Impact of Intelligent Speed Adaptation systems on fuel consumption and driver behaviour

Guillaume Saint Pierre and Jacques Ehrlich

Abstract

In 1999, the French Ministry of Transport launched a significant program of experimentation and evaluation in order to assess the effects of different kinds of intelligent speed adaptation systems in terms of acceptance by the drivers and effectiveness of speed reduction in their daily trips. The LAVIA (Limiteur s'Adaptant à la VItesse Autorisée) has been tested, in the Yvelines (France) according to three variants : advisory, voluntary limited and mandatory limited. An experiment carried out over one year on a sample of hundred drivers using twenty equipped vehicles, allowed recording a huge amount of data in naturalistic driving conditions. Important results on safety were depicted in several papers. Besides the initial objectives of the projects which were restricted to acceptance and safety impact studies, it appears that a key aspect, in line with sustainable mobility stakes, concerns LAVIA impact on fuel consumption. In this paper, after a will brief recall of LAVIA objectives, technical aspects and results, we will present the results of a new statistical analysis study which focuses on the respective impact of the three variants of the system on fuel consumption.

I. INTRODUCTION

Speed management is a preoccupation for public authority as speed is considered as the main cause of traffic injury accidents. Traditional methods of limiting speed have only been moderately effective. Using the latest intelligent transportation technology, speed enforcement can be enhanced through vehicle speed management programs, often referred to as Intelligent Speed Adaptation (ISA). An ISA system monitors the location and speed of the vehicle, compares it to a defined set speed, and takes corrective action such as advising the driver and/or governing the top speed of the vehicle. ISA systems effects on speed reduction and safety improvement is now well known (see [3] [4] or [2]), and a brief recall of the LAVIA project results on this aspect is given in this paper. Moreover, speed is closely related to fuel consumption and CO2 emissions rates, and many previous research projects on the usage of ISA systems are predicting a significant fuel consumption reduction. As fuel consumption is hard to measure, previous studies make use of state-of-the-art transportation/emissions modeling tools. This paper address the problem by using an instantaneous fuel consumption estimation model based on precise engine knowledge made available by OEM manufacturers partners of the LAVIA project.

This work was supported by the French National Research Agency

G. Saint Pierre is with Vehicle-Infrastructure-Driver Interactions Research Unit, Joint unit INRETS-LCPC, Bat 824, 14 route de la minière, 78000 Versailles-Satory, France guillaume.saintpierre@lcpc.fr

J. Ehrlich is the head of the Vehicle-Infrastructure-Driver Interactions Research Unit, jacques.ehrlich@lcpc.fr

There are many forms of ISA, most of them relying on modern technology such as Global Position System (GPS) receivers, on-board roadway databases, and/or wireless communication. There are several ISA implementation methods, based on how the set speed is determined [2] :

1) **fixed :** in this case, the maximum permissible speed is set by the user and the on-board control system never exceeds that value ; for this, ISA can be implemented as an independent on-board control system.
2) **variable :** in this case, the set speed is determined by vehicle location, where different speed limits are set spatially. This is the most common implementation of ISA, where the maximum vehicle speed never exceeds the speed limit for a given area. This can be implemented based solely on position information or based on broadcasted values. LAVIA system is one of them.
3) **dynamic :** in this case, speed is determined by time and location. The temporal aspect can vary based on road network conditions or weather. This information can be provided from a transportation management center via vehicle-infrastructure communication.

Another dimension to ISA systems is how it intervenes with driver behavior. Categories include :

1) advisory, where limits are displayed on a messaging device and the driver changes vehicle speed accordingly ;
2) active support, where the control system can change vehicle speed but driver can override ; and
3) mandatory, where ISA controls maximum speed and driver cannot override.

Concerning the variable ISA implementation, the most frequently cited result about possible fuel consumption reduction using ISA systems is a conclusion of an ambitious research experimentation that took place in England and made by the University of Leeds ([2]). Using simulation methods and with the assumption of a full ISA penetration, [1] claim ISA leads to a reduction in fuel consumption of about 8% in urban areas, whereas only 2% reduction is expected on highways. Other studies like [4] using also simulation models estimate the fuel consumption reduction around 11%. Those results leads public authorities to expect wide benefits from ISA systems, but some recent studies tend to mitigate those hopes. For example, the ISA evaluation made recently by the Monash University (Australia, see [6]) do not highlight any fuel reduction due to usage of ISA, except for 80km/hr limites zones, and for the combination of ISA and following distance warning (FDW) systems only. Concerning dynamic ISA systems, [8] are more positive. Using both simulations and real-world experiments, mainly during high levels of congestion, they find a 13% percent fuel consumption reduction.

It is of great interest to investigate the reasons of such different impact on fuel consumption. This paper address this assumption by means of statistical analysis based on data recorded in naturalistic driving conditions during the LAVIA experimentation and fuel consumption experimental model from a French car manufacturer which was partner of the LAVIA project.

II. The LAVIA program and experimentation

The Directorate for traffic and road safety of the French Ministry of Transport commissioned the National Research Institute on Transportation and Safety plus others public partners to investigate and to assess the potential of the LAVIA for helping the drivers to respect the speed limits by means of an on-road experimentation. Three man-machine interaction modes of the LAVIA system have to be tested : an advisory mode and two active modes (voluntary and mandatory). The project was conducted in three phases. Phase 1 involved the development of functional specifications for the LAVIA system and the data recorder system. In phase 2, the pre-evaluation phase, two prototypes have been driven over a fixed route of 90 kilometres by a set of 20 voluntary drivers to test for acceptance and usage against the original specifications. Phase 3, the naturalisitic driving evaluation, was the experimental phase conducted on a sample of one hundred drivers during one year, on wide area with different kind of road networks : urban, rural and motorway. Each driver goes successively through four modes of the LAVIA system by periods of two weeks : neutral/ advisory/voluntary limited/mandatory limited. The different operating modes were tested sequentially after a neutral mode (neither advisory nor active) in order to acquire information about the normal driver's behaviour as a reference for further comparison. The experimental design is a within subject design, where the control condition is the neutral mode. Usually that kind of experimental design needs to be counterbalanced. This means that one half of the subjects should start with the control condition and then switch to the experimental condition (active mode), and half of the subjects should do vice versa. Due to practical reasons, this has not been the case in the LAVIA experiment and there is a risk of the presence of a learning effect. LAVIA vehicles were equipped with a data acquisition system which recorded every 500 ms numerous driving parameters such as position, actual speed, speed limit, driver's action on kick-down, gas pedal, brake, windshield wiper etc. Thus a huge amount of data has been made available for different kind of statistical analysis such as usage, utility, usability and safety impact.

III. Fuel consumption data collection

As the LAVIA project was not originally designed to include consumption data collection, a specific approach has been carried out after the overall experimentation using both part of the previous collected data and precise knowledge of the engine behaviour. Thanks to an experimental fuel consumption model, it became possible to relate numerically the pressure on the accelerator pedal and the engine rpm to the volume of fuel injected each 500ms interval. This was possible for half of the involved vehicle fleet, leading to a data set of 44 drivers observed during 8 weeks and using the four different modes of the LAVIA system. This experimental model makes useless the usage of classical models for the estimation of fuel consumption that had wide spread use by many researchers (like the Positive Kinetic Energy model).

IV. Earlier statistical conclusions

In the first phase of the statistical analysis process, attention was focused on speed reduction and acceptability of the system itself. Consideration has been given to the sample of trips (frequency, average length or duration, proportion by trip motivation) to ensure a valid comparability between modes. In [3], speed distributions have been estimated showing clearly behaviours changes especially in active mode. The results showed that compliance with the speed limits improved among test drivers, leading to a peak in speed distribution around the limitation. As a potential drawback of the system, drivers tend to adopt speeds very close to the limitation as the accelerator pedal is controlled by the system in the case of a speed violation. The conclusions show that all active modes had positive effects on safety, with the largest effect of the mandatory system. Besides the safety improvement, it is often claimed that ISA also leads to a reduction in fuel consumption. This work address this assumption by means of multivariate statistical analysis based on indicators computed from each trip data.

V. Methodology

First approach developed in this work is based on the observed trips. With regard to vehicle variables (speed, accelerations, engine rpm, pressure on the accelerator pedal etc.), a range of indicators exist that could potentially yield some quantification as to the level of unsteadiness present in the traffic stream. In the same way, various statistical indicators can be related to the traffic conditions (percentage of vehicle stationary time, infrastructure type etc.) and the driver behaviour (percentage of time above the speed limit, gearshift strategy, acceleration peaks, brakes usage etc.). Such indicators are aggregated across all the six thousand trips made by the 44 studied drivers, and analyzed using multivariate statistical methods. Very short trips are excluded and 200 seconds at the beginning and the end of the trip are censored. The relationship between qualitative variables such as the mode of the LAVIA (active or not) or the trip motivation and quantitative variables such as average fuel consumption are highlighted using multiway anova and correspondence analysis. Clustering methods associated with multivariate analysis methods (PCA) are also useful to obtain homogeneous groups of trips in term of traffic conditions.

VI. Data analysis

Field trials studies show positive effects on speed behaviour and expect significant effects on fuel consumption reduction. To our knowledge, this has just been addressed using microsimulation modeling and fuel reduction induced by the use of ISA systems is still to prove in a large field trial. We claim that the LAVIA system do not generally induce significant fuel savings. Three types of questions are currently under investigation :

– How drivers use the LAVIA system in its limited mode ?
– What is the impact on the driver behaviour concerning gear choice in relation with speed ?

	Neutral	Advisory	Voluntary limited	Mandatory limited	F	p-value
Average consumption	11.4	11.7	12.2	11.6	6.21	0.0003

TABLE I

ANALYSIS OF VARIANCE FOR THE AVERAGE FUEL CONSUMPTION UNDER THE FOUR VARIANTS OF THE LAVIA SYSTEM.

– What is the effect of three modes of LAVIA on fuel consumption ?

Answering those questions is not a simple task because of the complexity and the variability of the driving situations. As described earlier, we construct a data set where the trips are considered as the statistical individuals. Those trips can be stratified with respect to some carefully chosen variables, but the first approach we present take account of the entire journey. The statistical analysis methods required to explore such a data set belong to the data mining area. This analyse will be described in the first subsection, while stratified approaches are conducted in the following subsections.

A. *Exploration of the dataset*

As usual, data mining approaches need a multidimensional exploration of the data set. In order to simplify the data set, this first approach make use of quantitative variables transformed to qualitative ones. Some correspondence analysis have been done (not showed here) using those transformed variables, leading to the conclusion that the major part of the variability of the average fuel consumption is explained by classical factors. The great influence of the percentage of time with the vehicle stopped is clear. This indicator is related to the congestion, and it is clear for everybody that congestion induce higher fuel consumption. This indicator is also related to the infrastructure type : congestions are more likely to occur in urban areas. As congestions induce frequent gearshifts, we also observe that the more the driver shift the gears, with respect to the time, the more the average consumption is high. This is clear if we consider the fact that fuel consumption is not so high on highways. This is due to the constant speed at a low engine rpm and without gearshifts. Taking account of the entire data set without any precautions leads to possible biased analysis. It is difficult to extract the information related to the usage of the LAVIA system because of the great variability inducted by variables such the presence of congestions, infrastructure type or speed limit value. First analysis conducted is presented at table V. This analysis of variance (anova) show a strong difference between the average fuel consumption under the four tested conditions ($p\text{-value}<0.05$), with higher values for the voluntary limited variant. Looking more deeply at this surprising phenomenon with the help of a multiple comparison test show that the difference is due to the voluntary limited variant only. This mean that there is no significant difference between Neutral/Advisory/Mandatory limited modes. As already highlighted, the tested variant order in the experiment is the same for all subjects. Searching for the evidence of a learning effect, we plot boxplots of the trip's average fuel consumption related to the day. Recall that the neutral mode has been tested the first 14 days, the advisory mode the following 14 days, and the last 28 days are used to test first the voluntary limited mode, and after the mandatory limited mode. Looking at figure 1 we see that the average fuel consumption repartition follow a decreasing trend, particularly if we consider the 95th percentile and the number of outliers. Therefore, the significant difference between the 4 variants of the LAVIA seems to be related to the learning effect at the beginning of the experiment with the active system.

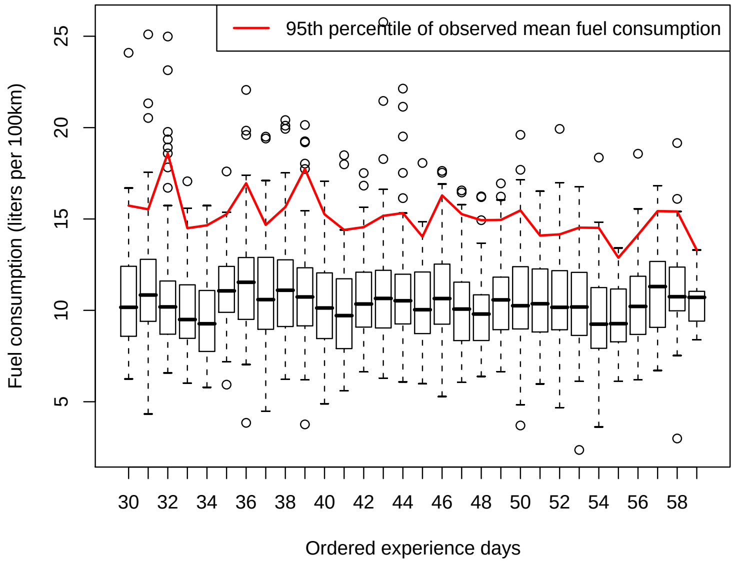


Fig. 1. Boxplots for the trip's mean consumption by the day of the experience. The line represent the 95th percentile.

B. *Stratified analysis*

Data collected during the LAVIA project can be assimilated to data collected in naturalistic driving conditions with many different observed driving conditions. The influence of the context (trip motivation, speed limit value, infrastructure characteristics, traffic condition etc.) has to be evaluated and controlled to validate the comparison of effects between modes. Fuel consumption is highly dependant on the traffic conditions, and higher values are therefore associated with trips under congested flow conditions characterized by small average speed, great percentage of vehicle stationary time and a high gear-shifting rate. We need to be very careful when controlling these traffic conditions to get proper and significant results. For that we need to stratify the sample according to some carefully chosen variables in order to deal with sections of comparable routes. The overarching principle of our approach is to be reduced to comparable situations, using the controllable factors at our disposal. Below are the various approaches proposed in this report.

1) classification algorithms : Study similar trips in terms of congestion, duration, average speed and so on.
2) Common sense : Use the variable "goal of the travel" and study trips from home to work.
3) Stratification according to the type of network.
4) Stratification according to the speed limits.

1) Driving conditions: The congestion phenomenon is crucial to deal with. Usually this is done by analyzing only observations where the time headway between the observed car and the vehicle ahead is greater than or equal to 3 seconds. This ensure that the observed speeds are not constrained by the vehicle ahead. Unfortunately, this variable was not collected during the LAVIA experiment. We use instead the trip's percentage of time with the vehicle stopped (speed=0), and we take account of the trips with less than 20% of the time with a null speed. Before trying some classification methods, we need to be careful in the variables choice. Classification trees are used to choose the significant variables, leading to a subset of variables with a great explanatory power. Variables used are the following : trip's % of time with speed equal to zero, % of time on urban areas, rural areas, and highways, average speed, duration, mean fuel consumption, number of gearshifts over duration, % of time above the speed limit, and the 95th percentile of the acceleration. Considering the necessity of dimensionality reduction, we apply first a Principal Component Analysis (PCA) before applying classification methods to the resulting subset. This approach leads to identify 4 homogeneous groups in term of traffic conditions, more tractable to highlight the LAVIA impact on fuel consumption.

The 4 groups found are : – Group 1 represents short-distance trips made in a urban area with high fuel consumption. – Group 2 is the one with the largest proportions of rural and highway infrastructure, with low fuel consumption and high average speed. – Group 3 is the largest one, associated with a classical behaviour, both in urban and rural areas. – Group 4 is the one with high average speeds, often beyond the speed limits and mainly in a rural environment.

The result of the anova is presented in table II. It puts forward a statistically significant influence of LAVIA system for groups 1, 2 and 3. The influence is very clear for groups 1 and 3, and a little less for Group 2. As has been previously discussed, there is a learning effect that leads to an increase in fuel consumption when using voluntary limited mode. This is reflected here since a multiple comparisons method only detect the influence of the voluntary limited mode. For the 4 groups found, there is no difference between Neutral/Advisory/Mandatory limited modes. There is actually a return to normal during the transition to the Mandatory limited mode. The only group for which the voluntary limited mode do not appear to increase consumption is group 4, where the average speed is very high and with great speed overruns. Note that the significance of the results is bigger (higher F statistics) for groups containing journeys made mainly in urban areas.

	Neutral	Advisory	Voluntary limited	Mandatory limited	F	p-value
Group 1	11.09	11.11	11.83	11.39	7.27	7.7e-5
Group 2	8.17	7.92	8.58	8.45	4.12	0.006533
Group 3	9.44	9.38	9.91	9.71	8.037	2.57e-05
Group 4	7.96	8.34	8.57	8.26	0.83	0.48

TABLE II

STRATIFICATION BY GROUPS OF SIMILAR DRIVING CONDITIONS. ANALYSIS OF VARIANCE FOR THE AVERAGE FUEL CONSUMPTION UNDER THE FOUR VARIANTS OF THE LAVIA SYSTEM.

2) Speed limits: Stratified the studied routes by the legal speed limit is another way to obtain homogeneous and comparable data. On each portion of the journey obtained after stratification is calculated the average consumption in liters/100km. The anova for each speed limit is shown at table III. It is striking to see how the impact of LAVIA system in active mode is dependent on the speed limit. Indeed, the p-values are very low for 30km/h areas, then higher as the evolution of legal speeds. It is very important to note again that only the voluntary limited mode causes increased fuel consumption (methods of multiple comparisons). The LAVIA system effect on fuel consumption therefore seems more important in areas where the legal speed is low. Note also that the variability in average consumptions is always lower when using LAVIA active modes (both voluntary or mandatory limited).

3) Infrastructure type: In order to stratify according to the infrastructure type, we proceed in the same way as for the legal speeds. From what we can read from table IV, only the urban network shows a significant difference in terms of consumption.

Zone	Trip number de trajets	Fuel consumption (litres/100km)	Neutral	Advisory	Voluntary limited	Mandatory limited	F	p-value
30km/h	1898	Mean Standard deviation	16.79 5.17	17.24 5.11	19.07 4.67	18.29 4.85	20.91	<.0001
50km/h	6830	Mean Standard deviation	13.59 3.72	13.62 3.97	14.13 3.99	13.61 3.4	7.92	<.0001
70km/h	2660	Mean Standard deviation	9.02 3.01	9.21 3.09	9.58 3.11	9.23 2.84	4.0	0.0075
90km/h	2680	Mean Standard deviation	8.57 3.23	8.75 3.44	9.06 3.48	8.83 3.15	2.48	0.0592
110km/h	1870	Mean Standard deviation	7.58 1.95	7.66 2.31	7.72 2.02	7.50 1.93	0.98	0.4013

TABLE III

STRATIFICATION BY THE LEGAL SPEED LIMIT. ANALYSIS OF VARIANCE FOR THE AVERAGE FUEL CONSUMPTION UNDER THE FOUR VARIANTS OF THE LAVIA SYSTEM.

Network	Fuel consumption (litres/100km)	Neutral	Advisory	Voluntary limited	Mandatory limited	F	p-value
Urban	Mean	13.25	13.39	13.93	13.34	6.7067	0.0001626
Rural	Mean	9.25	8.86	9.42	9.36	2.3677	0.06883
Highway	Mean	7.26	7.43	7.71	7.37	1.3926	0.243

TABLE IV

STRATIFICATION BY THE INFRASTRUCTURE TYPE. ANALYSIS OF VARIANCE FOR THE AVERAGE FUEL CONSUMPTION UNDER THE FOUR VARIANTS OF THE LAVIA SYSTEM.

	Neutral	Advisory	Voluntary limited	Mandatory limited	F	p-value
Inter-urbain	9.07	9.36	9.96	9.52	3.23	0.0217
Urbain	13.2	13.4	13.7	13.2	1.77	0.1505
Autoroute	7.5	7.8	7.9	7.4	0.56	0.6386

TABLE V

STRATIFICATION BY THE INFRASTRUCTURE TYPE, FOR THE TRIPS FROM HOUSE TO WORK ONLY (AND RESPECTIVELY, FROM WORK TO HOUSE). ANALYSIS OF VARIANCE FOR THE AVERAGE FUEL CONSUMPTION UNDER THE FOUR VARIANTS OF THE LAVIA SYSTEM.

But the difference comes again from the voluntary limited mode. This analysis is therefore perfectly compatible with the previous one.

4) Objective of the journey: The last stratification considered in this work relates to the trips between home and work. We know that they are the same for each driver, even if it is not always the case due to data collection errors. Applying an outliers detection method help to solve this problem. Indeed, the impact of a driving assistance system as LAVIA is likely to be better seen for identical routes between home and work (and respectively). Studying for each driver the change in fuel consumption for different LAVIA modes on the route between home and work is a way to bring an experimental type of framework allowing better controlling of the external factors not collected (weather, holidays, strikes and so on.). Results are displayed in table V. No significant difference in fuel consumption is observed in urban areas and on highways. A low significant difference (p-value slightly less than 0.05) is observed in rural areas, but a multiple comparison test only detects a difference between neutral and voluntary limited mode. This difference is therefore not very interesting and probably due to a bias related to the learning effect. Bias, which has been observed several times in previous analyses.

5) Preliminary conclusion: The stratified analyses presented in this chapter agree remarkably well on the following points. – Only the voluntary limited mode induces significant differences in fuel consumption for all analyses. This helps to confirm the existence of learning effect. – The existence of this learning effect implies that the LAVIA system may have a negative impact on fuel consumption when it is poorly controlled. – The impact of a bad usage of the LAVIA system is greater in urban areas, ie in areas limited to 30km/h or 50km/h. – The mandatory limited mode allows a return to a fuel consumption identical to the condition of control (Neutral mode).

The LAVIA system is a complex tool, which drivers have several days to tame. When it is misused, this system leads to increases in fuel consumption. The next section is devoted to some attempts to explain this phenomenon. Those LAVIA drawbacks must be understood in order to avoid them. When the system is used properly, after 2 weeks learning, there are no more increase in fuel consumption. But we do not observe the promised fuel consumption reduction. The LAVIA system therefore provides gains very clear in terms of security, but not in terms of fuel consumption.

VII. Impact of the LAVIA system on the driving behaviour

Subjects using LAVIA drives is a little slower, but it does not feel on fuel consumption. It appears that the driving activity is influenced by the LAVIA system, and that strategies used by drivers are different.

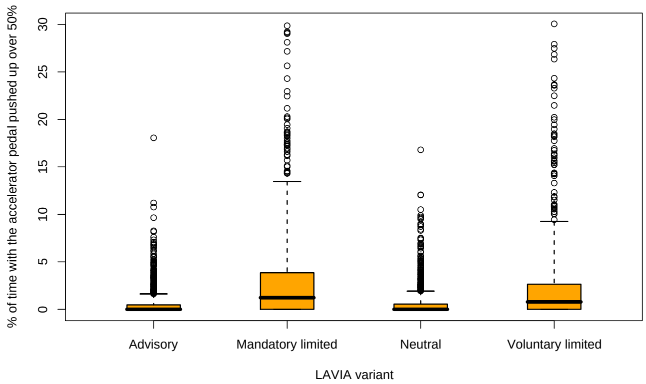
A. Acceleration

The first phenomenon concern the pression on the accelerator pedal. We calculated the variable giving the percentage of travel time for which the accelerator pedal is pressed for more than 50% and 75 %. The graphs 2 show the boxplots of these variables under the four LAVIA modes. Clearly, the LAVIA in its active modes induces a pressure on the pedal much harder than for Neutral and advisory modes. These overloads may be linked to kick-down, but given that this is a temporary action, it seems more appropriate to seek another cause for this phenomenon. The drivers knows that the injection is controlled by system, so they drive up to the limit, without taking into account the pressure on the accelerator pedal. The impact in terms of consumption is more debatable, but the cause could be the gear choice. Indeed, the injection of gasoline is limited when the limitation is active, but the gear is still defined by the user.

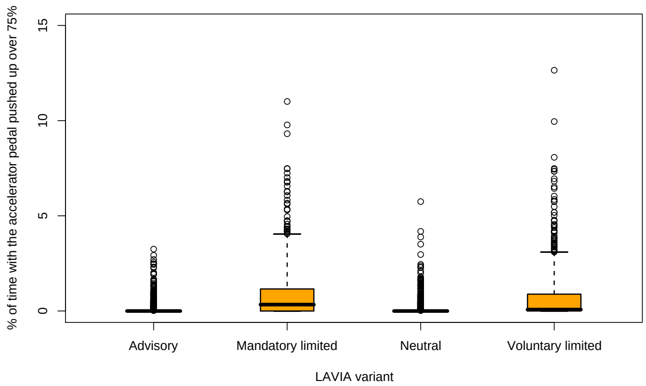
B. gearshift strategy

We are now entering a stratified analysis according to speed limits. It takes the form of three types of graphs. The first (3) gives the observed gear choices for the speed limit in question and for the 4 LAVIA variants. The second type of graph (4) shows the repartition of the couples (Instant Speed Œ Engine rpm) for neutral and mandatory limited modes. It was obtained using a Gaussian kernel density estimation (KDE) in order to highlight the accumulation points (associated with peaks) separated by lines levels.

In the case of the areas limited to 30km/h, Figure 3 shows that the gear distribution is different between modes : active modes of LAVIA induce lower gear choices. Looking at the graphs (4), we see that the space distribution of the couples (Speed Instant Œ Regime Engine) is also different. The mandatory limited mode implies



(a) Accelerator pedal pushed-in over 50%.



(b) Accelerator pedal pushed-in over 75%.

Fig. 2. Percentage of the trips with the accelerator pedal pushed-in over 50 and 75%.

that these couples do not go beyond 30km/h, but the choice of the second speed (2nd cloud from left) is by far the most represented. In contrast, when using the Neutral mode the gear choices are better distributed and the third speed is less adopted.

The problem is that the second speed is selected to drive at 30km/h with an engine rpm of 2000tr/min, which is greater than the engine rpm associated with the third gear. It is as if drivers using mandatory limited mode forgot how to switch to the third gear. The result is an higher fuel consumption when travelling in second gear at 30km/h (2000tr/min regime), that when we ride in the third 30km/h (regime 1500tr/min). This is confirmed by the fact that the probability of moving from the second speed in the third speed mode neutral east of 20.1 % and only 17.2 % in active mode.

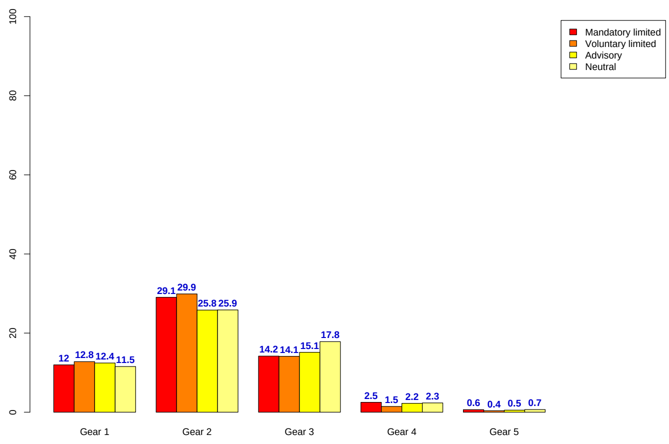


Fig. 3. Gear repartition for each variant of the LAVIA. Speed limit = 30km/h.

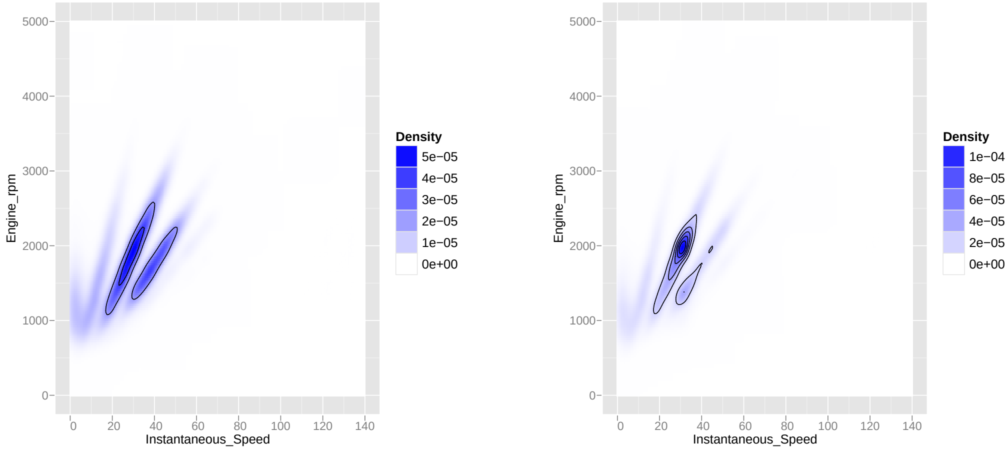
VIII. Conclusion

Speed management is a major aspect of road transport, and a 100% observance of the speed limits is often viewed as the perfect solution to a various set of problems (safety, congestions, greenhouse emissions etc.). As an example, the estimate of the Dutch Ministry of Transport of a 100% observance of the speed limits on road safety (see [4]) is that road fatalities will be reduced by 20% and hospitalised wounded by 15%. Fuel consumption and carbon dioxide emission will be reduced by 11% each. Such conclusions may be plausible considering the security aspects, but seems to be excessive if we consider the fuel consumption aspects. As a system that guarantee a strict observance of the speed limits, ISA system such the LAVIA should have highlight a fuel consumption reduction. Instead of a reduction,

First results show that voluntary limited mode of the ISA system leads to a significant increase in average fuel consumption, with less significance for the trips in inter-urban and motorway areas. Moreover, stratifying the trips by legal speed values show that only 30km/h zones (8% of the experimental zone) increase significantly the fuel consumption whereas no significant difference were found on the other zones. Investigations about possible explanations of this result lead to study precisely driver's behaviour and their gearshift strategies. Gear choices under active modes of the LAVIA system are slightly different from those corresponding to inactive modes respecting to the instant vehicle speed. It is therefore shown that active modes of the LAVIA system induce diminished attention, especially in the gear choice.

IX. Next steps

Other analysis methods will be carried out such as spatiotemporal analysis using GIS and digital maps with topology. More precise fuel consumption comparisons will



(a) Neutral mode, Speed limit = 30km/h

(b) Mandatory limited mode, Speed limit = 30km/h

Fig. 4. Non parametric kernel density estimation of the repartition of the couples (Instantaneous speed × Engine rpm).

be achieved by stratifying according to the routes instead the type of infrastructure. Specific attention will be paid to characterize the driving behaviour under active modes, and comparison with green-driving will be presented. Impact of the LAVIA on the driver behaviour in term of green-driving will be achieved.

REFERENCES

[1] O. Carsten, "Prosper results : Benefits and costs." Presentation at the PROSPER Seminar on 23 November 2005 in Brussels., Tech. Rep., 2005.

[2] O. Carsten and M. Fowkes, "External vehicle speed control," executive summary of project results. Institute for Transport Studies, University of Leeds, Tech. Rep., 2000.

[3] J. Ehrlich, F. Saad, S. Lassarre, and S. Romon, "Assessment of lavia systems : experimental design and first results on system use and speed behaviour," *Proceedings of the ITS World Congress*, 2006.

[4] Ministry of Transport, "Field experiment intelligent speed adaptation," ISA Tilburg. Final Report. Rotterdam, [In Dutch]., Tech. Rep., 2001.

[5] R Development Core Team, *R : A language and environment for statistical computing*, R Development Core Team, Vienna, Austria, 2005, ISBN 3-900051-07-0. [Online]. Available : http://www.R-project.org

[6] M. A. Regan, T. J. Triggs, K. L. Young, N. Tomasevic, E. Mitsopoulos, E. Stephan, and C. Tingvall, "On-road evaluation of intelligent speed adaptation, following distance warning and seatbelt reminder systems : Final results of the tac safecar project." Monash University, Tech. Rep., 2006.

[7] SAS Institute, *Base SAS 9.1 Procedures Guide*. SAS Publishing, 2004.

[8] O. Servin, K. Boriboonsomsin, and M. Barth, "An energy and emissions impact evaluation of intelligent speed adaptation." *In Proceedings of the IEEE ITSC 2006*, pp. 1257–1262, 2006.