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OPTIMIZATION OF ROAD SPEED-SECTIONING BY ASSESSING THE IMPACT OF A ROAD SPEED LIMITATION SIGN

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Abstract

Energy consumed by road vehicles has a high impact on climate changes; indeed this energy use accounts for 23 % of total energy-related Green House Gases (GHG) emissions of 2014 global GHG emissions. GHG emissions are growing constantly year after year, in spite of global objectives (COP) and researches on vehicle efficiency and modal shift. The contribution of the infrastructure to lower this energy is less studied, since it is often seen as immuable or too costly. This paper aims to demonstrate that simple and low-cost solutions exist for that purpose. Particularly a methodology has been developed, based on an optimization of the speed layout over an itinerary in order to improve the eco- driving potential of a given road infrastructure. The key point of this work is that inconsistency often exists between vehicle dynamics, road longitudinal profile and changes in regulation speeds. These changes in speed are defining the speed- sectioning of a route, and an optimization of this speed-sectioning can be easily carried out while displacing or modifying speed signs. The objective of this study is to build an optimized speed sectioning which minimizes the fuel consumption for realistic traffic and various driver behaviors, while maintaining the required safety levels. A progressive optimization loop has been worked out with a Python script including an embedded microscopic road traffic simulator. As a result, an optimized speed-sectioning is leading to a gain of 227 ml for 60 minutes of simulated flow of 100 veh/h/lane, for a modification of a single speed changing point. The overall benefits are reduced energy consumption, air pollution and noise which otherwise would have been produced by braking. This work brings an effective optimization tool for road managers and its practical application is passive and inexpensive. This methodology is suitable for rural and urbanized territories and easily adaptable to any type of traffic in various countries. In perspectives, the optimization process could be extended to a full road route and to a wide range of different speed-sectioning layouts.

Keywords: energy savings, road design, road exploitation, eco-driving, speed optimisation

1 Introduction

Road transportation has a large impact on greenhouse gas emissions (GHG) and climate change. Expert are considering that a roughly 15 % reduction in transport sector final energy use by 2050 compared to 2015 is needed to fulfill the "best" scenario of global warming below 1.5°C (IPCC 2018 report [1]). On the other hand, this IPCC report states that emissions from the transportation sector increased by 2.5 % annually between 2010 and 2015 and that transport accounted in 2014 for 28 % of global final energy demand and 23 % of global energy-related to CO_2 emissions.

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At this point, it can be concluded that our current transport system is not sustainable. The key point is road system since road vehicles account for nearly three-quarters of transport CO2 emissions (IEA, 2018, [2]). To comply with this environmental emergency, road vehicle emissions can be lowered by several means: limiting the car use, enhancing vehicle efficiency and developing the use of vehicles relying on non-fossil energies, reducing the infrastructure-linked energy demand.

This study contributes to this reduction of infrastructure-linked energy demand, by proposing a more convenient succession of speed limitations along a route, speed, which could increase eco-driving potential of the road. Indeed, this succession of speed limitations, called speed-sectioning could impede or favour driver ecodriving, depending on its adequacy between vehicle dynamics and longitudinal road profile.

The surrounding methodology of this study is detailed in [3], with experimental and simulations steps validated [4] before this present optimisation phase, but, out of other application example, a speed sign placed in a downgrade can impede ecodriving by forcing drivers to brake mechanically instead of to simply decelerated; a beforehand situation of the sign, in a uphill or plane section, could otherwise allow ecodriving.

Speed signs or other speed-sectioning points (roundabouts, pedestrian crossings, should then be considered both with consideration of vehicle dynamics and longitudinal road profile. Turns are another road parameter which can impede eco-driving with a non-optimal speed-sectioning, by limiting driver sight distance.

The objective of this research is to determine an optimization process of a route speed sectioning which minimizes the fuel consumption while meeting the safety constrains.

Another research field of lowering the infrastructure energy demand is to optimise the design of new roads, or to rebuild old roads, in the aim to lower the use phase energy demand (vehicles) without impacting too much its building and maintenance phases. This complementary research could lead to different longitudinal profiles or curves [5].

In the next section the methodology and its numerical implementation are described. A case study is used to support the proof of concept of the methodology. The last section concludes this paper.

2 Optimization methodology

2.1 Iterative road speed-sectioning optimization

Fig. 1 displays the proposed methodology. Starting from an initial speed sectioning, visibility distances of speed signs associated with this initial speed sectioning are determined (visibility distances can also be directly given by the user) and the associated maneuvers of vehicles allow to compute the fuel consumptions of vehicles by the mean of a traffic simulation for given vehicle data and driver behaviors. The output of this simulation is the sum of each vehicle fuel consumption. The algorithm optimizes iteratively the speed sectioning among of admissible speed sectioning according to road safety constraints and to road geometry. The optimization criterion is the minimization of the fuel consumption.

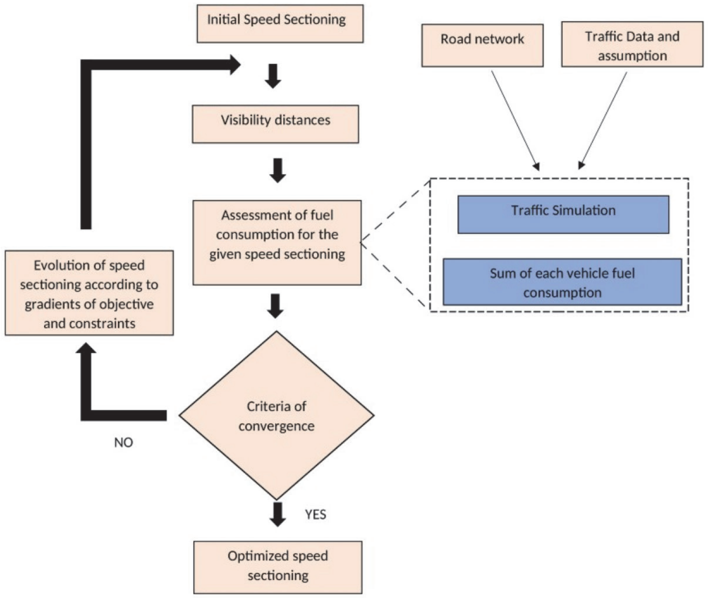

Figure 1 Optimization methodology

2.2 Optimization implementation with SUMO/Python

The previous methodology implies that the traffic simulation is carried out inside a loop. Opensource software Sumo was used on the ongoing research. Its crucial feature for this study is that Sumo can be launched and controlled from Python by using the Python library Traci. This feature is illustrated by fig. 2. this figure displays the implementation of the traffic simulation (blue blocks of fig. 1) by using the interaction between Python and Sumo. The blocks in green (resp. blue) are the blocks of instruction in Python(resp. Sumo). At first, the Traci library is loaded in the Python environment. Speed sectioning and visibility distance are given by the optimization algorithm. Then Sumo is launched. The first step in Sumo is to load xml files including information on road network and traffic data. Then Sumo enters in a loop. It computes one time step of the simulation. At each time step, Python's script changes the speed computed by Sumo of the vehicles which are inside the visibility distance of speed sectioning as well as those which are inside this section. The simulation is over when the number of iterations is reached which is equivalent to the simulation time when reached. If it is not the case, Sumo simulates traffic for a new time step. If it is the case, Sumo delivers an xml file including the fuel consumption of all vehicle. By processing this xml file, Python's script computes the fuel consumption associated with the given speed sectioning. By using this feature of the couple Python/Sumo to control directly the speed of each vehicle inside speed sectioning, it means that this speed sectioning can be modified from Python. This feature is the key of opening the door to the optimization algorithm. Moreover, by using this feature to control directly the speed of each vehicle approaching speed sectioning, drivers' modeling is accurate. With this interaction between Sumo and Python, the cast of each trajectory according to the type of driver can be done. In fact, the speed is proposed by the Python's script to Sumo which takes into account other factors: maximal deceleration of the vehicle and of the driver, tracking model between vehicles in order to compute the vehicles speed used in the simulation.

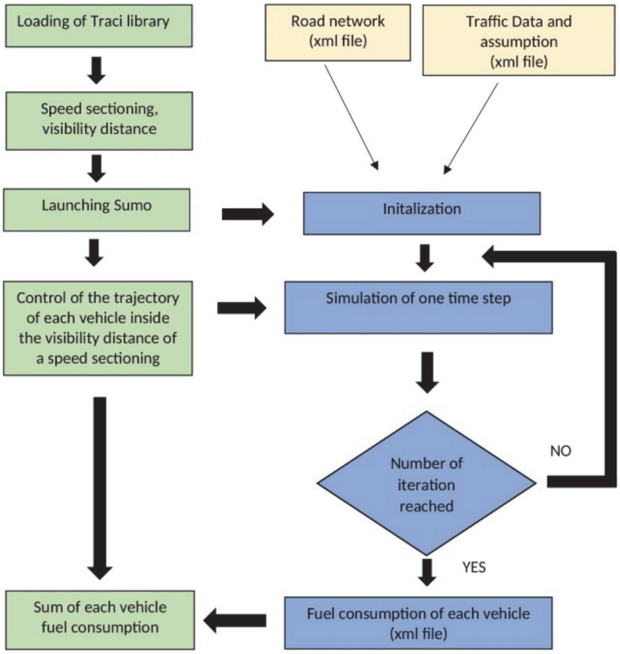

Figure 2 Interaction between Python (green color) and Sumo (blue color) to control trajectory of vehicle approaching speed sectioning

3 Case Study

3.1 Geographical and traffic data

Figure 3 Situation (google maps) and view of the considered speed sign

Fig. 3 represents the misplaced speed limitation sign in Bosnia-Herzegovina at its location. This ecologically black spot was documented in a previous study [5]. It consists in a speed section of 40 km/h on a road mainly limited to 80 km/h. This speed section of 40 km/h ensures safety conditions of nearby villages. The limiting speed sign of 40 km/h is located after a sharp turn. Thus, drivers are surprised, they have no other choice than to brake mechanically if they want to respect the speed limitation sign. The objective of the optimization algorithm is to find the best place to implement the speed limitation sign and by minimizing fuel consumption of the traffic while ensuring safety conditions to the nearby villages. The degree of freedom of the algorithm is the position of the speed limiting sign between the initial position and an maximum upstream position (300 m upstream).

The geographical position of the sign is located in mountainous rural area. It is on the path of two nearby villages. The length of the analyzed section is 7.6 km. Based on real traffic data the number of vehicle on this route is approximately 200-500 veh/h.The visibility distance for the actual panel is 50m. The next table presents for each position of a virtual panel located upstream of the current panel, the visibility distance. The time period of the simulation is 3600 sec. where 100 vehicles/lane are simulated.

Table 1 Visibility distance according to the position of the virtual panel

Pos (m)	0	20	30	50	60	80	100	130	150	260	300
Vis (m)	50	65	80	85	75	60	45	125	130	170	160

3.2 Sumo Setup

The model of environment is imported in Sumo by using open-street map.The simulation is conducted primarily on diesel vehicles with EURO 4 standards and HBEFA 3.2 protocols. Two types of vehicle are simulated: cars and trucks with three different types of drivers: aggressive, defensive, and eco-driver. It means that 6 (3x2) flows are simulated. The main characteristics are displayed as follows (C stands for Car, T for Truck)

Table 2 Drivers characteristics for the Sumo simulation

Type	**C-eco**	**C-agg**	**C-def**	**T-eco**	**T-agg**	**T-def**
Max dec. ($m.s^{-2}$)	0.40	1.00	1.00	0.3	0.9	0.9
Max acc ($m.s^{-2}$)	0.60	1.00	0.60	0.50	0.90	0.50
Speedfactor	1.03	1.10	0.90	1.03	1.10	0.90
Max Speed ($m.s^{-1}$)	30.0	38.0	30.0	22.2	27.0	22.2
Percentage	55	15	15	8	5	2

3.3 Drivers Modeling

- Drivers Model depends on the position of the vehicle:
- when a vehicle is approaching the village section or is in the village, the script Python proposes a speed computed according the type of drivers in order to cast the trajectory to a trajectory type. Sumo manages this speed by taking into account the maximum deceleration, speed factor and interaction between vehicles;
- outside this part of the road network, Sumo manages by itself vehicles speed.

Firstly, the interaction between Sumo and Python are presented, then the trajectory types omputed by our Python algorithm are described.

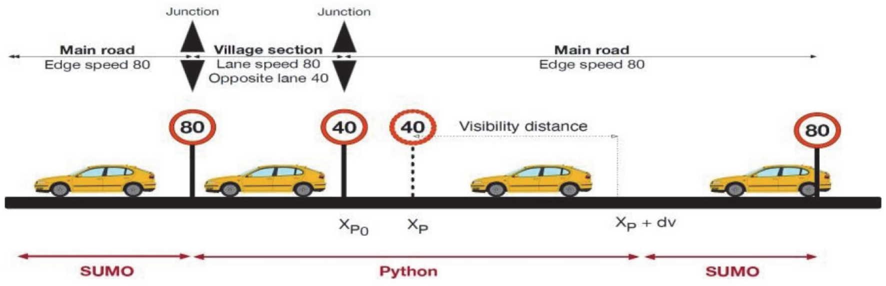

Figure 4 Simulation schema of a optimized speed-sectioning

Fig. 4 displays the interaction between Sumo and Python when a vehicle is approaching the village section. The model of the considered road network inside Sumo is a graph composed of edges and junctions. An edge includes two lanes. XP0 is the actual speed limiting sign position along the road. XP is the virtual position, dv is the visibility distance. Before entering in the distance of visibility of the virtual panel, the trajectory is controlled by Sumo. Afterward, Python's script proposes a speed to Sumo in order to control the trajectory until the end of the village section. For Sumo, there is no speed sectioning on this lane, the limiting speed is 80 km/h along all the lane. The speed sectioning is managed by the Python's script. This feature is critical to include the simulation in the optimization loop.

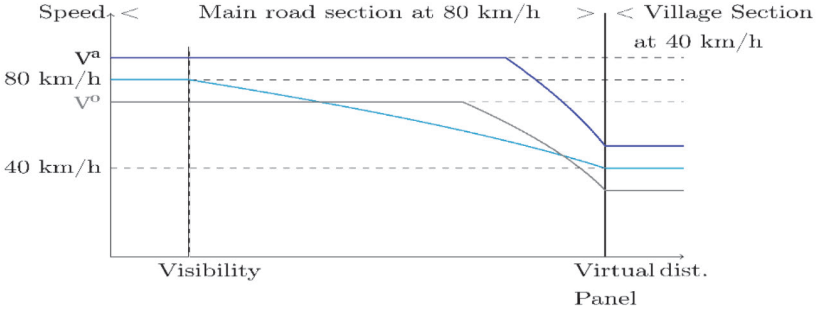

Figure 5 Three types of trajectory when approaching the virtual panel

The drivers trajectories approaching the virtual panel were cast according to the three types of drivers described above (aggressive, defensive and eco-driver).

Fig. 5 illustrates the behavior of two types of non eco-driver in comparison with the trajectory of an idealized eco-driver while approaching a speed sectioning. The blue curve is the trajectory of a vehicle driven by a aggressive driver. The driver speed, Va is slightly above the authorized speed 80 km/h. After seeing the speed limiting sign, the driver will brake mechanically with its deceleration of the driver type until reaching his new speed target. The grey curve represents the simplified trajectory of the defensive driver who will drive slower, at the speed Vo, than the regulatory speed and with a longer reaction delay. The deceleration is still important because she/he wants to comply with the speed limit although its longer reaction delay. The cyan curve represents the idealized eco-driver, who will release the gas pedal as soon as she/he sees the speed limiting sign. Its deceleration is the smallest of the driver types. The speed of the eco-driver is consistent with the regulatory speed.

Fig. 5 is an example of idealized trajectories when the visibility distance is long enough for each driver to brake according to its desired deceleration. If the visibility distance is too short, drivers have to decelerate more strongly to reach their desired speed after the virtual panel. Our Python algorithms adapts these idealized trajectories to the actual visibility distance.

4 Results

- The algorithm proposes to re-position the speed limitation sign 192 m upstream.
- The optimized fuel consumption is 72.3 l to compare with 72.5 l when the speed limitation sign is at its actual position.
- The gain is 227 ml for 60 minutes of simulated traffic flow of 100 veh/h/lane.

If these results are presented daily it would represent a gain of 5.5 l of fuel/day. On a yearly base a gain of 1988 l of fuel/year would not be spent in the atmosphere.
These results can be transferred in CO_2 emissions. Considering that the combustion of 1 liter of diesel ouputs 2.6 kg of CO_2.which is a simplified computation of emission factor given by [7]. One optimized single speed limitation sign could save up to 5250 kg of CO_2 not emitted in the atmosphere by year which is quite significant considering the low marginal cost to displace a speed sign.
The optimization is monocriteria on the fuel consumption. This can lead to unfeasible solution as to limit the speed along all the network to the minimum speed. The proposed methodology can avoid this drawback by monetizing the fuel and the driving time.

5 Conclusion

A new methodology to optimize speed sectioning has been presented. As a proof of concept, the optimization process was applied on a real single misplaced speed sign. Results are significant by saving 5t of CO_2.
The next step is to apply the optimization code on a larger road network. At short term, assessments of misplaced speed sectioning will be enriched by other criteria: air pollution and braking noise. At mid term, these academic results will be transferred to road managers by delivering them suitable tools to assess and to optimize speed sectioning of their network.

References

[1] De Coninck, H..: Strengthening and Implementing the Global Response, Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C, In Press, pp. 313–443, 2018.

[2] IEA (2019), Tracking Transport, IEA, Paris https://www.iea.org/reports/tracking- transport-2019

[3] Deljanin, E.: Eco-driving potentiality of road infrastructures according to the adequacy between infrastructure geometrical characteristics and vehicles speed, University of Nantes; University of Sarajevo, PhD Thesis, 2019.

[4] Coiret, A., Vandanjon, P.-O., Deljanin, E., Ortiz, M., Lortino, T.: Management of road speed sectioning to lower vehicle energy consumption, AIIT 2nd International Congress on Transp. Infrastructure Systems in a changing world, Rome, Italy, 23-25.9. 2019.

[5] Vandanjon, P.O., Vinot, E., Cerezo, V., Coiret, A., Dauvergne, M., Bouteldja, M.: Longitudinal profile optimization for roads within an eco-design framework, Transportation Research Part D, 67, pp. 642-658, 2019.

[6] Deljanin, E., Vandanjon, P.-O., Coiret, A., Causevic, S.: Ecodriving potential of roads according to their speed sectioning : Bosnia and France cases, 5th International Conference on Road and Rail Infrastructure, Zadar, Croatia, May 2018, pp. 987–992

[7] Emission factor database (EFDB) IPCC website, https://www.ipcc- nggip.iges.or.jp/EFDB/downloads.php