SIMULATION OF ROAD SPEED-SECTIONING BY ASSESSING THE IMPACT OF TRAFFIC AND ROAD INFRASTRUCTURE

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Abstract

In a context of climate change, lowering road vehicles consumption is a key point to meet CO2 reduction requirements. In addition to car technological advances, eco-driving is part of the solution but the road infrastructure should ensure its development. In a previous study, a gain of 5% in the spent energy was estimated on specific route by slightly moving some speed signs, but under the assumptions that drivers practice eco-driving and the traffic is free-flow. This paper deepens and widens these first results. The base of this research is to provide a simulation model to study the impact of traffic and speed-sectioning on the environment. Inside this model, the impact of different approach speeds to a speed-sectioning is assessed. The simulation is conducted within the Trafficware Synchro environment where parameters according to road infrastructure, vehicle and driver are based on real traffic data. Moving a speed limitation sign can contribute to a reduction of fuel consumption up to 8% depending on driver structure. This new methodology improves the accuracy of our first results and detects adverse effects as the possible emergence of congestion due to the modification of speed sectioning. In perspective this methodology represents a significant argument in road managers strategy. In addition it also represents an orienting point to investigate different action scenarios and a first step to a global optimization policy in managing road infrastructure.

Keywords: road traffic, climate change, environment, eco-friendly road

1 Introduction

Road traffic is inducing the consumption of large amount of fossil fuels, both for goods transportation and traveling for work, leisure, necessity. It is therefore accompanied with an important production of particle pollution and greenhouse gases, responsible of heath and climate change issues. Transportation is responsible for 24 % of direct CO_2 emissions from fuel combustion [1]. Response required to keep warming below 1.5°C and enhance the capacity to adapt to climate risks would require large increases of investments in low-emission infrastructure (IPCC 2018 report [2]). For the purpose of resources preservations and climate change mitigation, a solution on rural roads could be to provide more eco-friendly road infrastructure to the drivers. Traffic phenomena are complex phenomena that have been studied for many years to maintain the transport performance at the level of the -ever growing- mobility demand, and to ensure a high road safety level. The traffic can be observed experimentally for an existing road, to verify the associated mobility and safety performances, but simulations are a tool to evaluated traffic of projected roads or projected exploitation or new equipments of roads. Simulations

can be either macroscopic or microscopic. Traffic simulations for road exploitation strategy or ecodriving-friendly road design are difficult because various types of human behaviour have to be taken into account in addition to varying environmental conditions of roads as lightning and weather.
The approach developed by the "Trafficware Synchro 9"[3] model consists in considering that the phenomena of traffic originates from the actions and interactions of the various participants in the "road system" (road designers, managers, users, etc.), each actor having his own knowledge, goals and strategies. The modelling of the behaviour of the drivers is an essential point to obtain in simulation individual and collective behaviours "realistic", in that sense certain experimentations are needed to apprehend the large variety of the psychological driving inputs and reactions, within a full traffic system.
Then, for our research of environmental evaluation of roads, we have chose this simulation model in order to take into account different type of drivers, like eco- drivers, conservative or aggressive drivers, types that will be detailed in the following.

2 Simulation

Traffic simulation models are designed to predict system performance based on representations of the temporal and/or spatial interactions between system components (normally vehicles, events, control devices), often characterizing the stochastic nature of traffic flow. The traffic can be studied according to an "integrated" approach in which the identification, modelling and simulation of the actual practices of the drivers are at the heart of the modelled traffic [4,5]. Traffic simulation models may be classified according to the level of detail with which they represent the transportation performance, as well as flow representation, namely:
- in microscopic models, traffic is represented discretely (single vehicles); individual trajectories can be explicitly traced. Disaggregate performanc e measures are calculated based on explicit modelling of driver behaviour,
- in mesoscopic models, traffic is represented discretely (vehicles or group of vehicles); individual trajectories can be explicitly traced as for microscopic models. However, aggregate performance measures are calculated as for macroscopic models,
- in macroscopic models, traffic is represented continuously following the fluid approximation.

2.1 Calibration of a simulation model

The aim of this work is to assess the eco-friendly level that can be associated to infrastructure management options (speed sign positions), while fully taking into account the driver behaviour variety. For that reason simulations with a microscopic traffic model have been worked out, since macroscopic models are not able to describe the driver scale. Trafficware Synchro model has been chosen for the methodology validation, because of its capacity to represent both infrastructure and driver/vehicle particularities. This model has been developed in the United States of America, and it has default features of those roads, so basic calibration was needed to adapt the simulation to European standards. For example, the width of the roads is not the same as in Europe. Another parameters to tune are the length of the vehicles, driver types etc. These calibration possibilities are presented on Table 1 and Table 2.
Vehicles are distinguished by size, acceleration profile, and even occupancy (not relevant here). Drivers have reaction times related to traffic lights (green and yellow reacts).
Yellow reaction times are used here for the reaction time facing a limit speed sign and yellow deceleration rate are used in the same purpose. The diversity in driver behaviour are based on a combination of "yellow decel", "courtesy decel", and speed factor, which is the adaptation factor of drivers to the enforcement speed limit (table 2).

Table 1 Configuration of vehicles types

Vehicles Types	1	2	3	4	5	6	7
Vehicle Name	Car1	Car2	Truck SU	SemiTrk1	SemiTrk2	Truck DB	Bus
Vehicle Occurence (%)	0.64	0.16	0.60	0.10	0.05	0.05	0.20
Acceleration	File	File	File	File	File	File	File
Vehicle Length (m)	4.88	4.26	10.67	16.16	16.16	19.50	12.20
Vehicle Width (m)	1.80	1.80	2.40	2.40	2.40	2.40	2.40
Vehicle Fleet	Car	Car	Trk	Trk	Trk	Trk	Bus
Occupancy (# people)	1.3	1.3	1.2	1.2	1.2	1.2	20.0
Graphics Shape	Car	Car	Truck	SemiTrk	SemiTrk	DBTruck	Bus
Table Index (1 to 7)	1	2	3	4	5	6	7

Table 2 Configuration of driver types

Driver Types	1	2	3	4	5	6	7
Yellow Decel (m/s^2)	3.60	3.60	3.60	3.60	3.60	3.30	3.00
Speed Factor (%)	0.85	0.88	0.92	0.95	0.98	1.02	1.05
Courtesy Decel (m/s^2)	3.00	2.70	2.40	2.10	1.80	1.50	1.20
Yellow React (s)	0.7	0.9	1.0	1.0	1.2	1.3	1.3
Green React (s)	0.8	0.7	0.6	0.6	0.5	0.5	0.5
Headway @ 0 km/h (s)	0.65	0.63	0.60	0.58	0.55	0.45	0.42
Headway @ 30 km/h (s)	1.80	1.70	1.60	1.50	1.40	1.20	1.10
Headway @ 80 km/h (s)	2.20	2.00	1.90	1.80	1.70	1.50	1.40
Headway @ 130 km/h (s)	2.20	2.00	1.90	1.80	1.70	1.50	1.40

As schematized on Fig. 1, the simulation worked out under Trafficware Synchro relies on the infrastructure decomposed on nodes, lanes, links between current/destination lanes, vehicles referenced by id numbers and vehicle types, drivers of different behaviors assigned to these vehicles.

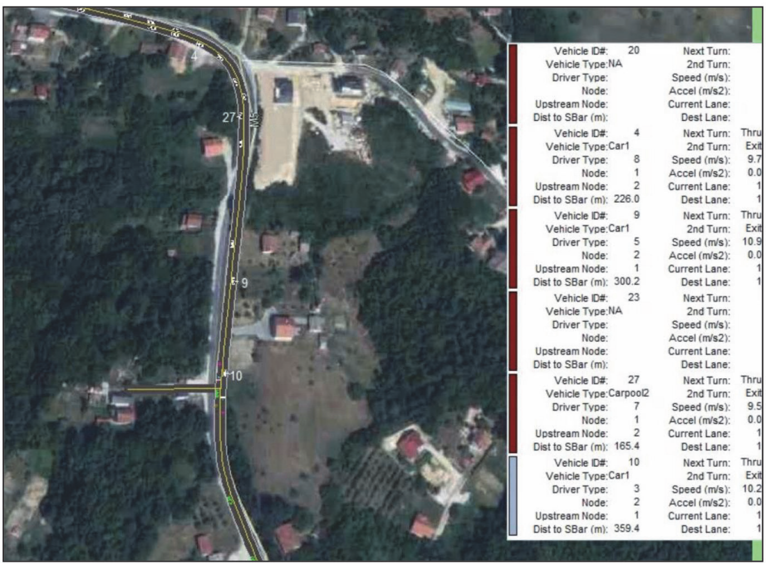

Figure 1 Simulation framework on Trafficware Synchro 9 by identifing each vehicle parameters

3D simulations have been worked out and executed in the Trafficware Synchro simulation framework, with various sets of vehicles/drivers/road management. The Fig. 2. gives an example of simulated traffic.

Figure 2 3D simulation in Trafficware Synchro 9

3 Results

Simulations that have been realized are targeting three baseline scenarios: Initial speed sectioning, Optimized speed sectioning and Pre-signalisation speed sectioning), for the evaluation of the road exploitation and its eco-friendly associated level. The better positioning of a speed sign could then be evaluated facing to an initial bad adequacy of the speed-sectioning to the longitudinal road profile. Pre-signalisation is another enhancement mean, although based on driver volunteer choice.
To emphasis the variety of driver behaviour, and the traffic speed spread around fixed limits, various approaching speed have been used for simulations, even at speeds higher than allowed speed.
All of the three scenarios and approach speed hypothesis gave us results and conclusions on how driver type can influence fuel consumption depending on driver's behaviour.
The length of the simulation area is of 1189 m. Traffic flows and composition are built upon road data recorded from JP Road of Federation of BiH.
Table 3. represents obtained data by the simulation software Trafficware Synchro 9 by defining fuel consumption and data on kpl (kilometers per 1 litre of fuel) in dependence on driver structure. Each column corresponds to one scenario. Each line corresponds to a combination of one type of driver and one approaching speed (70 km/h, 80 km/h, 90 km/h, 100 km/h).
We have classified the types of drivers into 4 types depending on their acceleration and deceleration: type 1 (aggressive, color red in the table 3) where the deceleration rate is 1.4-3 m/s^2, type 2 (defensive drivers, no color in thetable
3) where the deceleration rate is 0.7-1 m/s^2, type 3 (eco-drivers, color green) where the deceleration rate is 0.3-0.4 m/s^2, type 4 (combination of all types (40 % of aggressive, 30 % defensive, 30 % eco-drivers, color blue) in accordance to their visibility distance. In the simulation we have used the speed factor (SF in table 3) for each type of driver.
All realized simulations have "real time" durations of 15 minutes. Each simulation is repeated 10 times in order to extract simulation results with a satisfying repeatability.
Simulation results of fuel consumption are given in Fig.3, depending on driver behaviour and speed-sectioning hypothesis, varying with different approaching speeds and speed limitation sign placement.
Fig. 3a, 3b, 3c and 3d are respectively dedicated to the cases of aggressive driver, defensive driver, eco-driver, and a combination of previous drivers.

These results in Fig. 3 show the important impact of speed sign management on vehicle fuel consumption. As expected, the initial speed sectioning (purple bars) is leading to the higher fuel consumption, for any approaching speed or driver behaviour combination. The optimized speed-sectioning (green bars) leads always to better fuel economy than the intermediate solution of pre-signalisation speed sectioning (additional speed limitation sign of 60 km/h to amortize a speed variation), except for the very high approaching speed of 100 km/h and (a), (c), (d) drivers types. Indeed, in that specific case of very high speed, the pre- signalisation is encouraging drivers to decelerated very early, at the exception of the defensive driver which has the primary goal to maintain his speed, and don't benefit of pre-signalisation.
Eco-drivers are the driver category which takes the highest advantage in fuel economy of the optimized and pre-signalized scenarios. In the case of an approach speed of 90km/h, its initial fuel economy of 12 kpl (km/l) is raise for the both optimized and pre-signalized cases to 14 kpl (km/l). This is an improvement of 16,7 %. The methodology was targeting eco-drivers in order to offer them an infrastructure more eco-friendly, but results show that other types of drivers are benefiting of the speed management.

Table 3 Configuration of driver types and fuel consumption data

Speed/Type	Optimized (L)/(kpL)	Initial (L)/(kpL)	Presignalisation (L)/(kpL)
70-comb (SF-0.8,1,1.2)	22.5/13	23.4/12.5	22.5/13
80-comb	21.9/13.3	23.7/12.4	22/13.3
90-comb	21.7/13.5	24.4/12	21.9/13.4
100-comb	21.9/13.3	24.7/11.8	21.7/13.5
70-agg (SF-1.2)	21.7/13.5	24.7/11.9	21.7/13.5
80-agg	21.3/13.7	25.6/11.4	21.2/13.8
90-agg	21.3/13.7	25.8/11.3	21.5/13.6
100-agg	22.7/12.9	26.0/11.2	21.8/13.4
70-def (SF-0.8)	23/12.7	23.5/12.5	23/12.7
80-def	21.2/13.8	22.1/13.2	21.6/13.5
90-def	21.2/13.8	22.8/12.8	21.7/13.5
100-def	21.1/13.9	23.8/12.3	21.6/13.6
70-eco (SF-1)	20.5/14.3	21.5/13.6	20.6/14.2
80-eco	20.7/14.1	23.1/12.7	20.7/14.1
90-eco	20.4/14.3	24.3/12	20.6/14.3
100-eco	20.5/14.3	24.4/12.1	20.4/14.4

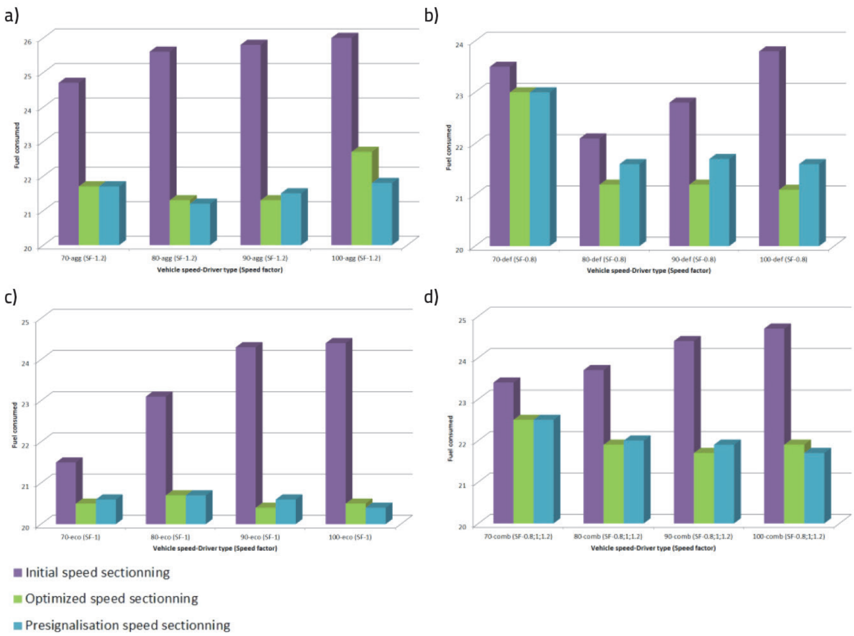

Figure 3 Simulation results of fuel consumption depending on driver behaviour, speed-sectioning with different approaching speeds: a) aggressive driver, b) defensive driver, c) eco-driver, d) combined (40 %agg, 30 %def, 30 %eco)

4 Limits and hypotheses

- The simulation model has potential to assess the traffic locally on a defined route, however it has also some disadvantages. Driving behaviour is modelled by continuous acceleration phases (speed adaptation factor), without the complexity of human driving sequences, often discontinuous and affected by factors as fatigue, stress, visibility altered by weather conditions.
- Nevertheless simulations show that fuel consumption gains are significant (11.5 %, from 23.1l to 20.7l) for eco-drivers while being inexpensive to implement for the infrastructure manager, because it is enough just to displace a speed limiting sign. A risk for the manager is that moving a speed sign may cause congestion. This can increase greenhouse gas emissions, which is contrary to initial methodology goal. Traffic simulations over full networks are then recommanded for assessing this risk in particular cases.
- Simulation results may underestimate actual fuel savings. Indeed simulation's route length can not be shorter than one kilometer in simulation framework of Trafficware Synchro as for physical restrictions, albeit in real world there can be two or three points of speed-sectioning to be optimized in such a one kilometer length. So, in dense areas, optimizing speed-sectioning could lead to somewhat twice the previously estimated fuel savings.
- Lastly, based on the research of Wilco [6] where a model of number of replications is explained and needed in a micro-traffic simulation to obtain reliable results, it is checked that the number of replications was sufficient: obtained results are very similar every time, conducted for each type of driver, because of the environment of Trafficware Synchro model already does certain number of MoE (measure of effectiveness) for each simulation as we calibrated, and validated the speed factor of each type of driver, the starting point of each vehicle and the measuring period.

5 Conclusion

Using this simulation model we have been able to see a eco-driving approach, and have realistic data. The simulated traffic conditions that are seen in the simulation model are similar as the one we have encountered during experimentation phases [7, 8]. The simulation was important to have a global view of eco-potentiality of the infrastructure in correlation to emission and energy parameters. Gathered data helped evaluate different situations in dependence to drivers structure.

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