LC*.
First, qualitative observations of the driver trajectories will be presented to compare the two methods.

REFERENCE TRAJECTORIES FROM BASIC AND ADAPTED METHODS

Comparisons have been made between the current driver trajectory and the two reference trajectories obtained with the two measurement methods. All the following examples have been obtained in baseline conditions (without performing any dual task).

Figure 9 gives an example of trajectories obtained for a whole run. The *Basic reference trajectory,* which is the same for each driver, is represented with a red dotted line, the *Adapted reference trajectory*, which is calculated for each driver as explained above, is represented with a green dotted line, while the current participant's trajectory is represented with a blue solid curve.

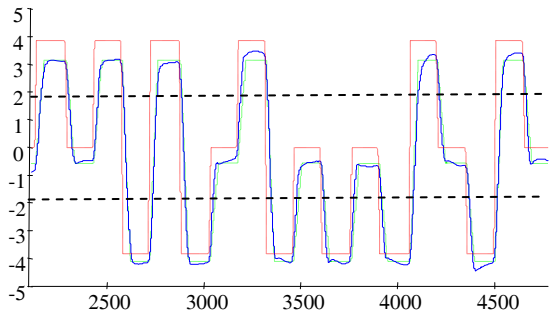

Figure 9: Comparison between Adapted curve and Basic curve

In this figure, the *Basic reference trajectory* seems to be very different from the realized trajectory, which appears to be closer to the *Adapted one*. The figures given below will give some reasons to explain such a result.

Detailed analyses have been made on different runs performed by the participants. Although the following examples are representative of whole runs, only short segments are given here, to better show the effect to be highlighted.

Tendency to drive on the right part of the lane

The driver whose part of a baseline is shown in Figure 10 adopted a tendency to drive on the right part of each lane of the baseline run. His/Her performance based on the *Basic Reference Trajectory* appeared to be poor. This participant obtained a *Basic Mean Deviation* of 1.32. Such a performance is higher than the level of 1.2 required retaining a participant in the ISO draft (ISO, 2008), meaning that this driver should be excluded from the participants.
The calculation of his/her performance based on the Adapted reference trajectory takes into account his/her tendency to drive on the right part of the lanes. In this case, he/she obtained an *Adapted Mean Deviation* of 0.28, which remained below the adaptive model acceptability criterion of less than 0.7 as it is mentioned in the ISO draft.

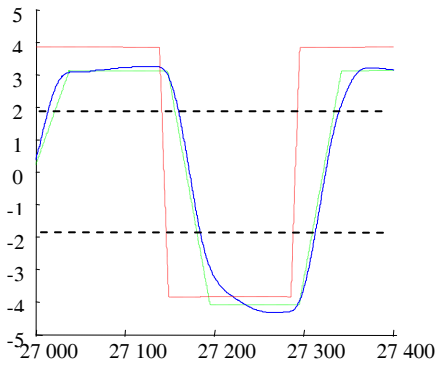

Figure 10: Tendency to drive on the right part of the lane

<u>Tendency to long lane changes</u>
The driver whose part of a baseline is shown in Figure 11 tended to make long lane changes. In this case, the *Lane Change Length* was higher than the one defined by the *Basic Reference Trajectory*. Such behaviour had an effect on the performance. As a consequence, his/her performance based on the *Basic Mean Deviation* was poor (*Basic Mean Deviation* of 1.49), and higher than the level of 1.2. However, the performance based on the *Adapted Reference Trajectory* appeared to be acceptable and below the acceptability criterion of 0.7 (*Adapted Mean Deviation* of 0.33).

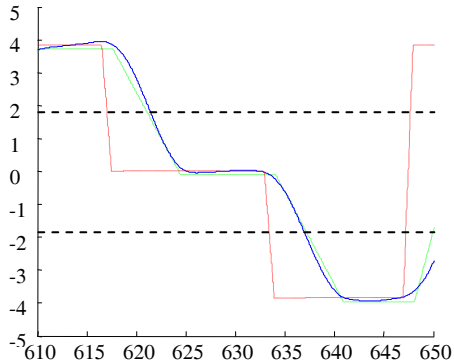

Figure 11: Tendency to long Lane Changes

The above results have been obtained for 2 of our 16 participants. But such behaviors have been observed for other drivers, even if it was not always in such an extreme way. The question which remains is that these drivers should have been excluded from the data in case of using the *Basic Model*. And so, even if they correctly changed lane each time during the baseline conditions. Comparatively, their performances were considered as being good enough with the adaptive model.

The comparison between the two methods shows that using the *Adaptive Model*, the realized trajectories are closer to the *Adapted reference trajectories* than using the *Basic one*. The performances are then better (with lower Mean deviation). The reason is that in the former case, the reference trajectory takes into account the participant's "driving style", for examples his/her tendency to drive on the right/left part of the lanes or to perform longer lane change than shown by the *Basic Model*.

PERCENT OF CORRECT LANE CHANGES

Measurement description

The correctness of a Lane Change is defined by the driver's position before and after its realization. To determine this position, the 3 lane-road has been divided into different zones, corresponding to parts of the lanes. The ISO draft (2008) recommends using segments of 40 to 140 meters after each lane change. The lane change signs being spaced approximately with 150 meters and the lane change instruction being displayed at a distance of 40 meters before the sign position, it was decided here to reduce these segments to 110 meters. By this way, we could avoid taking into account part of the trajectory corresponding to the next lane change in a given zone.

The zones L_1 to L_3 correspond to a correct position in $lane_1$ (left lane), $lane_2$ (centre lane) or $lane_3$ (right

lane), while the zones "O" correspond to *out of lane* positions (Figure 12).
The lateral position of the driver is defined by the zone which contains the longest part of his/her trajectory. However, when no zone contains at least half of the trajectory, then the position is considered as being *out of lane*.

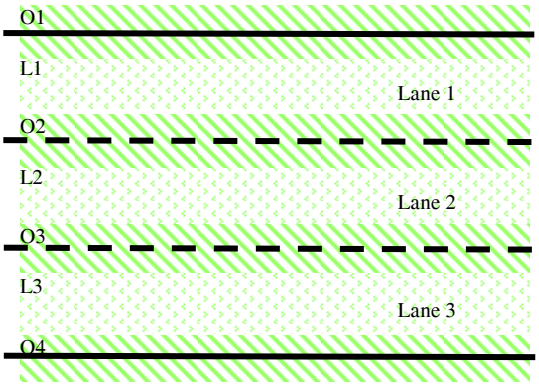

Figure 12. Lane change zones

The correctness of each lane change has been defined as follow:

- "Correct LC": the end position of the driver is in the attended lane,
- "No LC": the driver is in the same L_i zone at start and end positions,
- "Erroneous LC": the end position of the driver is in another lane than in the attended one.
- "Loss of Control LC": the end position of the driver is in one of the O_i zone,

At this step, differences between *Basic* and *Adapted methods* are registered, in terms of characterisation of the zones. Using the *Basic Method* the zones are centred on the middle of each lane, while using the *Adapted Method* they are centred on the $AdaptedPosXlane_i$. In both methods the zones consist in 2 meters wide and 70 meters length.

Comparison between the two methods

The lane changes performed by the participants have been categorised according to their correctness into "Correct LC", "No LC", "Erroneous LC" and "Loss of control". Global percents of lane changes taking into account all the performed lane changes have been first calculated according to the two methods. Then, such percents have been calculated for each condition under investigation: baseline condition, auditory tasks: AT1 and AT2 and Visual manual ones: VM1 and VM2 (Tables 1 and 2).

Table 1. Correctness of LC using *Basic Method*

Basic	Global	Baseline	AT1	AT2	VM1	VM2
Correct LC	92.7%	96.6%	96.5%	91.3%	90.6%	80.6%
No LC	0.1%			0.7%		0.3%
Erroneous LC	0.3%			1.4%	0.7%	0.3%
Loss of control	6.8%	3.4%	3.5%	6.6%	8.7%	18.8%

Table 2. Correctness of LC using *Adapted Method*

Adapted	Global	Baseline	AT1	AT2	VM1	VM2
Correct LC	97.8%	100.0%	99.7%	96.5%	96.5%	92.0%
No LC	0.2%			1.0%		0.3%
Erroneous LC	0.3%			1.4%	1.0%	
Loss of control	1.6%		0.3%	1.0%	2.4%	7.6%

First, comparison of the global results showed that the number of errors calculated using the *Basic Method* was much higher (5.1% more), than the one calculated with the *Adaptive Method*. Most of these errors were categorized as "Loss of control" errors.

Moreover, no error was registered in the baseline condition, using the *Adaptive Method*, while 3.4% (N=29) of the lane changes were considered as errors using the *Basic Method*. Only 6 of the 16 drivers were responsible for these errors obtained in Baseline condition and 22 of these 29 errors were due to only 3 drivers.

To illustrate what occurs in such situations, Figure 13 gives the trajectory of one of these drivers, in baseline condition. The blue solid line gives the driver's trajectory, while the dotted red and green ones give respectively the *Basic* and the *Adapted Reference Trajectories*. The 6 red circles indicate errors calculated with the *Basic Measurement*.
In this case, the participant tended to drive on the right part of the lanes. This tendency was taken into account by calculating his/her *Adapted Reference Trajectory*. In this case, his/her position after lane changing was compared with his/her $AdaptedPosXlane_i$ that was considered as being correct. Using the *Basic Model*, this position being too far from the reference trajectory was considered as being out of lane.

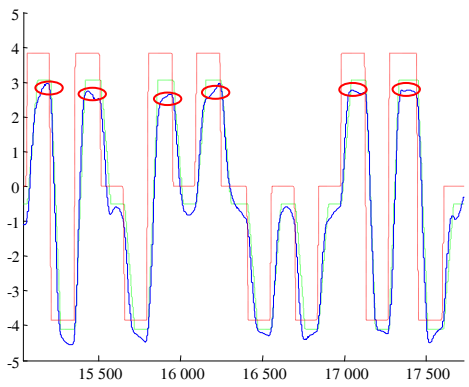

Figure 13. "Loss of control" errors in Baseline condition

Another example is given with Figure 14 in the Visual Manual task VM2 condition. Two "Loss of control" errors were registered (black circles) using both *Methods*. In these cases, the position of the driver appeared to be very far from the attended one, which explains the fact they were considered as out of the lane, whatever their calculation. However, 2 other "Loss of control" errors (red circles) were also registered using the *Basic Method*. In these later cases, the driver's position was closer to his/her *Adapted Reference Trajectory*, and considered as being correct using the *Adapted Method*.

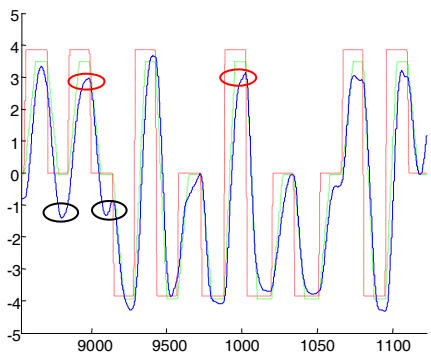

Figure 14. "Loss of control" errors in VM2 condition

More generally, the main differences obtained between both methods concerned the number of "Loss of control" errors, which seemed to increase with the task difficulty: from the easier auditory task to the harder one and from the easier visual manual task to the more difficult. However the number of these errors was higher using the *Basic Method* than the *Adaptive one*. Moreover, the difference between both measurements increased for the visual manual tasks. This could be explained due to the fact while performing the later tasks, the driver's trajectory was more impaired and then more difficult to interpret in terms of correct lane changes or 'Loss of control" errors.

CONCLUSIONS

From these analyses, it has been shown that using the *Adapted Method* allowed to obtain a *Reference Trajectory*, which was closer to the driver's one, than using the *Basic Method*. As a result, the mean deviation obtained in baseline condition was sometimes of a better quality. As a consequence, some drivers who would have been excluded using the *Basic Method* could pursue the experiment. Taking into account the correctness of the lane changes, differences between both methods were highlighted, especially in terms of "Loss of control" errors, whose number was higher with the *Basic Method*. It was shown that some of these errors could be attributed to driving specificities of the participants (tendency to drive on the right part of the lanes, to make long lane changes…) when was using the *Basic Model*. By taking into account the driving style of the participant, the *Adaptive Method* reduced the number of such errors. Moreover, it is believed that such a measurement would allow for a more naturalistic driving, as the driver could perform, for example, longer lane changes, without being stressed to terminate them before each sign position.

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