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Gear Shifting Behavior Model for Ecodriving Simulations Based on Experimental Data

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Abstract

Ecodriving is known as a way to quickly and efficiently reduce fuel consumption for the concerned ecodriven vehicle. However, the impact of ecodriving on a whole road network at a large scale is unknown. In order to perform studies in a micro traffic simulation software, a fuel consumption model coupled to a gear behavior model are required.

This study presents a gear shifting behavior model able to represent as well the variability of drivers as the difference between ecodriving and normal driving. This work, based on the evaluation of the real driver behaviors during 42 trips, has been partially validated with a result of 60% of time spend in the correct gear.

Future works will be concentrated on a detailed validation of this model and on its implementation with a fuel consumption model.

1. Introduction

1.1. Context

Since a few years, ecodriving is more and more considered as a promising solution to palliate environmental issues (Beusen *et al.*, 2009; Barth and Boriboonsomsin, 2009). This ecological way of driving has two main advantages: it has been proven to be the fastest way to reduce fuel consumption and

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GES and pollutants emissions for a considered ICE vehicle and it is almost free to practice (Saboohi and Farzaneh, 2009; Wåhlberg, 2007; Zarkadoula *et al.*, 2007). Nevertheless, the real impact of ecodriving in the traffic system has rarely been studied globally. The problem consists in assessing the impact of ecodriving on fuel consumption and GES on a global scale according to the rate of ecodriver in the population.

Preliminary numerical studies (Qian and Chung, 2011; Orfila, 2011) have shown the possibility to model ecodriving in a traffic simulation tool in order to propose an answer to this question. However these simulations lack from the main parameters, especially in Europe, that are the engine speed and engaged gear ratio because of the complexity of the modeling.

1.2. Previous work

Within this subject, the different studies on gear shifting behavior studies can be classified in three categories:

- Studies on the driver behavior and his efforts applied on the gearbox. For instance, a study from Harley *et al.* reported driver's errors when manipulating the gear shift lever
- Studies on the optimization of gear shifting operations for automatic and robotic transmissions. An example can be found in (Haj-Fraj and Pfeiffer, 2001), where an optimal control of shifting operation is proposed.
- Studies on gear shift indicators that warn the driver to change the gear ratio at the optimal vehicle velocity in order to reduce fuel consumption. A report from AEA Energy and Environment analyzed the impact of this kind of system and concluded on the efficiency of gear shift indicators.
- Studies on gear shift modeling. For example, van Arem *et al.* proposed a simple model where upper and lower limits for engine speed trigger the gear shift action. However, the variability for a specific driver and between drivers has not been modeled.

1.3. Objectives

The aim of this study is to propose a gear behavioral model that can be used to better understand ecodriving. The used methodology relies on an experimental study, constituted by a group of 21 drivers travelling on a rural route. Each driver has done the trip twice: once in normal driving and once in ecodriving. The results permitted to understand the variability of driver behaviors, mainly on the amplitude of the engine speeds but they also permitted to find a global gear model. The main difficulty of this study was to build a model able to represent a wide range of drivers and a modification in the driver style, from normal to eco driving.

2. Methodology

In order to build a gear behavioral model that can be used to evaluate fuel consumption in a traffic simulation, several steps have been performed:

- Real gear ratio selection behaviors are estimated using experiments on an open road where the detailed geometry and properties (road curvature, cross slope, grade and friction) are known. All drivers travelled this route twice: Once in normal driving mode and once in ecodriving. In each try, the gear ratio has been reconstructed from the ratio "speed/engine speed" which has been acquired using a CAN bus connection.

- Based on these results, a gear behavioral model has been fitted and model parameters have been determined for normal driving and ecodriving conditions. Data used for fitting are the engine speed value and amplitude versus the selected gear because the engine speed is considered as the main factor impacting the gear change behavior.
- Then, this model has been partially tested and validated on a specific road where normal and ecodriven routes have been followed. The experimental and modeled selected gears have been compared.

3. Description of experiments

3.1. Experimental protocol

In these experiments, in order to evaluate the real gear shift behavior, 21 drivers travelled twice on a 14 km long route: once in a normal driving style and another in ecodriving. These tries represent nearly 600 km travelled. For the ecodriving trips, simple advice, based on the main rules of ecodriving, have been given to drivers. More details on this protocol can be found in (Saint Pierre and Andrieu, 2010).

3.2. Experimental vehicle

The experimental vehicle is a Renault Clio 3 estate with ICE (Internal Combustion Engine). The fuel is gasoline.

3.3. Data acquisition chain

The data acquisition chain is as discrete as possible not to bother the driver in his task. It is mainly constituted by a CAN bus connector and an acquisition card that reads all data transiting from several sensors on the vehicle. Signals used in this work are:
- Vehicle longitudinal speed: expressed in $m.s^{-1}$, it is delivered by the vehicle odometer.
- Engine speed: expressed in rotation per minute (rpm), it is read on the CAN bus.
- Experimental time: expressed in microsecond (μs), it is generated by an internal clock on the acquisition card.

Other signals have been measured in order to control the quality of the results, such as the vehicle acceleration, the gap with the preceding vehicle, the position of the throttle brake and clutch pedal. A small camera was also installed on the dashboard to sense the driver abnormal reactions.

3.4. Tested route

The tested route was a 14 km long road that has been chosen because it represents types of road from urban to interurban road sections. Highways have not been tested in this work as it is not considered to be very influent in ecodriving. The route is constituted of various road geometries in terms of road curvature, cross slope and grade.

3.5. Results

Different driver behaviors, in terms of engine speed, have been observed during the experiment. Figure 1 represents an example of results for a specific driver. The maximum engine speed reached before the drivers shifts up the gear in a normal driving way are represented by the black boxplot while the

ecodriving way is the blue boxplot. The red and the green boxplots respectively represents the minimum engine speed reached before the driver shifts down the gear in a normal driving way and in ecodriving.

It has been noticed that, for every driver, the upper limit of engine speed had always the same shape. This can be seen in figure 1, especially for the upper limit in normal driving conditions. In ecodriving, the shape is more flat. An explanation of this phenomenon could be that drivers reach high engine speed levels in normal driving to have a high acceleration level and in ecodriving, they try to reduce the engine speed.
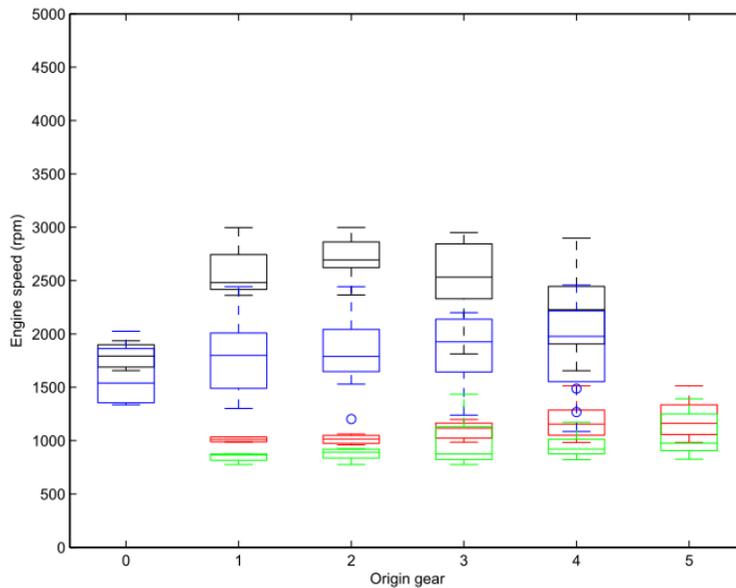

Fig. 1. Example of upper (black and blue) and lower limits (red and green) for a specific driver in normal driving (black and red) and in ecodriving (blue and green).

4. Gear shifting behavior model

4.1. Median engine speed model

The aim of the gear shifting behavior is to predict the gear ratio engaged by human drivers only by using the vehicle velocity as input in order to be applied to micro traffic simulation outputs. The median engine speed model is based on the assumption that the median engine speed can be used as a threshold that triggers the gear shift action. The first modeling realized in this study consisted in shifting gears at constants thresholds, in rotation per minute, depending on the gear engaged. This threshold has been determined as the median of all driven cycles. The main drawback of this modeling was that the level for precision of the prediction was really bad, i.e. only 20% of predictions were good. This effect is due to the impact of driving style. To improve the realistic aspects of the modeling, two parameters have been selected to represent the driving style:

- The engine rotation speed at which the driver shift from 2nd to 3rd gear, denoted ω_{max2}.

- The shape factor, δ, based on the maximum engine rotation speed between neutral and 1st gear, denoted ω_{max0}, and the maximum engine rotation speed between the 2nd and the 3rd gear, denoted ω_{max2}

$$\delta=(\omega_{max2}-\omega_{max0})/2 \qquad\qquad (1)$$

Using these parameters , the maximum engine speed triggering the shift up action can be estimated for each gear ratio:

- ω_{max2}, from the second to the third gear, is directly the parameter of the driver
- ω_{max3} from the third to the fourth gear, is considered as equal to the engine speed between the second and the third. This can be explained by the figure 2 representing the distribution of engine speeds. It can be seen that distributions for engine speed between second and third gears is close to the distribution of engine speed between the third and the fourth gears.
- for other gears, it is derived from the shape factor δ as explained in figure 3.

$$\omega_{max0=}\ \omega_{max2}-2\delta \qquad\qquad (2)$$
$$\omega_{max1=}\ \omega_{max2}-\delta \qquad\qquad (3)$$
$$\omega_{max4=}\ \omega_{max2}-\delta \qquad\qquad (4)$$

The shift down action is triggered at a driver's independent value of engine speed. Furthermore, these engine speed values, given in table 1, only depend on the selected gear ratio.

Table 1. Estimated minimum engine speed table

Destination gear	Engine speed (rpm)
4	1180
3	1130
2	1040
1	960
Neutral	940

The final model performs the following computation steps:

- Model's parameters initialization: The engine speed limits are computed according to driver's characteristics. Gear ratio is also initialized in concordance with the initial vehicle speed. Generally, if the initial vehicle speed is null, then the gear is in neutral position.
- Engine speed computation: Computes the engine speed from the gear ratio and the vehicle velocity.
- Gear recalculation: At each time step, the gear is recalculated using the maximum engine speed of each gear ratio from equations 2, 3 and 4, but also the minimum engine speed from table 1. The principle of this computation is the following:
  - At the initialization step, the gear is neutral. If the velocity reach a limit (1km/h), then the gear switch to the first position.
  - Then, for gears from 1 to 4, the gear shift up if the greater threshold is reached and shift

down if the lower threshold is reached.
○For the 5th, gear it can only be shifted down with the lower limit.
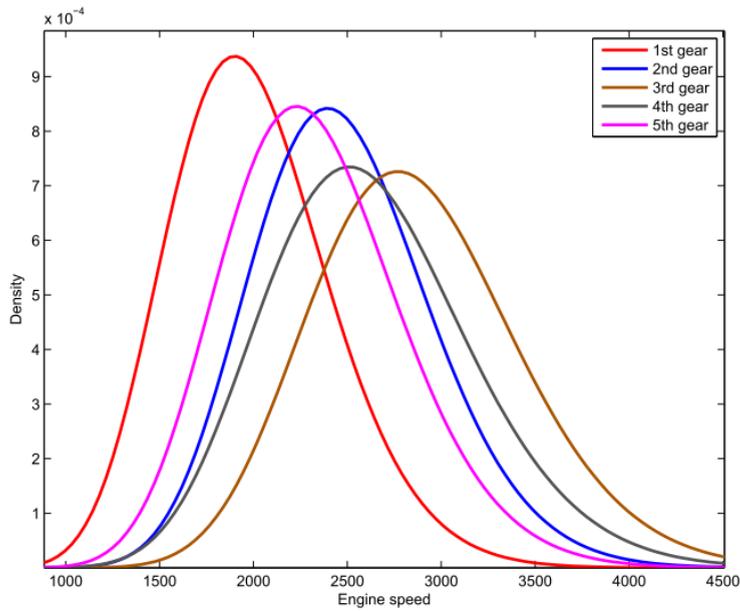

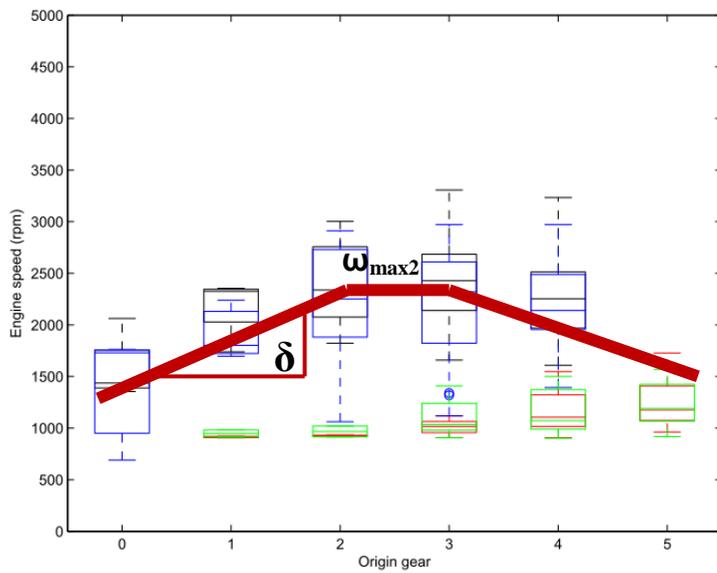Fig. 2. Maximum engine speed distribution for gear shifting.

Fig. 3. Graphical description of the gear shift model. Boxplots represent gear shifts for all 21 drivers.

5. Modeling validation

The gear shifting model has been tested on real case where the vehicle velocity, engine speed and gear ratio have been logged. Only from the velocity, a gear ratio have been estimated and then the engine speed has been computed for normal driving and ecodriving. Results on figure 4 shows that the predicted engine speed from the modeled gear ratio and the vehicle speed is well estimated most of the time (76% of good estimations). For all drivers in normal driving and in ecodriving (42 trips), the quality of estimation, *i.e.* the time spent in the correct predicted gear, varied from 40% to 76% and the mean is around 60%. The discrepancies come from a temporary abnormal driver behavior that the model cannot predict.
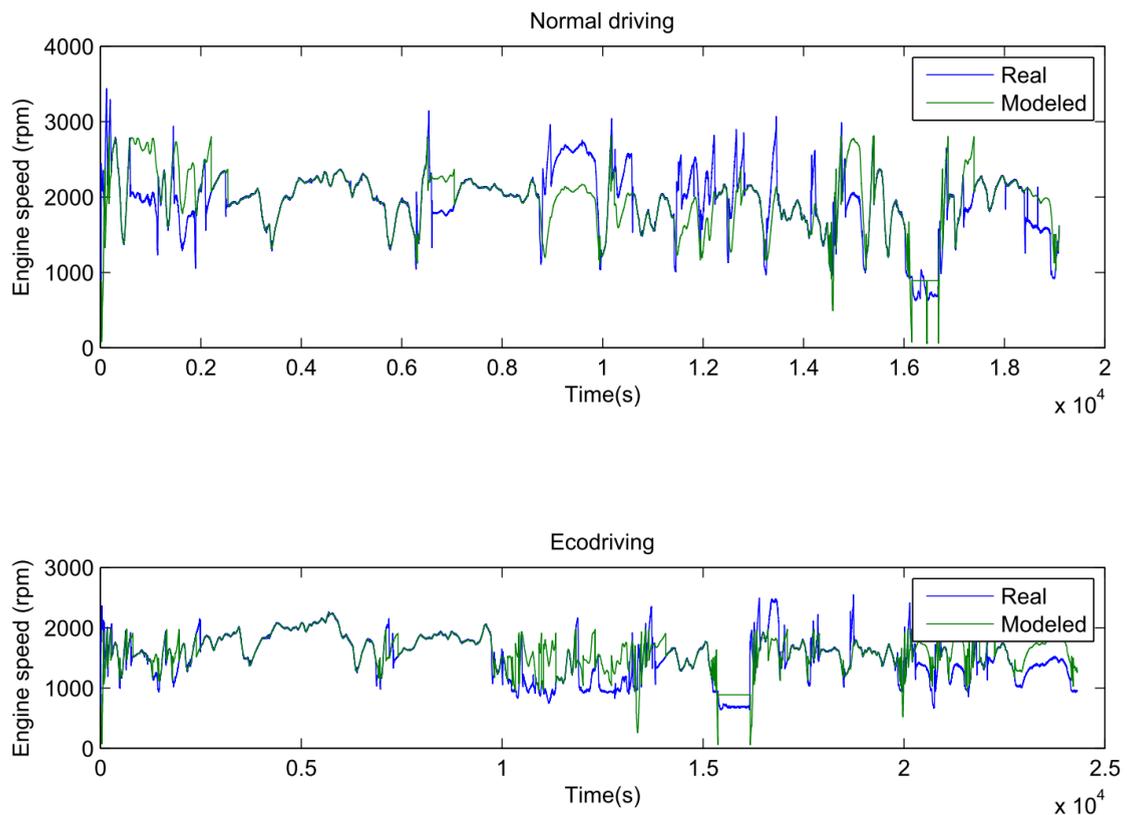

Fig. 4. Simulated engine speed compared to experimental engine speed in normal driving and ecodriving

6. Discussions

Within this study, several results have been achieved:
- The driver gear shift behavior has been studied with the engine speed for normal driving and ecodriving conditions. Results shows that the engine speed is not constant with the engaged

gear nor linear. The engine speed increases in the first gears until the third gear, then decreases for the last gears.
- On this analysis, a model with two parameters have been proposed to describe the gear shift behavior. The first parameter is the maximum engine speed between the second and third gear and the second parameter is the slope representing the variation of engine speed according to the engaged gear.
- A partial validation of this model has also been achieved by comparing the real engine speed to modeled one. Results show a mean correspondence of 60% in terms of selected gear.

However, several drawbacks in this study have to be highlighted:
- Extrapolation of the drivers behavior selected in this study to all drivers: this can be corrected by increasing the number of drivers in future experiments.
- Extrapolation of results to all road categories: this can be corrected by testing on dedicated road sections with a longer distance.
- The modeling is currently not able to model a driver that shifts several gears at the same time.
- The modeling does not take precise situations such as road grade or the presence of crossings to compute the maximum engine speed: taking into account these parameters should improve the modeling.

7. Conclusions

This study has presented a gear shifting behavior model able to represent as well the variability of drivers as the difference between ecodriving and normal driving. This work, based on the evaluation of the real driver behaviors during 42 trips, has been partially validated with a result of 60% of time spend in the good gear.

Future works will be concentrated on the validation of this modeling then on the improvements, especially to better take into account the road geometry and design. This model will also be included in a fuel consumption modeling to be applied on micro traffic simulation outputs.

Acknowledgements

References

Barth, M., K. Boriboonsomsin (2009). Energy impacts of a freeway-based dynamic eco-driving system. *Transp. Res. Part D*, **14**, 400-410.

Beusen, B., S. Broekx, T. Denys, C. Beckx, B. Degraeuwe, M. Gijsbers, K. Scheepers, L. Govaerts, R. Torfs and L. I. Panis (2009). Using on-board logging devices to study the longer-term impact of an eco-driving course. *Transp. Res. Part D*, **14**, 514-520.

Haj-Fraj, A. and Pfeiffer, F. (2001) Optimal control of gear shift operations in automatic transmissions. *Journal of Franklin Institute*, **338**, 371-390.

Harley, E. M., Trachtman, D., Heckman, G. M., and Young, D. E. (2008) Driver Gear-Shifting Behaviors and errors. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, **52**, 1898, DOI: 10.1177/154193120805202314

Norris, J., Walker, H., Stones, P., Davies, R. (2010) *Assessing the efficacy of gear shift indicators. Final report to the department of transport*, AEA, Millbrook

Orfila, O. (2011). Impact of the penetration rate of ecodriving on fuel consumption and traffic congestion. *Young Researcher*, Copenhaguen, Danemark.

Qian, G. and Chung, E. (2011). Evaluating effects of eco-driving at traffic intersections based on traffic micro-simulation. *Australian Transport Research Forum 2011 Proceedings*, Adelaide, Australia.

Saboohi, Y. and Farzaneh, H. (2009). Model for developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption. *Appl. Energy*, **86**, 1925-1932.

Saint Pierre, G. and Andrieu, C. (2010). Caractérisation de l'éco-conduite et construction d'un indicateur dynamique pour véhicules thermiques. *PRAC 2010*, Paris, France.

van Arem, B., de Vos, A. P. and Vanderschuren, M.J.W.A (1997). The microscopic traffic simulation model MIXIC 1.3, TNO report.

Wåhlberg, A. E. af (2007). Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behavior and technical feedback. *Int. J. Ind. Ergon.*, **37**, 333-343.

Zarkadoula, M., G. Zoidis and E. Tritopoulou (2007). Training bus drivers to promote smart driving: A note on a greek eco-driving pilot program. *Transp. Res. Part D*, **12**, 449-451.