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« Eco-driving potentiality of road infrastructures according to the adequacy between infrastructure geometrical characteristics and vehicles speed »

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Introduction

Our transportation system is efficient, with a lot of alternatives constituted by road-, air-, water- and rail-based systems. However its building and usage are engendering environmental and economical issues. Particularly, the use phase of the road transportation system implies the consumption of considerable quantities of fossil energies. It is therefore not sustainable, since transportation has to adapt to an ecological, economical and energetic transition. Issues are of two main types: energy availability in a possible context of peak oil, and environment impacts in particular in the widely recognized context of global warming -or climate change- generated by humans.

According to the IPCC 2018 report [143], scenarios consistent with a global warming below 1.5℃, depend on a roughly 15 % reduction in transport sector final energy use by 2050 compared to 2015. On the other hand, the same 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.

Recent research of the International Panel on Climate (IPCC) has shown that the larger part of remaining CO_2 emissions come from direct fossil-fuel use in the transport and industry sectors, with 80 % of oil consumption used in road transport [43, 146].

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, by lowering its use phase energy without impacting too much its building and maintenance phases.

The first mean aims to reduce car use itself, it is realizable in dense, pedestrianized cities and medium-density transit corridors. On the contrary car dependency is high for low density cities and suburban areas [73]. Practically individual vehicle use can be partly replaced by public transport (electric tramway, trolleybuses or compensate by other transportation modes as bicycle and walk). Territory layout is a part of the solution, by minimizing distances between workplaces, homes and commercial places [165].

Apart this use limitation mean, the other means concern the three complementary parts of the Driver-Vehicle-Environment model (D-V-E).

Many researches have been done on how to optimize energy efficiency of vehicles and how to promote the benefits of eco-driving, but road infrastructures are less studied in this context since they are usually seen as unchangeable energetic constraint.

On the contrary, some researches show that infrastructure can have a significant role to play to reduce vehicle fuel consumption: at first, design of roads can be energy-efficient oriented [169], but road exploitation can be optimized too in order to save vehicles used energy.

This last aspect constitutes the core of this present research, which, from an energy point of view, proposes assessment and optimization of the adequacy between vehicle dynamics, longitudinal road profile and route speed sectioning, defined as the succession of speed limitations by road signs, roundabout and crossings, as well as road longitudinal profile and turns. Drivers should be fully taken into account in such approach, by considering their perceptions, actions and behaviors, facing to the road managers original or optimized choices. In detail, this thesis aims to ensure that infrastructure doesn't impede eco-driving in regards to vehicle dynamics, driver behaviors, road profiles and successive speed limitations on the followed route.

Considering these factors, it appears that road conditions and geometry are directly affecting eco-driving applicability [45]. For example, in a first work of Coiret, Vandanjon, and Cuervo–Tuero [40] the benefits of changing a road sign position have been demonstrated for enabling eco-driving in the adverse situation where vehicles have to decelerate on downhill situations.

The present thesis extends this preliminary work by proposing a criterion of eco-driving potentiality for such situations of variations in speed on a route and by establishing an energy evaluation of these situations, validated by experimental measurements. Lastly a flow simulation model has led to the determination of fuel consumption gains for vehicles flows travelling on variously optimized road speed variations, here called road speed sectioning.

The framework of this thesis is a collaboration between Ifsttar (The French Institute of Science and Technology for Transport, Development and Networks) and The University of Sarajevo. This work was supported by Campus-France.

The publications that are directly related to the thesis are:

- a publication in CETRA 2018: Eco-driving potential of roads according to their speed sectioning: Bosnia and France cases [51];

- a publication at the TIS 2019 congress (congress referenced in Scopus): Management of road speed sectioning to lower vehicle energy consumption;
- a publication currently being revised in the journal Transportation Research Part D: transport and environment (quartile Q1): Vehicle energy savings by optimizing road speed-sectioning.

The manuscript is divided in two parts. The first part is the bibliography which explores all the components of the Driver-Vehicle-Environment model from an energy point of view. The second part describes the steps to optimize speed-sectioning: simple criteria to assess Road Speed-sectioning, Experimental evaluation, Simulation and Optimization.

PART I

Bibliography

In this part, Infrastructure, Vehicle, Driver, Traffic, and their interactions will be explored in relation with the thesis subject. The last chapter is dedicated to eco-driving, eco-routing and eco-exploitation as these topics are directly linked to the thesis. Before analyzing the Driver-Vehicle-Environment model, the emergency environmental issue and the role of road classification/modes are recalled.

CHAPTER 1

TRANSPORT ISSUES: OIL AVAILABILITY AND ENVIRONMENT

1.1 Oil usage background

Road transportation is facing both environmental issue and energy availability linked to massive use of fossil energies. One indicator of these issues is the peak oil concept. Peak oil concept is in reference to Hubbert [94] where since all sources of oil derived from fossil sources are nonrenewable, oil production cannot be sustained indefinitely.

The concept of peak oil is referred as the hypothetical point in time when the global production of oil reaches its maximum rate, after which production will gradually decline.

Hubbert assumed that oil production would peak when half of the resource had been extracted, producing a bell curve (a symmetric logistic curve) now referred to as Hubbert's curve. This is in correlation to the work of Sek, Teo, and Wong [148] where it is demonstrated how producers inflated their estimated reserves to maintain their extraction quotas.

There are different organizations of interest in the domain of transportation energy. The International Energy Agency (IEA) has been founded in the framework of the Organization for Economic Co-operation and Development (OECD). European Environment Agency (EEA-EU) and California Environmental Protection Agency (CalEPA-USA) are oriented on the environment preservation.

Based on IEA statistics fig. 1 displays the world oil production which will shift from classical sources to nextgen oils. Indeed, production reduction of current fields will not be compensate by the fields in development. New fields have to be found to maintain the current oil production. In order to meet the demand requirements of non-conventional oil (e.g. bituminous sands), enhanced oil recovery products (EOR) and natural gas liquids will have to largely increase (Jiao et al. [100]).

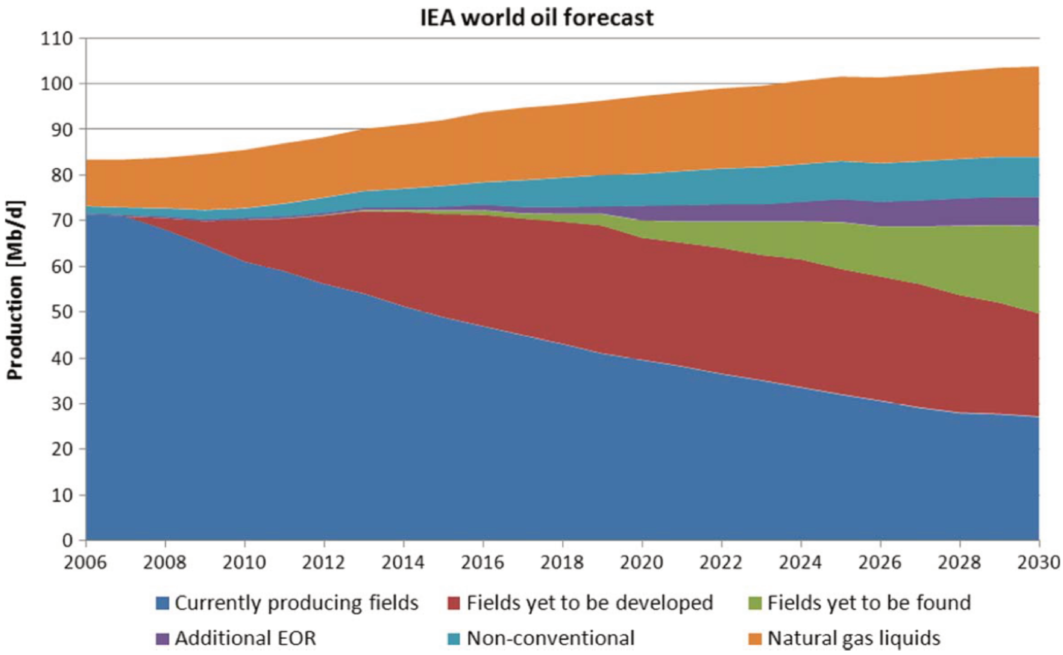


Figure 1: *World oil production [8]*

Vehicle emissions have impacts on health, for instance with estimated historical excess of NO_x emissions of 491.7 kilo-tonnes to 5000 early deaths (Chossière et al. [37]). Future estimated emissions in the absence of vehicle modifications will emit 802.2 kilo-tonnes to an additional 8200 early death. Moreover, according to Anenberg et al. [12], across 11 markets-regions representing approximately 80 % of global diesel vehicle sales, nearly one-third of on-road heavy-duty diesel vehicle emissions and over half of on-road light-duty diesel vehicle emissions are in excess of certification limits.

Perspectives are not reassuring: according to a 2013 OECD report, greenhouse gases (GHG) emissions from the transport sector will increase from 30% to 170% between 2010 and 2050 according to the different growth scenarios envisaged.

At the same time, in fig. 2 out of the synthesis of the Intergovernmental Panel on Climate Change, it can be seen that some GHG scenarios would have strong impacts on temperatures.

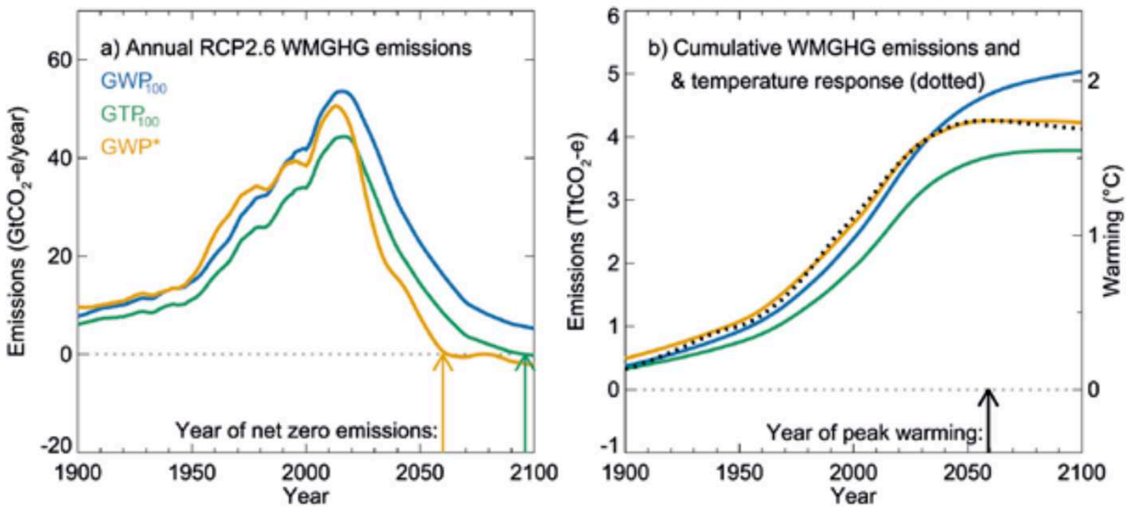


Figure 2: *GHG - Temperature scenarios [143]*

1.2 Context of roads energy demand

From the very beginning of moderns civilizations, roads ensure transportation of goods and people, while discerning long-distance transit roads, from medium-distance inter-urban, urban and access roads.

Industrial development has led to the creation of mass markets vehicles and with them the need for a rapid development of the network. For example, in France, according to the Ministry of Ecology, Sustainable Development and Energy (MEDDE), the National road network is constituted of 20,000 km of principal roads and highways, 378,000 km of departmental roads, 630,000 km of communal roads and 600,000 km of rural roads.

Beyond its economic function of people and goods transportation, road infrastructure is a land-use planning tool, while fixing distances between the zones of activity, shopping, leisure and residence.

Roads are useful, but they have to claim the less use of oil energy as possible. Investigation on construction or use phases, and for various parameters should be done, as for example for the impact of wind on vehicle energy consumptions Coiret et al. [41]. The impact of different infrastructure designs needs to be well understood and modeled to give road administrations a basis for management decisions (Abdallah, Belloumi, and Wolf [2]). Energetic construction cost has to be taken into account too, in a life cycle analysis (Jullien, Dauvergne, and Cerezo [103]).

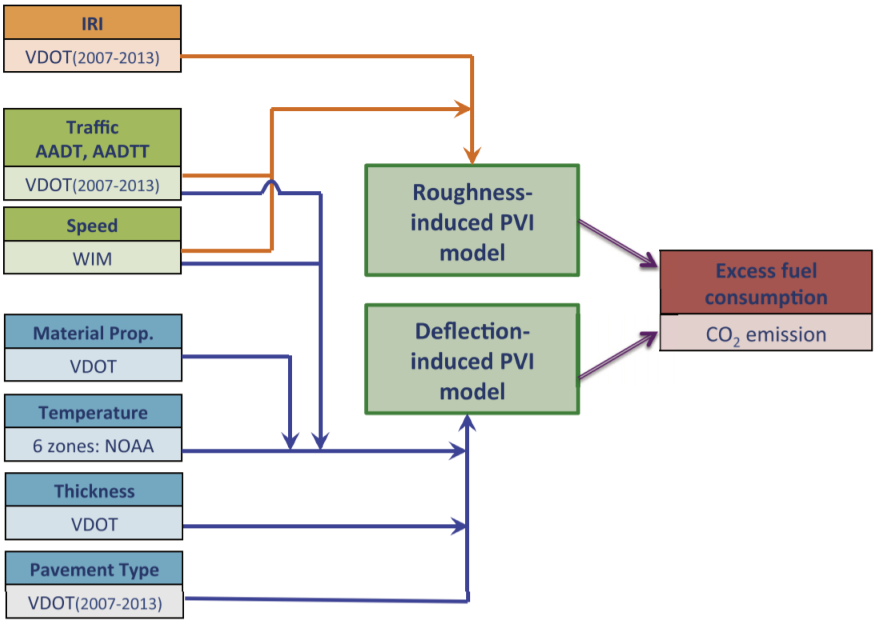


Figure 3: *Flow of network analysis; the inputs and the output of deflection- and roughness-induced PVI models [118]*

Rolling resistance and gradient are well known parameters of vehicle energy consumption, but effects of lane variables or different speed regimes are of importance too. One example is road unevenness, which does not only contribute to the rolling resistance of the tire but also generates energy losses in the suspension system. Fig. 3 is a good illustration of the excess fuel consumption evaluation from roughness (tyre-related) and deflection models (suspension-related), starting with structural properties (in blue), vehicle usage (in green) and standardized indicator of texture IRI.

Based on the IRI descriptive parameter (International Roughness Index) researched have conclude that a 10% reduction at car's rolling resistance can reduce fuel consumption up to 0.33% (Johannesson and Rychlik [101], Mehrsa [127]).

CHAPTER 2

INFRASTRUCTURE

Investments on road infrastructures have been always motivated by economic and social services as transportation of manufactured products, food and goods from distant regions, mobility for work or leisure, etc..

Many of the researches on infrastructure has either searched to understand incremental changes within these established infrastructures or explored how to optimize existing system structures (Loorbach, Frantzeskaki, and Thissen [117]): In his seminal work, the historian Thomas Hughes examined how modern infrastructures evolved and expanded into large socio-technical systems, through three sequential phases [140]. First, in the establishment phase, the high uncertainty of future demand is combined with a strong need for massive investment. Second, in the expansion phase, the system becomes established on an initial market and various economic forces, such as economies of scale, scope, and reach mentioned by Elburz, Nijkamp, and Pels [60], though also creating momentum. In this phase dominant designs emerge, and dominant technologies and practices become institutionalized. Third, with extensive investments made in infrastructure over a long period, large socio-technical systems tend to enter a stagnation phase characterized by lock-in to specific technological trajectories and to institutionalized standards and regulations. In this phase, the established infrastructure leaves little room for agency and innovation [140],[84]. Later studies of socio-technical transition have complemented this picture. For example, the multi-level perspective (MLP) framework, defined in the work of Geels [76], Rip and Kemp [141] suggests that socio-technical transitions are enabled through the interplay of multiple developments at three levels: socio-technical landscapes, socio-technical regimes, and technological niches. Changes at the landscape level, which could be slow (e.g. climate change), exert pressure on the regime to change. According to this line of thought, if the pressure is significant, the regime could become destabilized, creating an opportunity for alternative niche innovations to break through demonstrated by Geels and Schot [77]. Research on niche innovations has largely concerned how to

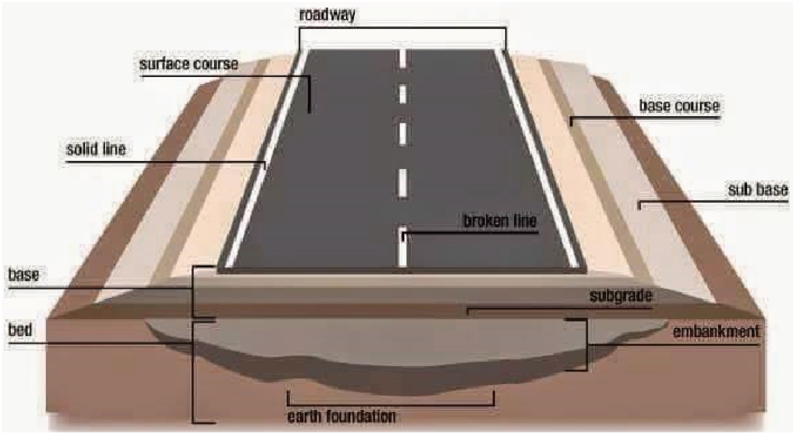


Figure 4: *Cross section of a road (Source Meriam-Webster/Road science)*

create momentum for promising technologies so they can be protected from existing regime lock-ins [168],[141]. The dominant idea has been to create niches, for example, protected spaces such as R&D (Research/Development) programs and demonstration projects, in which promising, radical technologies can develop and mature, buffered from the selection mechanisms of the commercial environment [154]. According to the literature, these niches should foster experimentation, permitting niche innovations to gain sufficient momentum that may trigger shifts in the social-technical regime (Skjøth et al. [154]). Based on the MLP framework, Bolton and Foxon [25] identified an additional fourth phase in the life cycle of infrastructures, with elements identified according to their function in the fig. 4: function of support, bearing, visibility, etc.

Life cycle model of infrastructure, such as in fig. 5, is justified as existing assets age and institutionalized technologies become outdated. Within this Life Cycle model, road infrastructure planning is undergoing major changes (Busscher, Tillema, and Arts [33]): infrastructure development is increasingly considered in relation to environmental degradation, climatic impacts and societal trends. Then, in planning practice, transport infrastructure policy accommodate a sectoral (for only a given sector) or a circumferential approach, with efforts that can have different targets (Freitas-Salgueiredo et al. [70]).

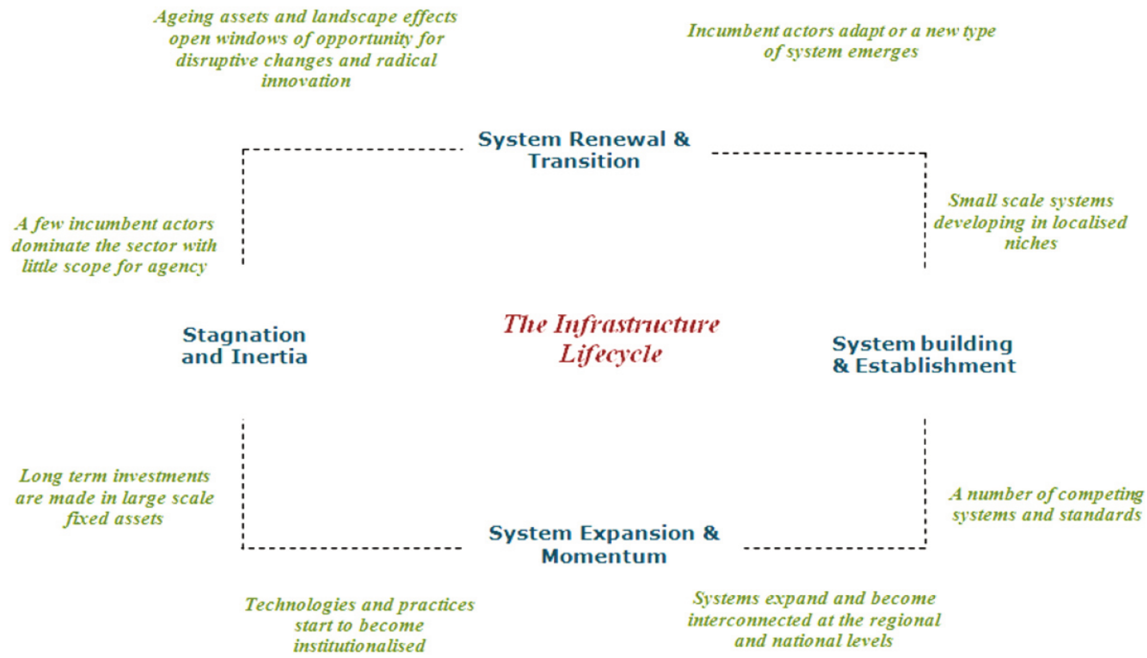


Figure 5: *The infrastructure life-cycle model [25]*

2.1 Categorization of roads

Due to the increase in the number of vehicles and their usage, roads become more congested. In order to ensure the rational and safe movement of vehicles and other traffic participants, the development of the road network should be balanced with the increasing trend of traffic.

This development is linked to the categorization of the roads, their rank, their equipment. Road categories are differentiated by vertical traffic signs, roadway design, equipments, and intersections. Some differences belong to the construction, reconstruction rehabilitation or usage phases.

2.1.1 The importance of roads in a road network context

The emergence of a human settlement in a given area depends on the local economic conditions and on its connections with neighboring in either way (road,rails, etc) [124]. Some roads are parallel with the main directions of a country and are referred to as longitudinal, while those that connect land in width are called transverse roads. Roads

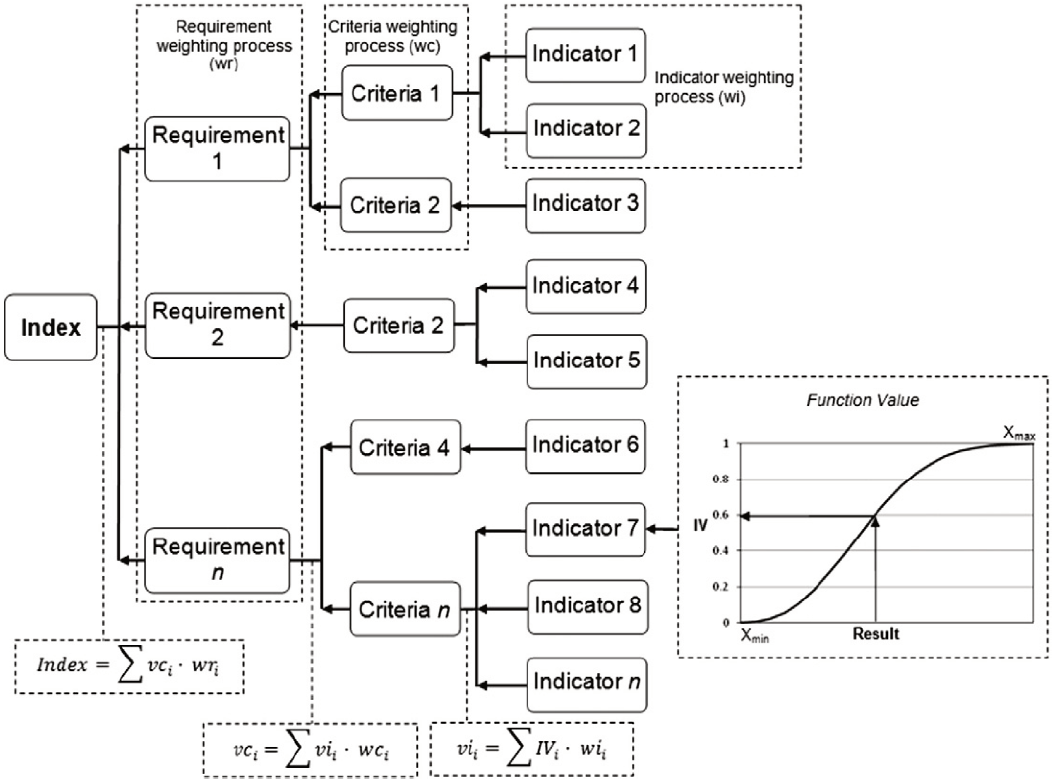


Figure 6: *Theoretical structure of MIVES [137]*

spreading largely through territories and countries are usually called corridors. These roads are of great importance for several reasons, among which the most important is economic development [131]. Principal roads are completed by middle length roads that spread within the country, with social and economical functions.

Decision models for road building and managing have been worked out in order to support stakeholders and managers [137]. Fig. 6 schematize the Integrated Value Model for Sustainability Assessment (MIVES), which sorts non-uniform investments. Its final goal is to compare projects with non-common characteristics (that is to say: buildings, transportation systems located in different areas, with different costs or territorial impacts), to choose and to build roads with best global results. In correlation with MIVES we can relate to the real impact on infrastructure as demonstrated in SIIP (Sustainability Index of Infrastructure Projects) with parameters included in fig. 7.

The projected speed is one of the principal parameters of a projected road. In the work of Zidane [181] indicators as speed monitoring, speed inputs, obstacles are

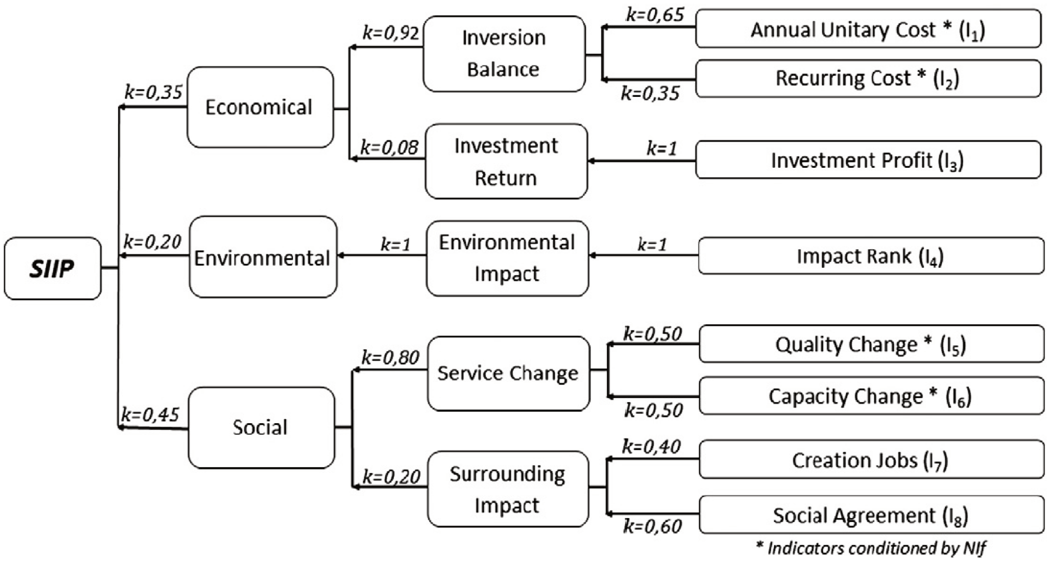


Figure 7: *Decision tree of SPII on road infrastructure [137]*

presented and the relevance of a projected speed is stated, for ecological and other goals.

Various researchers such as Igondova, Pavlickova, and Majzlan [95] have a different approach, for example using a Ecological Impact Assessment (EcIA) method related to Directive 2011/92/EU, amended by 2014/52/EU. This method presents a new rapid conception to the assessing of ecological impacts of road projects.

2.1.2 Support terrains of roads

Natural terrains or support terrains of roads, depending on the project stage, have an influence on road geometries, costs, energy demands (construction and use phases), and also vehicle handling, ride quality, and stability (Flahaut [65]). Fig. 8 illustrates the importance of terrain on road profile. Generally large excavations results in more needed energy for the construction phase, but are allowing more plane layouts which limits the use phase consumption [150].

Terrains can be classified into one of the following four types [142]: plain terrain, rolling terrain, hilly terrain, and mountainous terrain.

Plain terrain is flat with small longitudinal slope, of the order of 0-0.5% according to SETRA [150]. Needed reinforcements to create roadway are typically rare, and

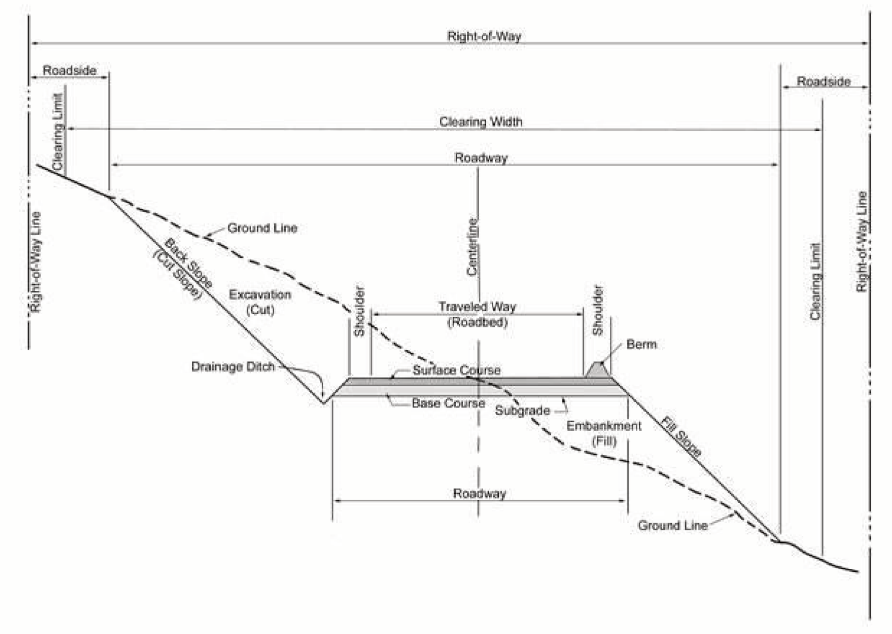


Figure 8: *Cross section of a road [142]*

attention is focused on drainage by creating sufficient cross fall.

The rolling terrain is also relatively convenient for the construction of roadway, with height differences reaching approximately 70 meters according to [150], [151], [142], depending on country classifications.

The hilly terrain is a lot less favorable for the construction of roads, with relative altitude difference of up to 150 meters [150], [151], [142]. Facilities that provide support like bridges, retaining walls, etc. are very common. The cost of building such facilities sometimes exceed the sum required for the construction of certain sections of this road. Landslides may appear on such terrain in certain geological conditions, which can completely destroy roadways.

Mountainous terrain is the most unfavorable terrain for road construction, with higher altitude differences ([150], [151], [142]). Landslides and rockfalls on such terrain are very common. For this reason roads built on this terrain are usually of lower rank, because the construction of the road of high rank would be too expensive and other route are generally preferred.

2.2 Roads as a part of a network

Individual roads are forming extra-urban and urban networks. Urban networks are more complex and the forms of transport that use it are more diverse: car, buses, trams, pedestrian, bicycle, etc. (Lozano, Granados, and Guzman [119]). Distribution rates for speeds of these vehicles are significantly different, especially in the areas of high longitudinal gradients (or slopes), which is taken into account as a very important criterion for the application of specific solutions (e.g. a special lane for slower vehicles). Suburban and urban networks have interactions (Fontes et al. [68]):

- ensure the continuity of long-distance flows, all this while protecting the local amenities of the negative impact of road transport;
- introduction of long-distance traffic flows that have a target or source in the urban area.

This is usually resolved through taking into account the hierarchical level of settlements and a functional rank of the rural roads within the road network (Loorbach, Frantzeskaki, and Thissen [117]). The ideal conditions of development of urban and suburban roads are rarely seen which, of course, requires a compromise between basic rules (Louhghalam, Akbarian, and Ulm [118]). Planning road networks is finally a balance between transit efficiency and local access.

2.3 Traffic signs and road equipments

Depending on the regulations and policies of each country, traffic signs and road equipment are defined by guidelines for road managers, in designing and implementing road signs. Users, who often travels at different speed, could have variable perceptions of theses signs [110]. These variations in perception imply to evaluate signs and equipments while considering many parameters (Griškevičiūtė-Gečienė and Griškevičienė [83] and Orfila and Coiret [133]):

- road type (category);
- socially defined permissible driving speed;
- psycho-physical characteristics of typical drivers on each type of road;

- characteristics of the road surface, and surface water; (drainage)
- traffic load;
- intersection, other infrastructure;
- vehicle dynamic.

Road traffic signs are a collection of elements standardized or harmonized with international standards which direct the flow of vehicles and pedestrians, provide a variety of information to traffic participants [150, 151, 142]. The main task of traffic signs is to clearly and unequivocally indicate to users in which part of the network they should move and how to realize the efficient and safe movement to the desired destination ([110] and Toledo [166]).

The implantation of traffic signs shall ensure:

- evaluation - drivers have only few seconds to evaluate information from signs, i.e. to perceive the necessary information, and to eliminate redundant information (Hartmann and Ling [87]). Different operations are involved in this process from spotting (detection, observation) to identification (recognition and decision) (Brewer et al. [28]).
- concentration: design of traffic signs without significant stresses to the user (information must be functionally separated so that the user concentrate on the message that is relevant to him);
- selection: proper design as the entire system of traffic signalization is depending on the selectivity and prioritization [110].

In Louhghalam, Akbarian, and Ulm [118] such principles have been reported for the case of vertical traffic signs.

The basic requirements that must be met in the design of traffic signs [150],[151],[28],[142],[110] with emphasis on the work of Bazire and Tijus [18] are:

- Uniformity - Signaling must be uniformly designed, independently of the network where it will be installed;
- Homogeneity - all objects on the road network, which have similar characteristics and functions, must be equipped with signaling elements in the same way;

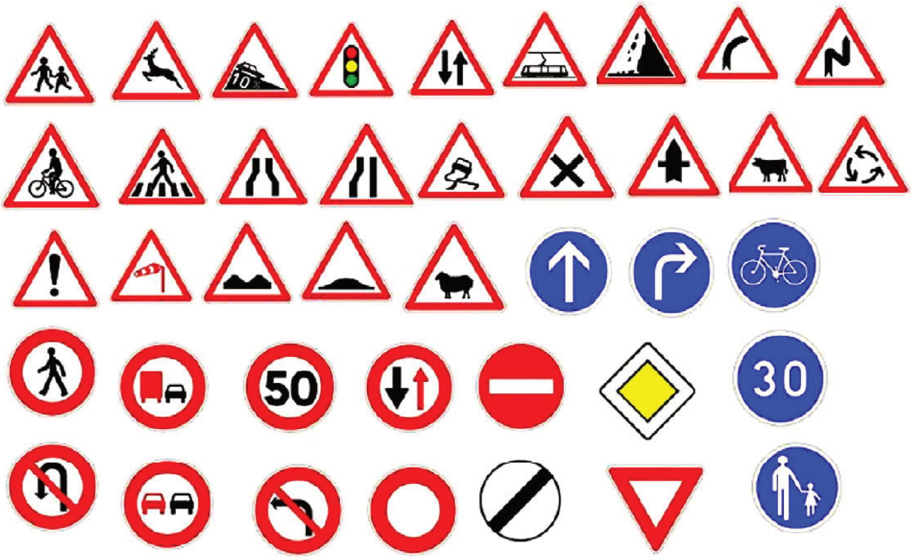


Figure 9: *Some of road signs most frequently used [18]*

- Ease - designing with a level of detail that ensures full efficiency (avoiding unnecessary details);
- Continuity - signaling should be designed to ensure the movements along a certain road network;
- Visibility - signaling elements should be visible not only in all weather conditions, but also in terms of the environment where they are placed (buildings, trees, poles lighting elements, etc.);
- Clarity and legibility - for signs with characters, which are required to be configured so that the driver in a short period of time accurately comprehend the message;
- Constancy - need for elements to maintain their appearance in terms of shape, size and color to the day and at night.

Fig.9 displays different signs used in France. They belong to categories as danger signs, intersection and priority panels, prohibition, and obligation signs, etc.

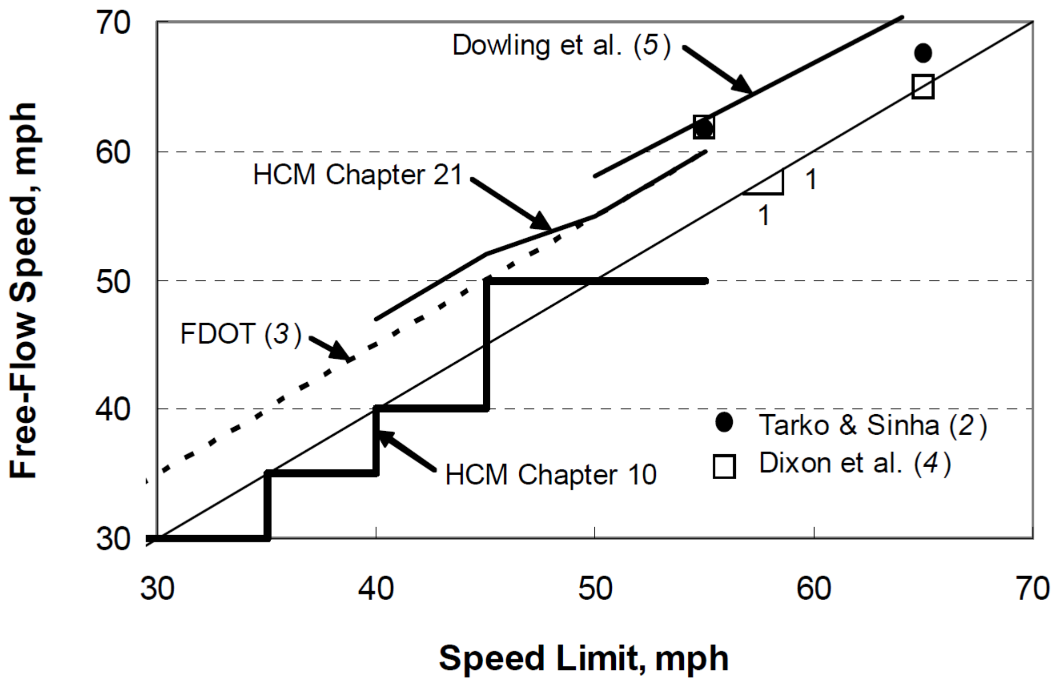


Figure 10: *Comparison of guidance relating free-flow speed to speed limit*

2.4 Speed regulation and zoning

Because conditions at any location change with fluctuations in traffic and variations in weather and visibility it is customary to set speed limits for average physical and traffic conditions and for less favorable weather and visibility.

Speed limits are likely correlated with free-flow speeds, as it is displayed in fig. 10, based on the HCM manuals and traffic flow softwares. With the exception of the guidance provided in Chapter 10 of the HCM, there is a trend where the free-flow speed is 5 to 7 mph faster than the speed limit. However, it should be noted that Ye, Tarko, and Sinha [176], Dixon et al. [55] and The Florida Department of Transportation (FDOT) found that free-flow speed is only slightly above the speed limit when the speed limit is 65 mph. Personal experience and practice typically lead to free flow speeds just below a threshold where it would cost the driver a traffic fine, however with a large variation in it.

Ye, Tarko, and Sinha [176] examined speed data from 116 speed measurement stations on arterial highways in Indiana. Their analysis found that several factors were correlated with free-flow speed: heavy-vehicle percentage, time of day, speed limit, land use (i.e., urban, rural), number of lanes, and road category. They found that speeds were lower on facilities with more lanes. They also found that higher percentages of heavy vehicles during the day were correlated with lower speeds but the reverse was true during the nighttime.

Dowling et al. [57] examined speed data from 10 speed measurement stations on four rural highways in three states. They developed the following relationship between free-flow speed and speed limit:

$$S_f = 14 + 0.88 S_{pl} \tag{1}$$

where, S_f = free-flow speed, mph can also be converted in km/h; S_{pl} = posted speed limit, mph can also be converted in km/h.

In fact, these researchers have consistently found that the average speed changes only 2 to 3 mph when the speed limit changes by 10 mph. This trend has been found on streets and highways, when the speed is increased or decreased by 5 or 10 mph. It implies that the slope of the three trend lines in fig.10 is too steep.

CHAPTER 3

VEHICLE

Deljanin and Kiso [49] recalled history of vehicles. Steam, combustion, and electrical engines had all been attempted by the mid 1800's. By the 1900's according to Fuhs [71], it was uncertain which type of engine would power the automobile. At first, the electric car was the most popular, but at the time a battery did not exist that would allow a car to move with much speed over a long distance. Even though some of the earlier speed records were set by electric vehicles, they did not stay in production past the first decade of the 20^{th} century. The steam driven automobile lasted into 1920's. However, the price on steam powered engines, either to build or maintain was incomparable to the gas powered engines. Not only was the price a problem, but the risk of a boiler explosion also kept the steam engine from becoming popular. The combustion engine continually beat out the competition, and the early American automobile pioneers like Ransom E. Olds and Henry Ford built reliable combustion engines, rejecting the ideas of steam or electrical power from the start. As this thesis is based on Internal Combustion Engine (ICE) which are more used in public in the next paragraph we will explain the introduction to ICE from an energetic aspect.

The EU Directive 2003/30 stipulated that by 2010, 5.75% of fossil fuel should be replaced by renewable fuels and the European Automobile Manufacturers' Association (ACEA) set the target to reach a 120 g/km emission in 2012, and in the next few years to reach emissions of less than 100 g/km where some of the car makers succeeded.

In relation to Euro-Normes Directive 2007/46/EC passenger vehicles produced in 1995 had CO_2 emissions of 185-200 g/km and in 2002 160-180 g/km. By implementing the European CO_2 Reduction Program, emissions dropped to 140 g/km, corresponding to fuel consumption of 4.5 l/100 km for diesel and 5 l/100 km for petrol-powered vehicles.

Similar measures to reduce greenhouse gas emissions are carried out through out the world. USA, Canada, Japan, Korea, China, Australia have legal or voluntary regulations on this issue.

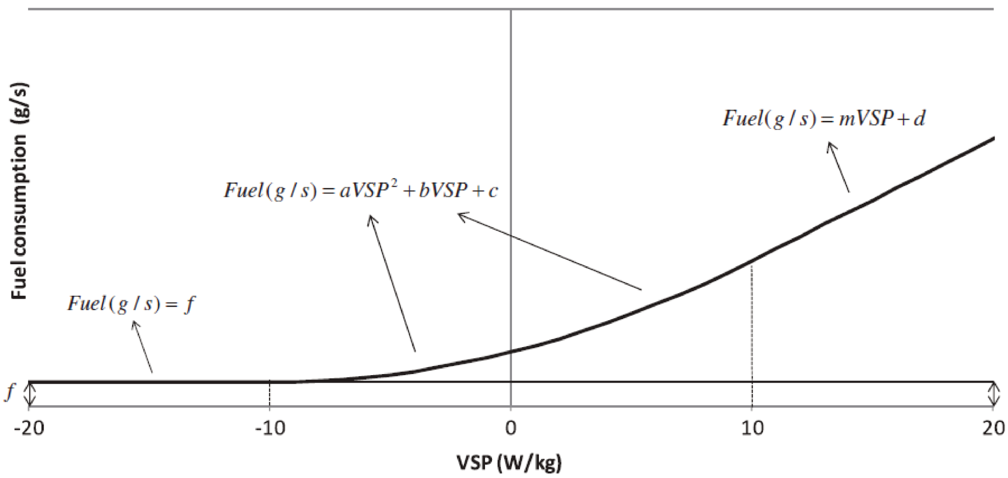


Figure 11: *Generic trend of fuel consumption as function of VSP mode, using three generic equations and 6 variables [59]*

Asia has surpassed all continents in CO_2 emissions due to the rapid development of some countries, especially China and India, in just a couple of years, they have overtaken the leading place of CO_2 emissions countries from North America and Europe. This situation in the CO_2 emission is certainly a compliance with the Kyoto Protocol, and a strict ban on trade in CO_2 emissions in Europe, which annually leads to emission reductions; those data are in relation to the work of Jiao et al. [100].

3.1 Classification of power-driven vehicles

One of the important characteristics to asses a vehicle is the Vehicle Specific Power (VSP), which represent the power needed by a vehicle in a given driving situation and on a given road route.

Fig. 11 presents the generic trend of fuel consumption, regarding the areas of application of equations detailed in Duarte et al. [59]. This trend, with its 6 variables, was used in certification driving cycles, but here we are using it in a reverse manner: the total fuel consumption was known (and its VSP time distribution). The fuel consumption variables were defined according to the certification values for different vehicle. This work focused on the development of an innovative methodology to estimate the VSP model fuel consumption based only on public available data, namely the European certification cycle information. Therefore, a novel simple and fast method was developed for different vehicle technologies (SI-spark ignition, CI-compression ignition and hybrids) to enable an energy characterization of a vehicle according to the specific power required while driving, without the need to perform on-board vehicle measurements of individual vehicles (Duarte et al. [59]).

Furthermore, characterization of fuel use and emission rates with respect to VSP modes enables comparisons of different fuel and vehicle technologies using real-world duty cycles (Coelho et al. [39]).

Vehicle power is linked to the notion of speed, with two major variants:

- Vehicle speed - The speed at which the vehicle can move usually is called technical speed and it depends on the structure of the vehicle itself and the engine power. Most engine vehicles today can generally move at high speeds, even when roads are presenting high longitudinal slopes (Duarte et al. [59]), except for heavy vehicles.

- Speed as a characteristic of the road infrastructure - The mean speed to travel over a given distance in a given time is defined as the exploitation speed, including any loss of time. It reflects the transportation quality of service. Reducing the exploitation speed may be due to a number of factors, which are commonly present in the quality of the pavement structure, its technical indicators, the characteristics of the terrain (Abou-Nasr and Filev [3]).

3.2 Operational characteristics of ICE

According to the book of Filipovic [64] engine data contains performance characteristics, i.e. nominal power and nominal RPM (rotation per minute) which qualify the performance level of the engine. Nominal power is effective power that manufacturer guarantees engine can develop under certain exploitation conditions. Other power terms are:

- permanent power - the highest effective engine power which can develop indefinitely, without transgressing the limits of thermal and mechanical stress;

- limited power - maximum effective power that the engine may develop only for a limited time;

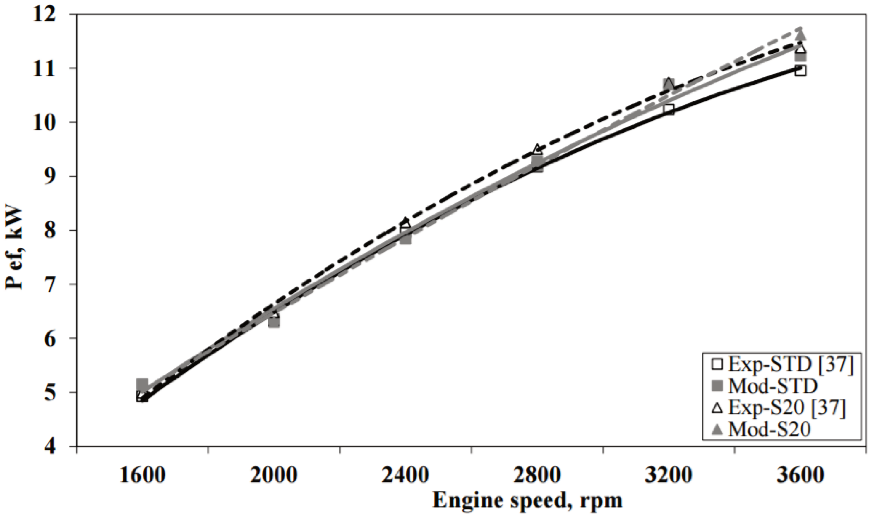


Figure 12: *Diagram of engine speed-power [82]*

- maximum power - maximum effective power at which the engine can work from 1.5 to 15 minutes, without thermal and mechanical damage depending on the type of vehicle reference to ISO 1585.

Depending on the resistance of movement,vehicle speed, terrain, road conditions etc., while engine vehicle is operating, it depends on minimum and maximum engine speed RPM and P_{ef} (Effective power) laying on the curve between abscissa- defined by minimum and maximum engine speed RPM and ordinate defined by P_{ef} (Effective power) expressed in kW and demonstrated in fig. 12.

Even that this thesis scope do not cover all thermal characteristics of a ICE which are presented in the work of Gonca [82], the performance characteristics are important and they can improve or deteriorate with respect to different conditions of compression ratio, engine speed, equivalence ratio, stroke length and mean piston speed.

Engine performance is conditioning acceleration/deceleration characteristics of vehicles. Significant difference exists in deceleration behavior of different vehicle types. In fig. 13 the importance of acceleration and its impact on using eco-driving techniques is observable. However this is a experimental run where a technic of eco-driving is demonstrated and named "speed and glide" to provide smooth driving and anticipation of traffic. It is apparent that the velocity of the eco-driving vehicle was often limited below 56 km/h with fewer and milder acceleration/deceleration events when compared

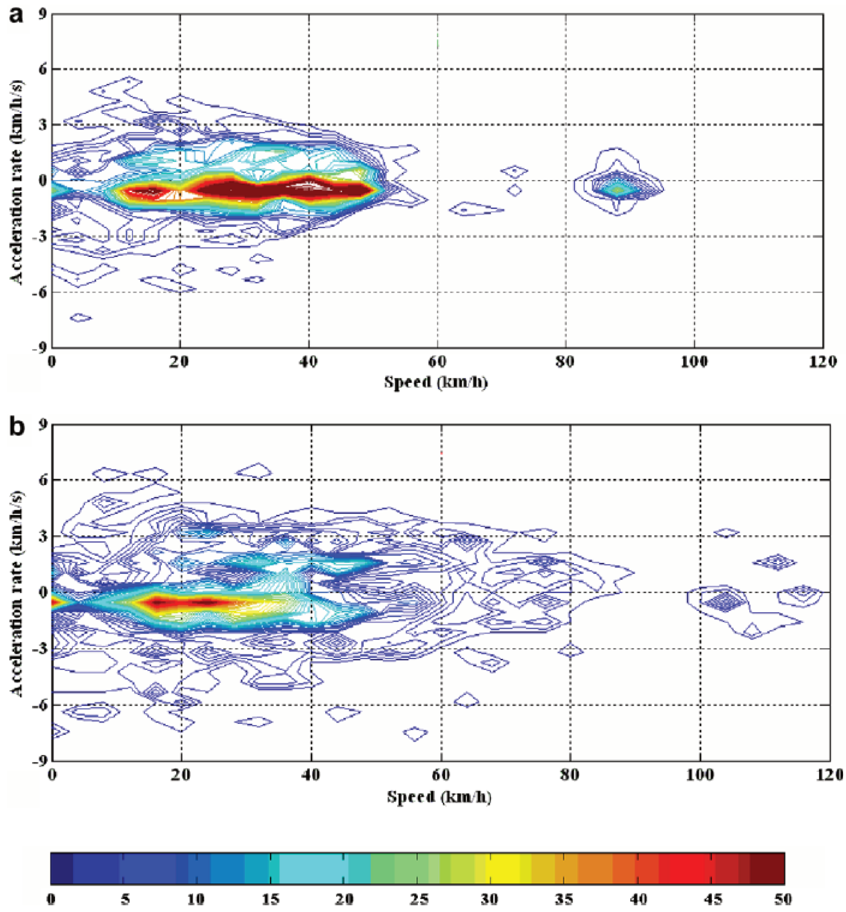


Figure 13: *Speed-acceleration histograms for both (a) eco-driving and (b) non-eco-driving vehicles [17]*

to the histogram of the non-eco-driving vehicle in accordance to Barth and Boriboonsomsin [17]. The importance of the technic "speed and glide" is defined in using an appropriate techniques of eco-driving in correlation to road traffic and terrain. That defines the optimization rate of each techniques which is explained in the eco-driving,eco-routing eco-exploitation chapter.

Fig. 14 is a synthesis of deceleration rates experimented in published researches from 1960 to 2005. A wide variation in deceleration values is observed. Studies undertaken by some researchers show that vehicles employ higher deceleration rate while decelerating from higher desired speed. Deceleration rates proposed/observed are less or equal to deceleration rate where comfortable deceleration rate is 3.4 m/s^2. Literature review yields a variety of deceleration models. Samuels and Jarvis [145]

Author	*Year*	*Speed range (km/h)*	*Deceleration Rate (m/s^2)*
Gazis et al.	1960	72	4.9
St. John and Kobbet	1978		1.07
Parsonson and Santiagio	1980		3
Bester	1981		0.6-1.9
Lee et al.	1984		0.28-0.96
Wortman and Fox	1994	48.3-80.5	2.1-4.2
Wortman and Matthias	1983	57.6-76.4	2.5-4
Brodin and Carlsson	1986		0.5
Watanatada et al.	1987		0.4-0.6
McLean	1991		0.5-1.47
Bennett and Dunn	1995	60-70	1.39
		70-80	1.78
		80-90	2.22
		90-100	2.34
Akçelik and Besley	2001	60	3.09
Wang et al.	2005	40-50	2.4
		50-60	2.39
		60-70	2.67
		70-80	2.52
		80-90	2.55

Figure 14: *Deceleration rates observed by various researchers [107]*

proposed the simplest and constant deceleration model that assumes constant deceleration over entire deceleration manoeuvre that is not realistic (Akcelik and Biggs [7], Bham and Benekohal [22],Wang et al. [171]). Deceleration characteristics of vehicles are observed to be non-uniform and lower deceleration values are used during starting and finishing of deceleration manoeuvre. A time-lap of 45 years of research is taken into account and the importance of considering different methods, models is examined to achieve an even higher standardization and application of eco-driving in correlation to infrastructure, but without deteriorating the security and comfort aspect.

Slope/gradient can have an influence on traffic flow regarding speed discontinuance as well as speed limitation for different types of vehicles. To limit emission values Ragione and Giovanni [139], appropriate techniques must be used in construction of roads and their influence on every aspect of the D-V-E model. In the following fig. 15 it is clearly observable how the impact of road gradient can have on fuel consumption and the GHG emissions.

With taking all the characteristics into account the gearbox is taken into account as well as is serves to convert the driving force. In accordance to the work of Freitas Salgueiredo [69] this subsystem receives as inputs the different gear ratios engaged along the speed profile, the torque at the wheels, the wheels rotational speed and ac-

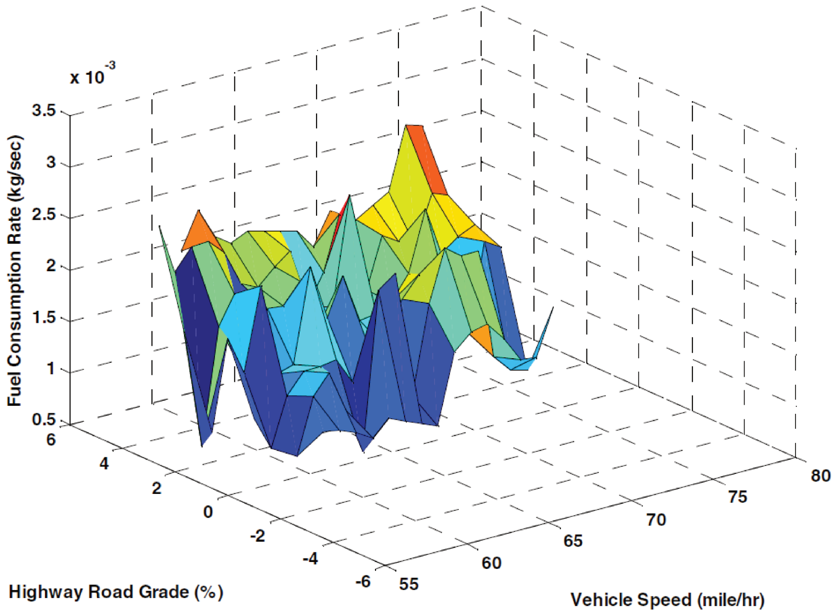


Figure 15: *Fuel Consumption Rate as a function of the Vehicle Speed and the Road Gradient on a Segment of a Highway Road [3]*

celeration. It calculates the torque on the clutch side of the gearbox and the crankshaft rotational speed. These calculations involve the use of the gear ratios, defined by the vehicle manufacturer. The final transmission ratio, N_t(f), is the product of the final drive ratio N_f and the corresponding transmission ratio $N_t(gear_0$(t)).

To better demonstrate the impact strategy of each related to acceleration/deceleration, the fig.16 can be considered, with fuel consumption variations calculated using the mean fuel consumption of the upper and lower average speed bound for each speed lane direction. The results of the scenario (speed variations from 50 until 70 km/h) are analyzed using a classic multi-way analysis of variance detailed in the thesis of Freitas. It shows that strategies are used, strategy 1 is associated with significantly lower fuel consumption than all the other strategies, while strategies 3 (lower bound of constant speed) and 2 (engine braking) are shown to be similar. Direction W–E (west-east) slightly increases fuel consumption, and the 3^{rd} gear has significantly higher fuel consumption when compared to 4^{th} gear.

Strategy	Acceleration & decel. in neutral ("coasting") 50–70 km/h				Acceleration & decel. engine braking ("same gear") 50–70 km/h				Constant speed lower avg. speed bound 60 km/h				Constant speed upper avg. speed bound 70 km/h			
Gear of the test	3		4		3		4		3		4		3		4	
Track directions	W–E	E–W	W–E	E–W	W–E	E–W	W–E	E–W	W–E	E–W	W–E	E–W	W–E	E–W	W–E	E–W
Average speed [km/h]	60.0	59.7	60.0	59.5	60.1	60.1	60.5	60.1	57.9	57.7	57.7	57.7	67.2	67.2	67.3	67.3
Fuel consumption [L/100km]	4.6	4.7	4.6	4.1	5.9	6.2	5.2	4.8	6.2	5.8	5.3	4.6	6.8	6.2	5.6	5.0
FC_{var} (ref.LB avg-sp.) [%]	26	19	13	11	5	–7	2	–4								
FC_{var} (ref.UB avg-sp.) [%]	32	24	18	18	13	0	7	4								

Figure 16: *Mean results – average speed and fuel consumption – obtained in the tests realized for the speed variation scenario from 50 until 70 km/h [69]*

3.2.1 Speed characteristics of the engine

According to Filipovic [64] speed characteristics are represented in Fig. 17 as the changes of engine parameters depending on the change of rotations per minute (RPM).

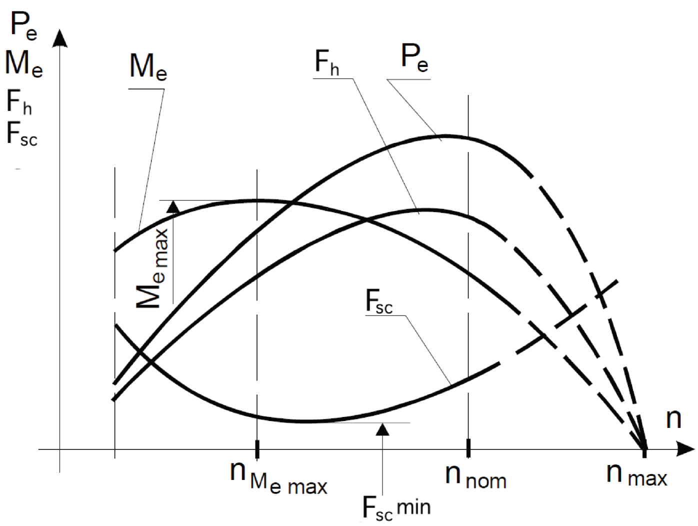


Figure 17: *Speed characteristics of the engine [64]*

Power change as a function of engine speed in Fig. 18 is determined to certain values, usually done by studying engine on a test stand. Other parameters are also determined, such as: engine torque (M_e), mean effective power (P_e), hourly fuel consumption (F_h), specific fuel consumption (F_{sc}) and so on. If obtained values are presented graphically in fig. 18, a picture of their change depending on the CO_2 at the respective position of the adjustment organs (that is, load change) will be received referred to the work of Fontaras et al. [67]. There is a correlation between fig. 18 and fig. 17.

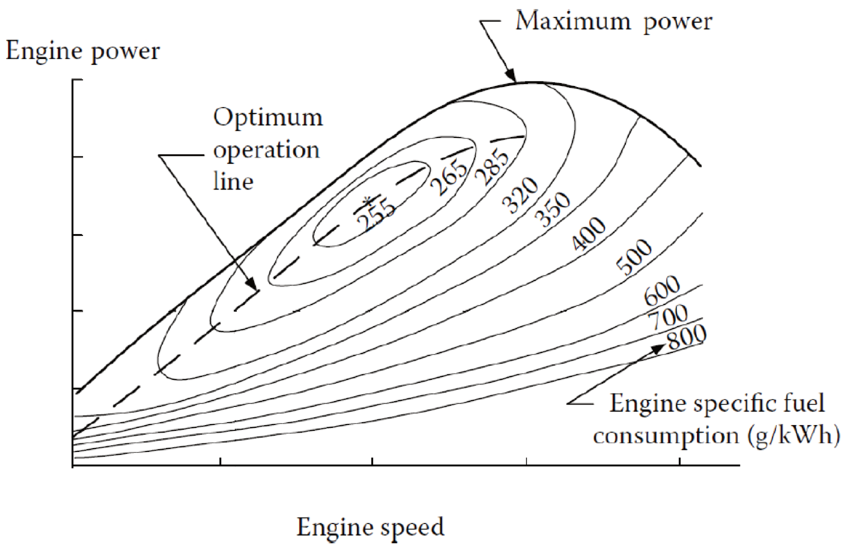


Figure 18: *Typical internal combustion engine specific fuel consumption map [20]*

The most important speed characteristics of the engine are effective power curve and torque curve.

Comparing flows of these curves for Gasoline and Diesel engines where parameters as μ_P is the coefficient through which the influence of the degree of power utilization on the efficiency of the engine has an optimal value of 1. Other parameters are instantaneous engine power - P_i and maximum power - P_m and are expressed in Fig. 19 (Ben-Chaim, Shmerling, and Kuperman [20]). Analytical approach to evaluating vehicle fuel consumption under standard operating conditions were described, using two different operating modes: constant speed and acceleration movements.

3.2.2 Combined (universal) characteristics

Combined engine characteristics are represented by so-called combined or universal characteristics diagrams, in which each coordinate axis represents one characteristic

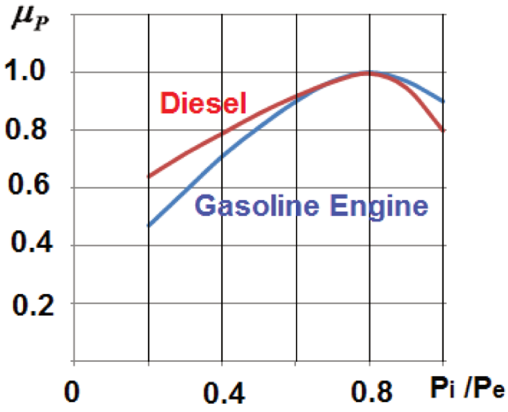


Figure 19: *Coefficient of the power utilization on diesel and gasoline engines [20]*

engine parameter. Those parameters are effective power, specific fuel consumption, and sometimes exhaust temperature of the engine. Curves of equal specific effective fuel consumption surround presented in fig. 17 and thereby define the so-called most economical pole, that is, determine CO_2 and load where highest economic efficiency is achieved. Universal characteristics diagrams offer the possibility of objective comparison of different engines in terms of economy. Diluted lines of equal consumption show that such engine provides economical operation in wider ranges of load and speed change. In this respect, diesel engines are much more favorable than gasoline engines. According to Filipovic [64] the position of economy pole and equal consumption lines flow is a result of very complex interactions of complex phenomena, where most important are: work materials exchange, mixture formation and combustion, mechanisms of thermal and mechanical losses and others all of these elements and characteristics.

With some of these characteristics explained we can observe the exploitation of these characteristics in the environment and the impact provided by it. We are introducing the standards and norms applied to regulate emissions gases of vehicles.

In 1970, the Economic European Community started to define measures to reduce air pollution from positive-ignition vehicles. The regulation defined several types of tests to quantify the exhaust gas emission and the methods and specifications to perform them. In order to harmonize legislation against air pollution due to engine vehicles, the foundations were laid to introduce the EURO emission standards in 1991 (European Economic Community, 1991), which became effective with EURO 1 in July 1992. In correlation to EURO norms evolved during the years at stepped up on a new level in

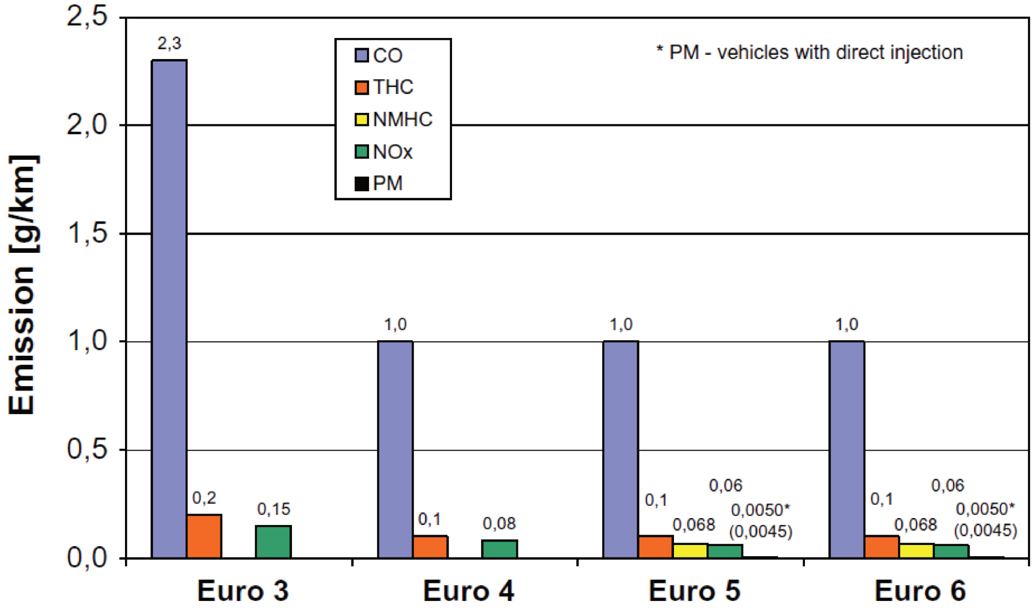


Figure 20: *Progress in European emission regulations for passenger vehicles fitted with spark ignition engines [23]*

the correlation to driving cycles (Fig. 20).

The current standard driving cycle where each vehicle is tested in predefined conditions – New European Driving Cycle (NEDC) – was introduced in 1998- defined by the The World Forum for Harmonization of Vehicle Regulations and consists of four urban transient cycles – Urban Driving Cycle (ECE-15) – and one extra-urban speed profile – Extra-Urban driving cycle (EUDC) – performing a total of approximately 11 km in correlation with Dieselnet [54] to demonstrate its effect on the environment. This speed cycle is performed on a chassis dynamo-meter following a strict procedure of gear changes and tolerances of speed and acceleration. Synthesizing the work of Duarte, Goncalves, and Farias [58] a portable emission measurement system (PEMS) mounted in a vehicle was used to determine fuel use and emissions regarding each Vehicle Specific Power (VSP) mode in correlation to time. According to André [10], André and Rapone [11] most of the studies tend to compare real-world driving cycles and certification, but most of them in different routes, therefore under off-cycle conditions.

3.3 Analysis of the impact of vehicle speed on traffic

If you are on a road with a single lane (2X1) fast vehicles usually have to overpass slower vehicles using the lane for the opposite direction in which lead themselves and other road participants in danger. When overtaking or passing traffic lane intended for the opposite direction they can be taken whereby faster vehicle must adjust their speed to slower participants (Glaser et al. [81]). It is logical that such interference depends on the size of traffic due to occupancy lane of the opposite direction. The speed at which a vehicle can move depends on the size and percentage of certain types of traffic or structures according to Fontes et al. [68]. Road intersection, signalized intersection and crossing with railways will reduce in exploitation speed by increasing vehicle operating costs and negatively affect the flow of traffic and as well increase emission (Pandian, Gokhale, and Ghoshal [136], Deljanin, Deljanin, and Herić [46]). Links between traffic and emissions are schematized in fig. 21.

Vehicles characteristics and dynamics must be well known so that the pavement of the upper and lower construction will be be able to receive and safely transfer the vehicles pressure without damaging certain points of the pavement construction [150]. It can be concluded that the vehicles which arise in public transport must have legally limited pressure per axle.

To facilitate the normal exploitation and the speed of heavy weight vehicles, the road should be carried out with appropriate elements that allow sufficiently appropriate speed for the smooth and safe traffic flow of all vehicles [151]. This can be achieved in various ways, for example: certain signs, then physically separating traffic of lower speeds, extending roadway width that will allow the unhindered passage of vehicles with higher speeds.

It is also important to mention the work of Ziyadi et al. [182] where the estimation of energy consumption and emissions from vehicles is done at various operating conditions and roadway-roughness levels. The gains of this model represent that vehicle efficiency accounts for about 27% of the potential total energy savings and potential savings from pavement roughness can be up to 7% (Fig. 22).

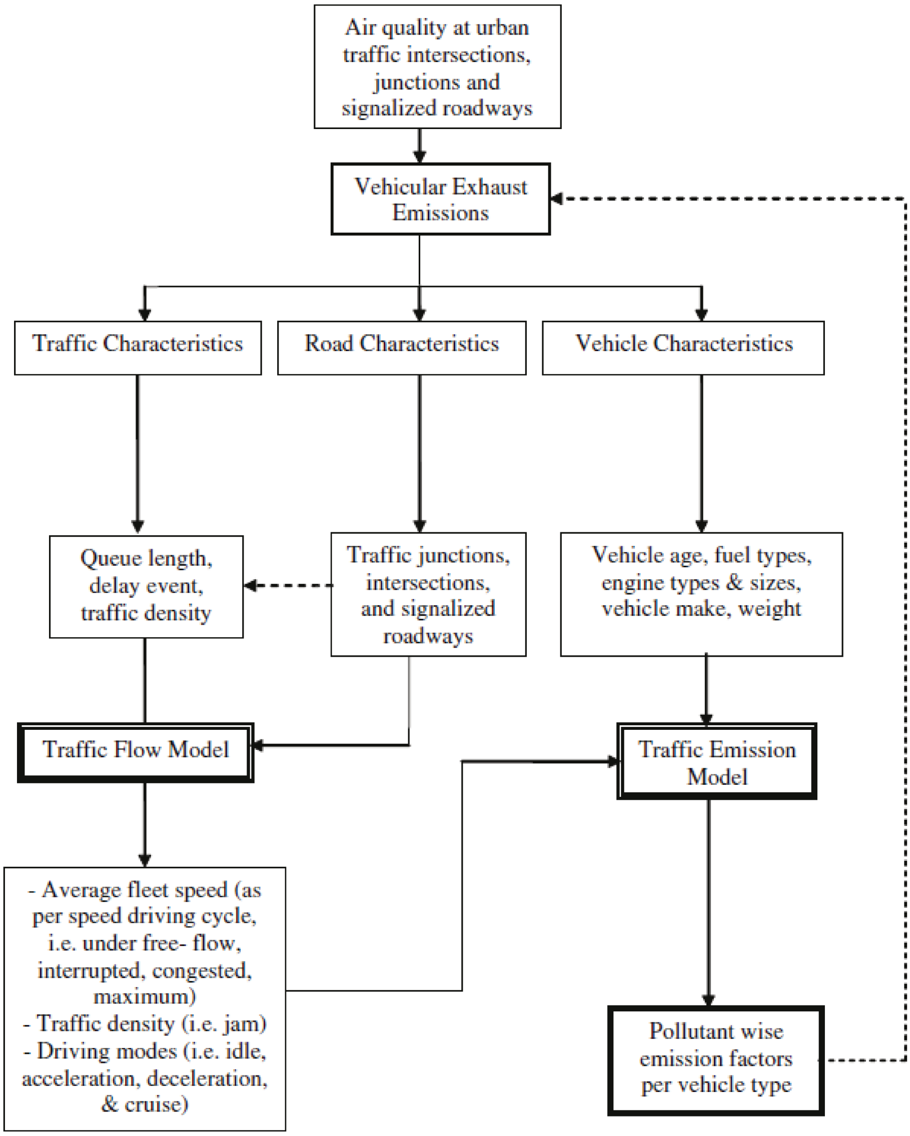


Figure 21: *Vehicular exhaust emission modelling tree [136]*

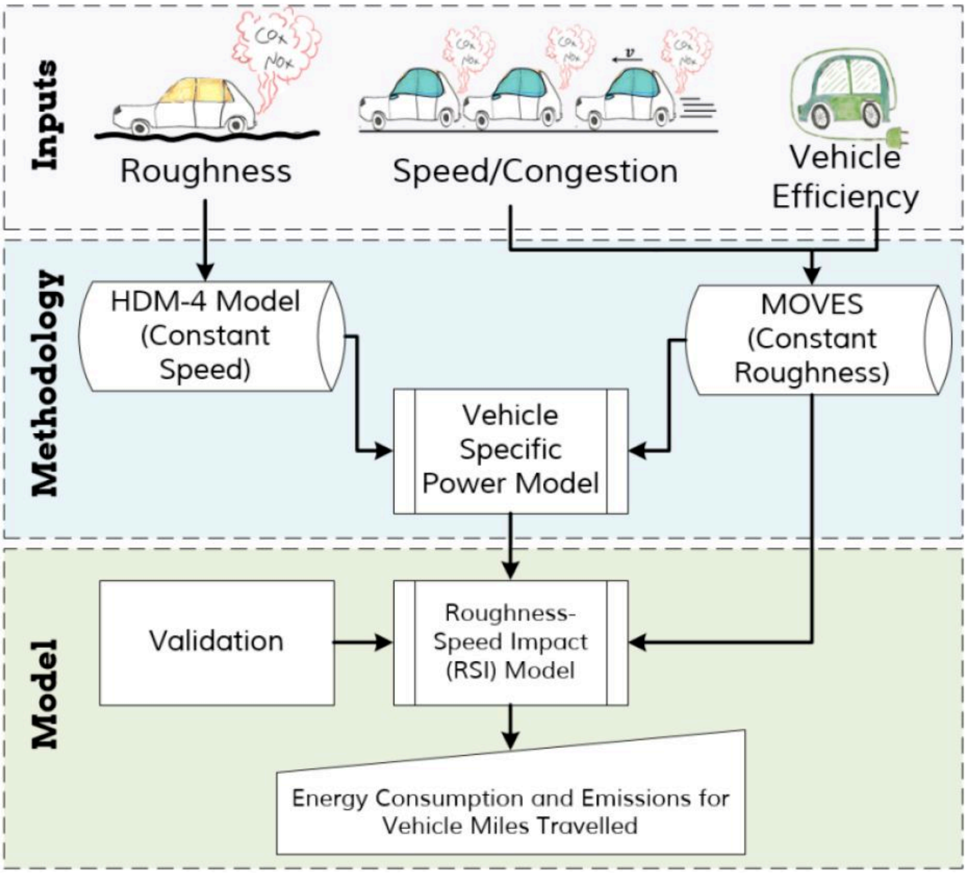


Figure 22: *Roughness–speed impact model-development flowchart [182]*

CHAPTER 4

TRAFFIC

4.1 Measured or simulated traffic

Road traffic is defined by the number of vehicles on a considered lane, sometimes by discerning the types of vehicles. The traffic is generally measured by devices located in the roadside (loops, optical cells), in order to evaluate the rate of use or congestion of the roads. This relates to the term capacity. Capacity is the maximum vehicle flow-rate that can be passed through the observed section of the traffic lanes or road over a certain period of time. The traffic can also be simulated to evaluate the use of lanes not yet created, or to evaluate the evolution of road capacity. Traffic counts are the basis for research, forecasting, planning and road infrastructure management.

Traffic evaluation is able to exhibit road usage variations. As an example, in urban areas the peak hour traffic could account for as much as 10% of the daily traffic (Mehanovic [126]).

One of the goal of traffic analysis or simulation is to achieve a well designed road management plan ans complete the spatial road planning maps. According to Mehanovic [126] planning is a process that is carried out in order to establish a plan for development of certain areas, in economic, demographic, social and traffic situations. Today, it is not enough to just predict the movements and possible development, but it's also needed to actively plan, create and implement the measures necessary to achieve intended goals.

4.2 Traffic on networks

The traffic network consists of nodes, and branches (links) connecting them. Traffic network marked S = (N,A) denotes a network where a set of nodes is labeled as N, and set of links between them is labeled as A. Networks can be formed on different principles. Regarding roads, we distinguish rural network, where cities or settlements are nodes, and urban network, within cities, where the intersections are nodes.

Networks can be divided by different criteria, and the main is related to functional characteristics, with a method and a model realized in to achieving a perception of a macroscopic (large scale) and a microscopic (small scale) approach to analyze data which influence the GHG emissions and the impact of traffic to fuel consumption (Zegeye et al. [178]). In this sense, networks or individual roads can be divided into roads exclusive for vehicle traffic; mixed traffic roads; pedestrian traffic roads. Roads can be divided by socio-economical significance: main, regional, or local roads.

Analysis of traffic networks and intersection characteristics are relevant for planning an adequate strategy. In the first context it is important to considere intersections, which are the bottlenecks in traffic, that is resistance in traffic networks and their importance are mentioned in the work of Zegeye et al. [178].

4.3 Route planning

Analysis of travel formation is the first stage in a four-phased procedure of predicting transport demand. Quality of assessment of travel formation directly affects the assessment of the other phases: travel distribution, modal division, and attribution of travel (Colonna et al. [42]). Trip analysis establishes the relationship between city activities and transit movements, in order for that relationship to be used for future transport demand. Transport demand is usually expressed by the number of travel endpoints. Start point of travel is usually tied to the house (either as start or finish), and travel attracts are usually tied to jobs, markets, recreation, leisure etc. Travel creation model involves modeling both the start points and attracts of travel. Process of travel formation analysis consists of finding methods for establishing appropriate functional dependence between the movement volume and land use.

Analytical methods for modeling the movement formation would be:

- models that determine the number of movements depending on the development of an area;

- models that use regression analysis to determine dependence of travel numbers on socio-economical factors and land uses;

- models of cross-classifications or categorical analysis.

To make the correlation of this methods, analysis and models as a unity in the entire system we have to take into account the size of traffic which is our next section.

4.4 Traffic parameters

Transport of goods or passengers at a distance is commonly called transport work, which is expressed in net tonnes of transported amount of goods or passengers. The sum of the payload and the empty weight of all vehicles represents the gross traffic load that may be measured in gross tons. Generally road traffic size is expressed in two ways: traffic count; gross traffic load.

Traffic count is the total number of vehicles that pass through a certain section of road per time unit (Lu et al. [120]). The volume of traffic depends, on many elements such as the time of observing the passing vehicles i.e. day and time, the structure of transport, types of vehicles, etc.

Planning the perspective traffic is a special expertise in the technology of transport according to the book of Mehanovic [126]. For example reconstruction or modernization of existing roads will cause a redistribution of traffic in a way that most of the vehicles that previously moved on some detours will now appear on the new road.

Traffic volume of a road is the size of the whole traffic expressed in gross weight of goods, passengers and vehicles which pass through observed section in time unit. Traffic volume is obtained by counting vehicles (passenger vehicles, buses, trucks, etc) that pass through the observed cross-section of the road in measured time. Estimate of the average weight of individual vehicles and the average weight of cargo trucks gives information about the road-load (the pressure supported by the road in a given time) detailed in the work of Lu et al. [120].

4.5 Driver behavior in traffic situation

Knowledge and skills of drivers, in a situation of traffic, have advantages and disadvantages in term of transport efficiency, safety and eco-driving.

In terms of emergency or a possible risk of dangerous situations for drivers, indications and variables of the driver importance in a D-V-E model are given in the work of Orfila et al. [135]. These factors are closely associated with the age of drivers and their experience. When considering the population of drivers by age, two groups that are most represented in the frequency of accidents are: young drivers up to 24 years and persons older than 60 years (Colonna et al. [42]). For young drivers, their social irresponsibility is expressed, they do not think about the consequences, even though they are predisposed to be the best drivers. It is most important to teach this group of drivers to respect traffic regulations. For drivers who are older than 60 years there is a change in mental and physical characteristics due to poor coordination of movements, poor visual function, prolonged reaction time, which is manifested especially on long trips.

Regarding to experience or inexperience, studies have shown that drivers which have accumulated more driving experience, cause less traffic accidents without being old. Experience could benefit both to road safety and eco-driving. If training for the driving starts later, drivers are much slower and more difficult to adjust to driving (Aria, Olstam, and Schwietering [14]).

If considering gender, women are more likely to adhere to traffic regulations, drive defensively, with increased caution, have better fineness of movement of arms and legs in traffic situations, but learn and get their first experience harder. Male drivers are more often driving aggressively, ride near the center line, but they are better in the speed of response and the method of processing information through instruments(Stahl, Donmezand, and Jamieson [158]).

Furthermore, the behavior of a driver has a direct impact on the environment and the vehicle emission. In the work of Beckx [19] emissions are associated with various trip purposes, from 0.704 g/km for shopping and service-related trips, 0.756 g/km for transit trips, 0.735 g/km for touring.

As we have introduced the term- driver in the next chapter we will be defining major psychological activities of drivers and their constitution as a variable in a system, their structure and behavior in the D-V-E model.

CHAPTER 5

PSYCHOLOGY

5.1 Human/driver personality

A human as an individual, as a worker, as a driver, can have unexpected deviations from the established results, conclusions of scientific knowledge. In the words of Patricia Delhomme an expert in the field of psychology there are many different definitions of personality, but basically all contain three important personality traits which is used in this thesis to define our types of drivers:

- very stable- defined by anger, searches for sensations - aggressive driver
- stable- attitude motivations by standards, defined as eco-driver or defensive driver
- transient or temporary patterns - morning or night, emotion management disorder - defensive driver or aggressive driver

Rot [144] defines personality as a "unique organization of features that is formed through the interaction of the organism and the social environment and determines the general, the individual's distinctive pattern of behavior." What are the personality traits, how many there are, what is their importance in the structure of personality, how he made their classification are questions that require answers, therefore also of the personalities of road users, especially the driver.

Number of researchers define the structure of personality as:

- characteristics of physical constitution;
- ability (physical, mental, sensory and psycho-motor);
- temperament;
- the needs - motives and motivation;

- attitudes and perceptions;

- interests and will.

Hereditary and educational factors play an important role in the formation of personality. Repetition is a form of educational factor and, in particular, repetition makes driving behavior to become automated, that means that the single actions of driving, such as navigating and changing gears, are conducted frequently with no conscious decisions being made [109]. Drivers have to change their automated behavior in relation to familiar routes into deliberately controlled behavior from an eco-driving aspect, in order to optimize their driver behavior and be able to perform certain tasks of eco-driving. Considerable effort is required for this process to happen. First thing first, in order to change their driver behavior, drivers need to have an intention and to put it into practice. For the investigation of a intention a psychological theory of attitude-behavior is implemented as TPB (Theory of Planned Behavior). The assumption that individuals make rational decisions, is something on which the TPB is based and the purpose of implementing it in every section of the thesis. Thaler and Sunstein [164] considers this technique paternalistically; they believe that it is legitimate to influence behavior in order to help people live longer, better and healthier lives, and to anticipate mistakes. To perform as a respectable citizen and be eco-friendly is one of the aim of the thesis. There is a simple example of this theory: the state of Texas wanted to reduce the amount of rubbish along the highways. The expensive campaigns had failed; the young men, in particular, did not stop throwing their garbage on the public road. Those responsible for the sanitation program then decided that they needed a slogan "appealing to the patriotic spirit of the Texans". Focused on the target of young Texans, the state called on famous football players to participate in commercials in which we saw them picking up trash and calling people by "Watch out for Texas!". Today, this slogan is declined on many supports. During the first years of this experiment, the amount of detritus had decreased by 72%. No stress or threat in this experience but a boost to behavior change. In the TPB, the motivational factor is constituted by behavioral intention, this factor influences behavior directly and that represents the effort, and in order to perform a behavior individuals are willing to make this effort.

Then TPB can help to evaluate if eco-driving is applicable in relation to social norm standings, this considers that eco-driving is conditioned by the fear of social norms to apply or not the eco-driving, playing on their responsibilities as respectable citizens. In addition to its effect via intention, behavior can be predicted directly by the means of perceived behavioral control. Eco-driving was not previously investigated by the TPB, but other aspects of driving behavior is consisted of numerous TPB-based studies in relation to Lauper et al. [109].

5.2 Drivers commands in dependence to roads

5.2.1 Concept and types of skills

Abilities [1] are possibility and success of personalities to perform certain tasks and activities. Skills are ability to do something well, performance of certain activities and operations, execution of certain tasks. In accordance to Horrey et al. [91] abilities cover levels of satisfaction of certain human and social needs. In real world driving situations, there are many opportunities for drivers to interact with external devices and information. Some researchers tried to differentiate some of the tasks and engagement while controlling the difficulty, interesting material presented without giving any kind of instruction can draw attention of a driver, this can potentially lead to delayed breaking responses to critical road situations.

5.2.2 Body, health and physical fitness

Optimal health status will have a beneficial effect on physical strength, endurance, alertness and efficiency in responding and functioning. It will have significantly favorable impact on the psycho-social status, communication, interaction and transaction with others, resolving the stress and conflict situations that are common in everyday life, especially in traffic. So physical performance significantly conditions skills that matter for the status of drivers (Blanco et al. [24]). Conversely, physical handicap could particularly affect drivers skills. At last, driver's physical ability is closely associated with the appearance and feeling of fatigue.

[1] according to British dictionary-possession of the qualities required to do something; necessary skill, competence, or power: the ability to cope with a problem

5.2.3 Mental abilities

Mental skills are abilities of perceiving, understanding, memorizing, thinking, reasoning [29]. The dominant intellectual (mental) capability is intelligence. This is the ability to grasp the important relations between data and finding new solutions. In modern traffic, driver meets many signs and is confronted with very complicated situations in which he must respond quickly and accurately, and predict the consequences of his/her actions. To verify that, one study tested 6,000 drivers who were driving for 15 or more years, but did not experience any traffic accident. Results showed that all drivers have an average or above average intelligence in reference to Warner and Åberg [172] with relation to their behavior and acceptance of ISA (Intelligent Speed Adaptation). So called partial capabilities are also important for participants in the traffic also in relation to ISA, i.e. drivers:

- ability to understand mechanical relations (i.e. technical intelligence);
- greater ability and skill in understanding the work of an engine, detection and correction of faults (errors) and their elimination;
- ability of space relations assessment (spatial visualization) - ability to observe objects (sudden obstacles, etc.) that are in motion, annotation of own distance from an object, the speed and direction of his/her and other people's vehicles.

5.2.4 Psycho-motor abilities

Most of the actions carried out while driving are related to psycho-motor abilities, habits and automation of these activities (movements of the arms, legs, fingers, coordination of movements of arms, legs, eyes ...). Based on tests (Faure, Lobjois, and Benguigui [63]), it is possible to distinguish the psycho-motor abilities of the body as a whole and psycho-motor abilities of limited parts of the body (torso, legs, arms, fingers ...). It is possible to distinguish (Diekstra and Kroon [53]) the strength (power) of movement, impulsiveness (the rate at which the movement is performed), the static accuracy (the accuracy and security of maintaining the position of the body or individual organs), dynamic precision (accuracy), coordination (harmonious combination of movements), flexibility (the ability to rapidly change and replace movement). In particular impulsivity determines the duration of the reaction time, i.e. the time it takes to pass from the appearance and perception of obstacles to psycho-motor reaction of driver.

The time that passes from the moment of noticing the dangers to the end of the driver's muscular response is called response time. Very often that time is incorrectly called reflexes. Reflexes exclude the knowledge (conscious reaction) and deciding factor from the process, what is the essential difference.

Braking or decelerating reaction time of drivers in an important notion, both for safety and environmental concerns. Reaction time is composed of observation and decision time, psycho-motor time and it is preceeding overall braking time, including vehicle mechanical durations.

Reaction time is typically between 0,5 - 1,8 seconds when in accordance to Glaser et al. [81]:

- Driver expects the reason to brake and is ready to immediately brake-0,5-0,7 seconds;
- Driver handles the vehicle controls, movement of other participants-0,9-1,1 seconds;
- Driver's attention is directed to the event by the road, he is talking or is thoughtful 1,4-1,8 seconds [167].

5.2.5 Sensory abilities

Visual acuity, or the ability to distinguish the various structures at certain distances is extremely important while driving. In the work of Herman [89] a mathematical approach and formulation is given to demonstrate the importance of stimuli in a traffic network and the interaction of traffic dynamics through human.

When it comes to driving, anticipation plays an important role, as well as in hazard perception and eco-driving. Researchers shown anticipatory aids to facilitate earlier deceleration prior to conflicts, this has been done with respect to safety and better reaction times in combination with smoother, improved deceleration profiles. In previous research Stahl, Donmez, and Jamieson [157], experienced drivers were more likely to exhibit anticipatory competence and act to avoid potential conflicts, these were the findings derived from a study. Considering that experienced drivers possess heightened skills for the timely and accurate interpretation of the local traffic situation, this finding was expected. Prior research in hazard perception was in line with mentioned findings, where experienced drivers exhibited superior visual scanning patterns (Garay-Vega et al. [74]), and also early recognition of hazards situations (Matsoukas et al. [125]). Ståhl, Horstmann, and Iwarsson [156] defined that anticipation in driving is rooted in identification of stereotypical situations in traffic. In this sense, both hazard perception and anticipation rely on skilled perception and correct interpretation surrounding traffic situation. These mechanisms are learned competencies, abilities to compare the current situation to situations that are similar and that are stored in memory. These mechanisms, in which anticipation benefits from experience should be viewed as a top-down process, with mental models from past experiences (Hole [90]).

In regards to eco-driving, onboard visual systems that involve eco-driving have a positive impact on fuel savings, but these systems can potentially distract drivers. Eco-driving advice support system uses a highly visual display, in many cases, this display changes in real time. The intention of this system is to draw some attention to it, but it amounts to requiring "forced glances". This is why in this thesis it is more oriented on changing the aspects of the road infrastructure to promote eco-driving an to demonstrate all the benefits of it. As well as introducing different types of drivers and the interactions between them and the infrastructure by having results on fuel consumption and emissions. This is why it is important to exploit a D-V-E model in details.

CHAPTER 6

DYNAMIC INTERACTION WITHIN THE D-V-E MODEL

Before talking about the dynamics of the vehicles, a basic D-V-E (Driver-Vehicle-Environment) model is illustrated in fig. 23 which is used to understand the interconnection between these systems. The relation in a D-V-E model between entities are significant as in this thesis an optimization process is conducted to improve environmental impact of the use of road infrastructures.

6.1 Basics of vehicle dynamics

To analyze the behavior of a motorized vehicle in different situations and different driving conditions, it is necessary to, first of all, understand and explain the physical principles and laws governing them. Full mathematical modeling of all processes taking place in moving vehicle would lead to a large number of non-linear and mutually coupled differential equations, whose solving is difficult and time consuming. At the same time, since there are considerable differences of vehicle types, these models would be very specialized and difficult to apply to different vehicles. Model simplifications are therefore generally used.

In practice, vehicle dynamics are classified into the following sections:

- Longitudinal dynamics - forces act in the direction of movement; mainly studied aspects are resistance to movement and braking; vehicle movement is translational; mathematical approach is the simplest and mainly based on algebraic relations;
- Transversal dynamics - forces act in the direction of transverse axis, mostly in curves; mathematical models are usually much more complex compared to longitudinal dynamics, primarily because of complex behavior of the pneumatics;

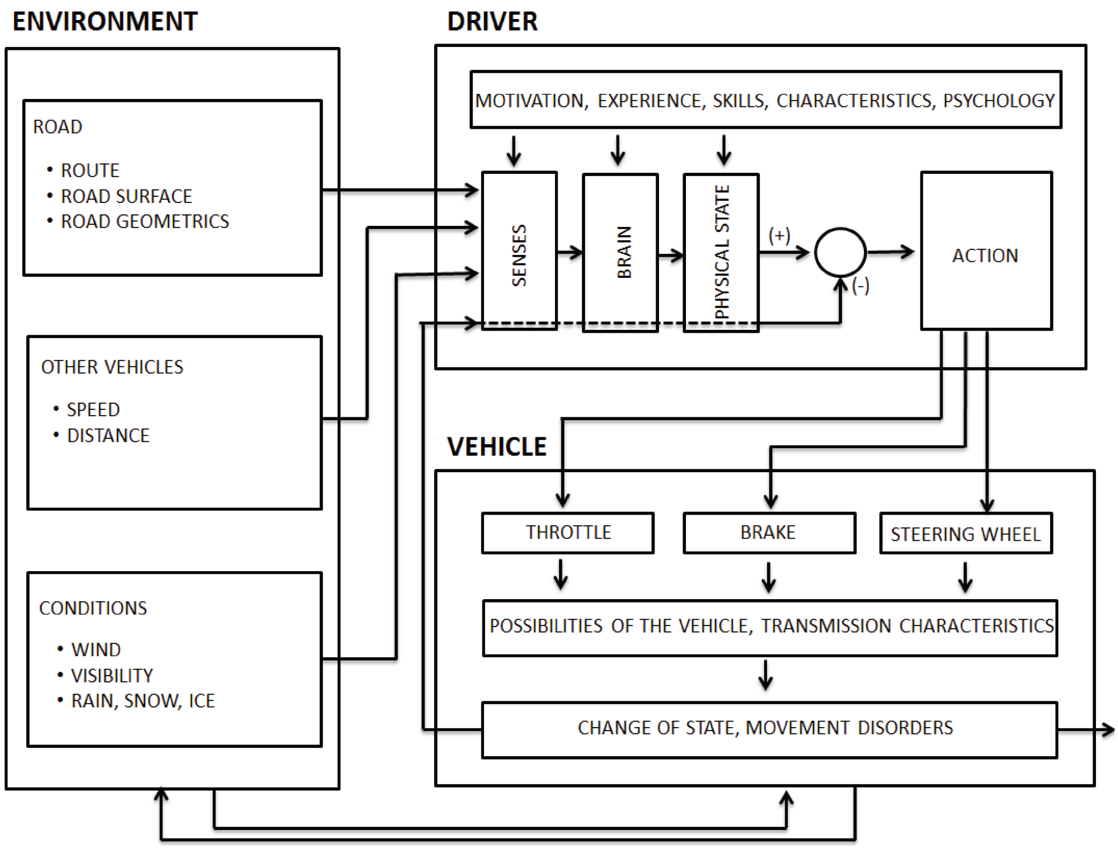


Figure 23: *D-V-E model*

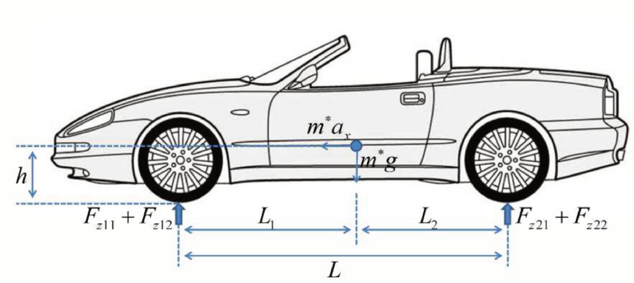


Figure 24: *Transfer of vertical charge [108]*

- Vertical dynamics - forces act in the direction of vertical axis. Movement of engine vehicle is followed by the oscillations of the vehicle, which are primarily caused by road irregularities or dynamical induced mass transfers.

Vehicle is presented as a system composed of a suspended mass (vehicle body) and four unsprung masses (wheels). Vehicle movement as a whole is described by translational movement of the selected pole (based on the law of changing momentum) and spherical movement around that pole (based on the law of change of angular momentum). The X axis is set longitudinally in direction of vehicle movement (suitable for the analysis of linear movement, departure of vehicle from one point, acceleration, braking), the Y axis represents the axis suitable for describing the lateral dynamics of the vehicle (curved movement), while the Z axis represents the axis that describes the vertical load and pad reaction. Determination of the center of gravity position is one of the most important factors that directly affect the stability of the vehicle. Center of gravity helps determine the characteristics of the vehicle such as driving stability, centrifugal force effects and inertia forces. In some cases, when the friction coefficient is large enough, and center of gravity high enough (e.g. trucks) there is a higher possibility of roll-over occurrence than slippage.

Taking into account vehicle dynamics and performance either at horizontal or slope terrain we have to apply calculation methods to calculate the energy and fuel consumption done in this thesis.

6.1.1 Vehicle longitudinal model

Vehicle longitudinal model rely on the fundamental principle of the dynamics::

$$M\vec{a} = \sum \vec{F} \tag{2}$$

With $\vec{a}$ the acceleration, $\sum \vec{F}$ the sum of the forces exerted on the vehicle, which are the aerodynamic force $\vec{F}_A$, the rolling resistance force $\vec{F}_R$ and the force of gravity $\vec{F}_G$ (fig. 25). In the case of a rise all these forces are opposite to the direction of movement of the vehicle (ie: the force of gravity hinders the advancement and therefore can not compensate other dissipative forces such as aerodynamics and rolling resistance. Note: in practice a "positive" aerodynamic force can not exist, this would imply very strong winds with regard to the speed of the vehicle and a large surface to wind ...).

$$\vec{F} = \vec{F}_X + \vec{F}_{ext} \tag{3}$$

$$\vec{F}_{ext} = \vec{F}_A + \vec{F}_R + \vec{F}_G \tag{4}$$

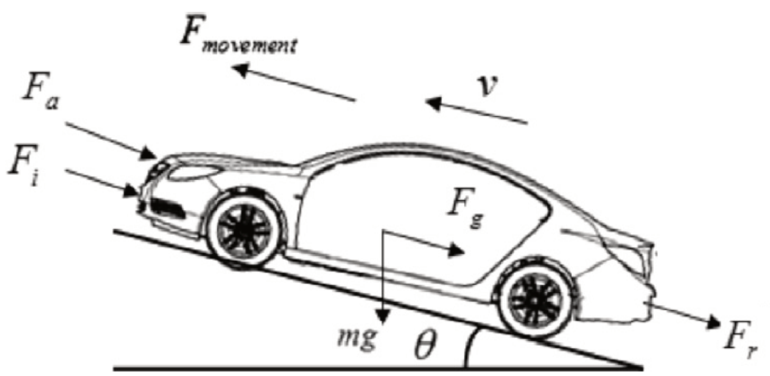


Figure 25: *Different longitudinal resisting forces acting on the vehicle [127]*

6.1.2 Forces opposed to vehicle movement

Aerodynamic force F_A is the air drag resistance:

$$F_A = \frac{1}{2} \cdot \rho \cdot S \cdot C_X \cdot V_r^2 \tag{5}$$

With ρ is the density of the air in kg/m^3, S the frontal surface of the vehicle in m^2, C_X the coefficient of aerodynamic resistance, V_r the relative speed of the vehicle to the wind in m/s.

Rolling resistance F_R is caused by the contact between the tire and the road:

$$F_R = M \cdot g \cdot C_R \tag{6}$$

With the C_R rolling resistance coefficient, M the mass of the vehicle in Kg, and g the acceleration of gravity in m/s^2.

Cenek, Davies, and Jamieson [35] found that C_R depended on the speed of the vehicle:

$$C_R = C_O + C_V v C_m \tag{7}$$

Engineers, who work on the design of a road define a slope as a section of road that descends and the ramp as a rising road section. In this thesis, the slope is used as a term of the path which gives the following relation:

$$F_G = M \cdot g \cdot \sin(\theta) \tag{8}$$

With θ the slope of the road.

It should be noted that the relationship $\theta \simeq \sin(\theta) \simeq \tan(\theta)$ is checked with an error of only 1.3% in the case of a slope of 10 degrees. Moreover, the formula $\tan(\theta) = GR/100$ or GR is the gradient of the road (GR) as a percentage.

6.1.3 Vehicle transverse model

In order to better understand the dynamics of the vehicle we can evoke the transverse model which is responsible for the modification of the trajectory fixed by the driver. This is due to the numerous transverse forces which are developed by the tires in the relation to the work of Do [56]: wind resistance, directional forces, centrifugal force.

6.2 Exploitation speed of a road

Exploitation speed of a road is a kind of performance in mobility efficiency. It is the effective mean speed of the vehicle flow. It can appear to be "under-average", while considering a road with a good design but a low exploitation speed. According to Benedetto and Pensa [21] this may be due to damage of pavement leading to the unification of speed differences-rates of all vehicles of a certain traffic flow, and such equalization of speed reduces the throughput of the road which has a direct impact on the increase in costs and bottlenecks. Improvements in road signaling and geometry (width) could increase the operating speed to a satisfactory level, reduce transport costs, and thus allow a better exploitation of the road. According to He et al. [88] separation of slower traffic on certain roads will increase the driving speed, and therefore the operating speed. The occurrence of frequent road crossing leads also to a certain decline in exploitation speed.

Factors affecting the operating speed defined by Shrestha and Shrestha [153] are:

- Road characteristics: Lane width, Pavement conditions, Paved shoulder width, Total number of lanes, Presence of median, Lateral clearance, Horizontal curve, Radius and length of the curve, Deflection angle, Straight sectional length, Gradient, Length of the grade, Alignment, Sight distance.
- Roadside environment: Number of intersections, Presence of road sign, Built-up areas, Land use.
- Human factors: Drive age, Driver capability, Public attitude, Enforcement.
- Vehicle factors: Vehicle types, Traffic volume, Presence of bicycles and pedestrians.

6.3 Road projected speed: Influence of visibility

Based on regulations and directives [150], [151], [142] traffic security and traffic flow quality require adequate visibility. The drivers visibility should allow timely speed reduction, stopping, or overtaking.

The lengths of the stopping visibility are the basis for calculating:

- the width of the field of visibility along the route (reading visibility);
- a visibility triangle at intersections (i.e. level crossings);
- minimum radius of vertical curvature;
- lengths for overtaking;
- visibility on the left lane (roads with physically separated one-way lanes).

For these calculations, the starting point represents the predicted speed -V_{pred}. In order to ensure a higher level of traffic safety, it is recommended that at two-way roads with two traffic lanes from Group A and B (outside agglomeration) for calculating the size of the minimum radius of the vertical curve and the distance to overtake, in consideration takes the following speed:

$$V_i = V_{pred} + 20km/h \leq V_{allow}. \tag{9}$$

where V_i-is the projected speed and V_{allow}- the allowed speed in dependence to geometric characteristics of the road

In extremely demanding spatial conditions, the stopping length can be reduced by using a higher quality aggregate (silicate aggregate), or by doing more frequent repairs of the wearing layer or by reducing the allowed speed.

The stop length (junction, speed limitation sign) is calculated according to the following form:

$$L_z = (V_p^2 - V_k^2)/(26 \cdot (a_z + 0.1 \cdot s_i)) \tag{10}$$

where V_p represents the initial speed and V_k is the final speed. The deceleration value of a_z [m/s^2] in this case must not exceed the allowed values of the friction coefficient, where the s_i-level of the longitudinal slope positive or negative.

The formula gives a visibility in meters. In reality this is the mechanical deceleration distance of the vehicle, but the designers of roads consider that the visibility of a sign must be at least equal to this deceleration distance, so it is called the visibility distance.

Visibility must be provided separately for each traffic direction, and for horizontal and vertical road characteristics. As an example, in fig. 26 distance visibility is given in an abacus for technical group A (fastest group from A, B and C groups) of roads depending on road classification of each country.

In the experimentation part of this thesis we have finer formulas to explain the abacus and comparisons to the optimized calculation with the real gathered data.

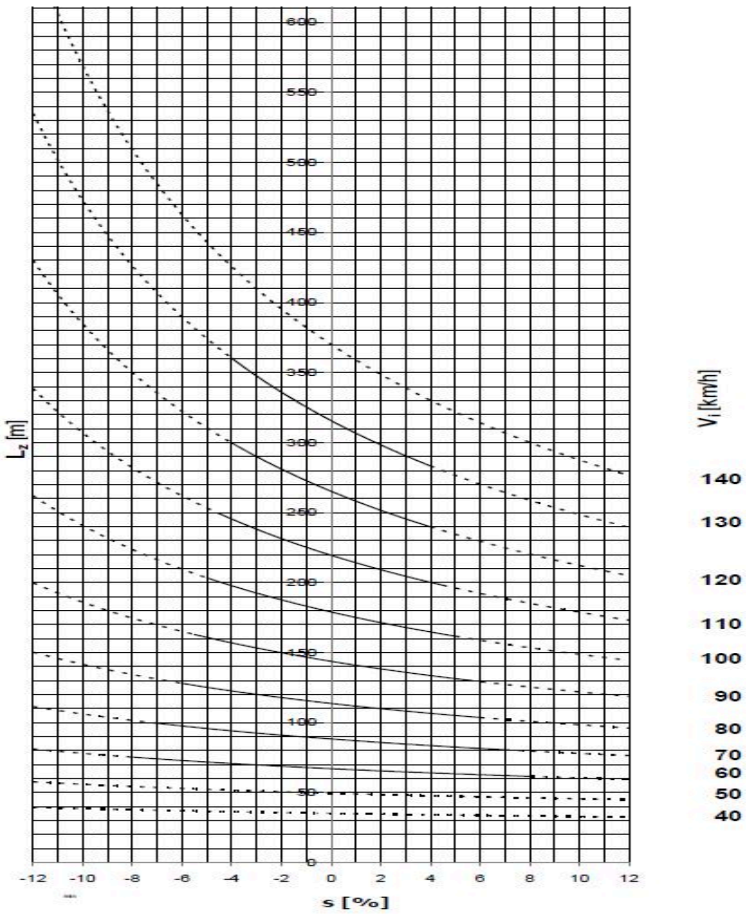


Figure 26: *Distance visibility for roads in technical group A [142]*

6.4 Road projected speed: influence of terrain types

In addition to visibility, projected speed depends on:

- intensity and structure of traffic which determines the grade of the road and its classification;
- nature of the terrain;
- importance of the road within the road network.

To improve traffic flow and meet mobility requirements, it may be tempting to increase the project speed of a road. However, this poses strong constraints and costs, since larger bending radius must be retained by turn and that the management of intersections must involve heavy structures (interchanges, bridges, tunnels, etc.). Locally, cost and terrain structures can lead to adopt a lower projected speed, called "exceptional speed".

According to [151], [142] the projected speed should not be less than:

- 80 km / h for highways (motorways);
- 60 km / h on the main roads (exceptionally 40 km / h on unfavorable terrain).

6.5 D-V-E system: energy demand

The different energies for road usage, construction and maintenance depend on road parameters such as (Gitelman et al. [80]): texture, unevenness, vertical alignment (gradient), crossfall, horizontal alignment (curvature), road and lane width, traffic volume and composition, traffic speed.

D-V-E model is adding other parameters (Deljanin, Deljanin, and Herić [47]): rolling resistance, surface defect, intersections and roundabouts, bridges and tunnels, traffic flow, traffic lights, road signs, road markings, driver behavior, vehicle type, tyre type, air resistance, temperature, wind, rain, snow and ice.

In the article of Deljanin, Deljanin, and Herić [47] some of these parameters were taken in consideration (such as traffic flow and driver behavior) to make further practical research on how to maximize the effect of eco-driving rules. In the same article, a calculation shows that a car that spends 7,04 liters of fuel per 100 kilometers by using eco-driving rules and taking into account the parameters above the reduction of fuel consumption can be from 1.90-2.11 liters, or even to 30 percent on the selected route based on United Nations Development Program (UNDP). Another measures was done experimentally by asking one question: "why drive on the road 90km/h instead of 80km/h?". At a distance of 20 km, the difference in driving time of 90 and 80 km/h is 1 minute and 40 seconds, and on the other hand, fuel consumption was greater from 2 to 5 percent according to OBC (On Board Computer) of the manufacturer. In addition to being a more economical ride at lower speeds, it is safer as it prevents accidents, and the stopping distance is shorter for 10m at 80 km/h then at a speed of 90 km/h. Further research was needed. Based on other research projects if we take into consideration more parameters the influence to reducing emissions and energy dissipation can be even greater. As example to take into account surface defects, incoming roundabouts and intersections, traffic lights etc.

There are a lot of consumption models targeting the road influence. One of the most advanced is the MIRAVEC model (Modeling Infrastructure Influence on Road Vehicle Energy Consumption European-Commission [61]). Considered also by Corporate Average Fuel Economy (CAFE) and Environmental Protection Agency (EPA) standards which are USA standards. These organizations defined sets of legislation which are based on the vehicle's footprint in difference from EURO standards. The EURO standard are set for GHG emissions in grams emitted per kilometer driven (g/km). Nesbit et al. [130] study adapted these standards to the European context by developing the following consumption equation. This thesis used those relevant standards and previous research projects.

Fuel consumption function developed:

$$F_{cs} = c_1 \cdot (1 + k_5 \cdot (F_r + F_{air} + d_1 \cdot ADC \cdot v^2 + d_2 \cdot RF + d_3 \cdot RF^2))^{e_1} \cdot v^{e2} \tag{11}$$

where F_{cs} is fuel consumption, F_r is rolling resistance, F_{air} is air resistance, ADC is average degree of curvature, RF is rise and fall (gradient), v is velocity, and c_1, k_5, d_1, d_2, d_3, e_1 and e_2 are empirical parameters.

$$F_r = (Cr_{00} + Cr_{Temp} \cdot (T_0 - T) + Cr_1 \cdot IRI \cdot v + Cr_2 \cdot MPD) \cdot m \cdot g \tag{12}$$

where T is the ambient air temperature, T_0 is the reference temperature, IRI (International Roughness Index) is an unevenness measure and MPD (Mean Profile Depth) is a measure of macrotexture.

The table in fig. 27 summarizes the thematic research worldwide between 1995 and 2016, depending on traffic demand, energy consumption, emissions, etc.

In the past years and still today traffic problems are increasing. New solutions are provided by ITS (Intelligent Transportation Systems) trying to make a correlation with the demand and the offer. Many researchers have done their research based on characteristics of the traffic, transport and the links to it. Some of the parameters are traffic demand, fuel consumption, fuel intensity, emission, policies, fuel prices, economic, and other factors. These parameters are all variable and each of them are mutually connected to each other directly or indirectly.Based on the article of Chai et al. [36] some authors studied the fuel consumption in real situation which is in direct correlation what is introduced in this dissertation, take the vehicle type or road condition or driving style into consideration, discuss the impact to fuel consumption and exhaust emission, such as Zhang, He, and Huo [179] estimate the elasticities of pollution emission and fuel demand with different vehicle types in road transport sector in China. They estimated the real world fuel consumption rates of vehicles in China sold in 2009. Zhang et al. [180] discuss the fuel consumption of city buses on different road conditions and vehicle masses by different driving styles, and Hu, An, and Wang [92] measured the fuel efficiency and exhaust emission of 16 diesel taxies in realworld on different roads, discuss the relationship between the fuel efficiency, exhaust emission and road condition. In further research by observing the fig. 27 the fuel price can have an influence on the choice of vehicle. Kayser [104] estimates the price and income elasticities of gasoline demand, and assume that gasoline price has the influence to vehicle choice, and Burke and Nishitateno [32] analysis the gasoline consumption and fuel economy in 144 countries, and found the effect of gasoline price to the choice of fuel-efficient vehicle and road fatalities.

More and more researchers are interested in road transport sector total fuel consumption all over the world, Ewing and Cervero [62] carried out meta-analysis to summarize empirical results on associations between the built environment and travel, and find that vehicle kilometers traveled (VKT) is most strongly related to measures of accessibility to destinations and secondarily to street network design variables. Other research projects shows that some countries relay on the transport networks as it represents a resources to them. The health issues in today's world plays a role, so more and more research projects base their work on emissions factor. In the past years the important parameter was and still is the fuel consumption, the variable which is connected to all others: consumption = CO_2 = climate change, emissions = pollution = health issues, so defining the fig. 27 below the advantage of new technologies and techniques to improve the research projects and find new ways to preserve our environment.

Lastly to better understand the fig. 27 one of the best way to have a model which is presented in this dissertation and to estimate the influence mechanism of road traffic systems are: from road capacity to the vehicle emission, through the traffic demand, fuel consumption, and also the other influencing factors, such as fuel price, income, urbanization. Traffic demand increased with the development of new urbanization and sustainable economic, due to the associated large scale movements of the labor force from the country side into urban areas, economic development of France and Bosnia-Herzegovina.

From the road manager point of view, policy can raise driving cost through parking fees, fuel tax, and other relevant policies, and discourage demand for vehicles with high pollution rates. Also there are policies which will be less restricted such as inducing less charges for eco-drivers which are directly connected to a database and recognized with a label formation of a eco-driver. Inducing eco-routing as the identification of the most energy-efficient route for a vehicle to travel between two points and is offered as a way in which drivers can reduce fuel consumption and consequently reduce the carbon footprint of their journeys by knowing the city or calibrating the GNSS to a digital map presented by the local authority a project in application to the city of Sarajevo. Congestion charges and parking fees have discouraged the vehicle travel accessibility to a certain extent, so by charging less the eco-drivers the population will accept this type of driving. The eco-driving method which is presented in the next chapter can have positive impacts on the charges but also have a direct impact of the drivers psychology. Such as contributing to environment which make peoples think and act to contribution on environment property. Only one constrain is the country of the logical people which are educated in eco-driving to have a more healthy view to the environment and the planet in general.

List of available researches on traffic demand and fuel consumption.

Index study	Traffic demand	Fuel consumption	Fuel intensity	Emmision	Policies	Fuel price	Economic	Other factor	Country
Samimi (1995)		√					√		Australia
He et al. (2005)		√	√	√	√				China
Haldenbilen (2006)	√	√				√	√		Turkey
Brannlund et al. (2007)		√	√	√	√	√			Sweden
Paravantis and Georgakellos (2007)	√	√		√			√		Greece
Clerides and Zachariadis (2008)			√	√	√	√	√		18 countries
Karathodorou et al. (2010)	√	√	√			√	√	Urban density	42 countries
Wang et al. (2012)		√	√			√			China
Sene (2012)	√					√	√		Senegal
Hu et al. (2012)		√	√	√				Road condition	Macao
Huo et al. (2012)		√	√		√				China
Alam et al. (2013)	√	√	√		√	√	√		Bangladesh
Gallego et al. (2013)	√			√	√	√	√		Mexico, Santiago
Kim and Brownstone (2013)	√	√					√	Land use density	U.S.
Burke and Nishitateno (2013)		√	√			√	√		
Asensio et al. (2014)		√			√	√			Spain
Hymel and Small (2015)	√	√	√		√	√			U.S.
Grote et al. (2016)	√			√	√			Congestion	
Sierra (2016)	√	√	√	√					Ecuador
Stapleton et al. (2016)	√		√			√			Great Britain
Yang and He (2016)		√	√	√		√			China

Figure 27: *Table of available research projects on traffic demand and fuel consumption [36]*

CHAPTER 7

ECO-DRIVING, ECO-ROUTING AND ECO-EXPLOITATION

7.1 Various energy savings approaches

Three aspects of eco-potentiality will be presented in accordance to road optimization as following: eco-driving, eco-routing and eco-exploitation.

Eco-driving is a mean for a driver to drive both ecologically and economically, with the aim to minimize its vehicle consumption while not making compromises on safety. It should not be confound with "hypermiling" for that drivers want to reach the maximal distance with a minimum fuel quantity (and by taking risks as following heavy vehicles too closely).

Eco-driving is an effective technique that implements known solutions for saving fuel, less pollution and conserving the environment. Although most of these solutions are easy to use, others are more complex and may require special safety considerations before using (Deljanin, Berkovic, and Deljanin [45]).

Eco-routing is another mean to lower fuel consumption, by using a standard navigation system, simply by providing an accurate calculation of low consumption route. A study by Lee and Cheng [112], which compared the effects of driving using a paper map with the use of a portable navigation system, found that drivers using a paper map during the journey wasted time while searching for a suitable route and were more likely to make a wrong turn or chose a longer route. In an urban road environment they found that the trip duration of drivers using a paper map was 16% longer and trip distance 7% longer. The differences were larger in an urban environment than a rural environment and this was considered to be due to the complexity of the urban setting which consequently demanded more attention to road conditions and other traffic participants. It was thought that this, along with a portable device located within the sight line of the driver and thus allowing more attention to be paid to traffic conditions, also resulted in better vehicle handling and therefore a more fuel efficient driving style. In terms of the route choice itself, Ahn and Rakha [6] demonstrated through field tests that emission and energy optimized traffic assignment based on speed profiles can reduce CO_2 emissions by 14-18% and fuel consumption by 17-25% over standard user equilibrium and system optimum assignment formulations as an example of eco-routing.

At last, the main objective of Eco-exploitation is to optimize the exploitation of roads to lower the consumption of vehicles that are moving along it. Eco-design and eco-exploitation are finally levers available to the road designers and road managers to reduce the users energy consumptions. The work developed in this thesis is centered on eco-exploitation and will illustrated this field of research.

To have better symbiosis with all of the three aspects explaining the importance of each one is relevant, so an introduction to each aspects is developed in the following:

Eco-driving is based on simple rules (Orfila, Pierre, and Andrieu [134],Deljanin, Berkovic, and Deljanin [45]):

- rule to change gears (for vehicles with manual transmission);
- rules of maintaining constant speed;
- least possible regime of the engine speed;
- rule to anticipate traffic;
- rules of vehicle maintenance.

Other rules are also present and it should be considered and treated "on advanced principles" such as tire pressure, etc. inspired by the work of Orfila, Pierre, and Andrieu [134] and Deljanin, Berkovic, and Deljanin [45].

7.2 Eco-driving: analysis of the rule to change gears

According to the work of Orfila, Pierre, and Andrieu [134], Deljanin, Berkovic, and Deljanin [45] analysis of the rule to change gears (for vehicles with manual transmission) is based on the fact that in a small period of time we have to increase the level of transmission and keep the RPM in level of 2,000 ≤ 2,500 . This applies to vehicles with gasoline and diesel engines. Of course, part of vehicle energy is lost by mechanical friction. These losses increase with the speed of the engine (or engine speed). Driving on a smaller RPM and higher gear, these losses are limited, which reduces fuel consumption. At a higher gear and at a low speed we create a reduced consumption of fuel. In order to optimally use the efficiency of the engine, a top of 2500 rpm is recommended to shift in a higher gear for engines on gasoline. Diesel engines are generally more efficient at low engine speeds (maximum of 2,000 RPM to a higher gear for diesel vehicles).

Webb [173] presented that it is possible to determine the fuel consumption in lb. per hr. for any point on the gear diagrams, since the power and engine speed will be known.

7.3 Eco-driving: rules of maintaining a constant speed

Fig.28 displays a diagram representing the driving and braking conditions at various gradients (inspired from Webb [173]). It indicates that slightly negative slope overcomes rolling resistance. There are clearly zones 1,2, and 3 representing distinct conditions. Zone 1 extends from the maximum up gradient the vehicle will climb to a small down gradient, and requires power from the engine. Zone 2 covers steeper down gradients, power being absorbed by the engine without brakes. Zone 3 covers still steeper down gradients, when the brakes also absorb power.

Zone 1 is represented by the following equation, there being a transmission loss from the engine to the driving wheels:

$$(R_a + R_r + R_g) = \eta_t \cdot R_e \tag{13}$$

where R_e is the tractive effort of the engine in lb. or g, R_r-rolling Resistances, R_a-air Resistance, R_g- gradient Resistance, R_b-braking Resistance, η_t-gear ratio. In zone 2, the power transmission is in the reverse direction,giving:

$$\eta_t \cdot (R_a + R_r + R_g) = R_e \tag{14}$$

Zone 3 gives a similar equation, but with the braking term added, so that

$$\eta_t \cdot (R_a + R_r + R_g + R_b) = R_e \tag{15}$$

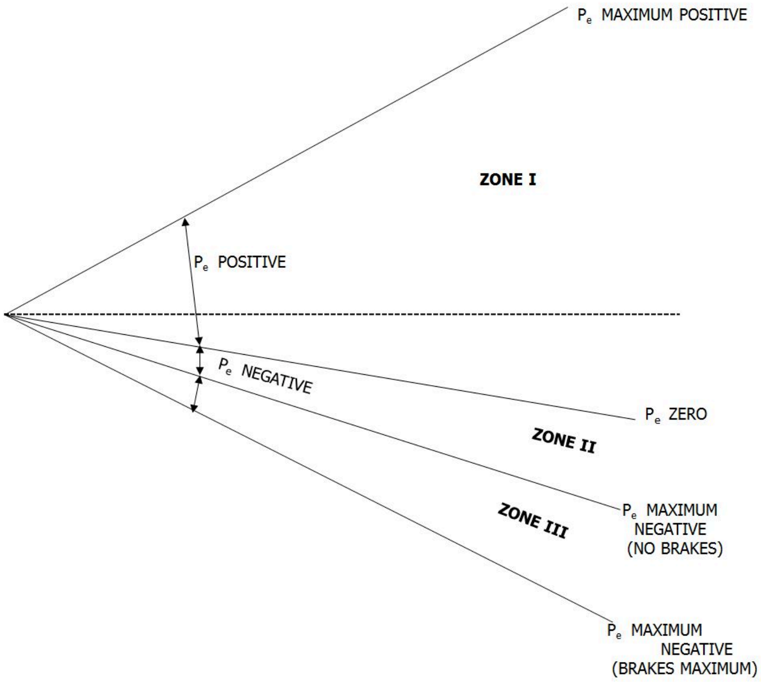


Figure 28: *Driving and Braking Diagram*

This is more conveniently written for computation purposes as:

$$R_b = \frac{R_e}{\eta_t} - (R_a + R_r + R_g) \tag{16}$$

In the above equations, Re could be positive or negative depending of the equation use. Ra, Rr, and Rb are always positive. Rg is positive or negative, depending on the direction of the gradient.

A poor knowledge of the upcoming events in a route could result in injecting fuel to propel a vehicle and having to brake afterwards, with some of the energy is lost by accumulating too much kinetic or potential energy. Constant acceleration and braking intensively consumes energy and therefore fuel. So unnecessary braking and acceleration can be avoided. Using a constant speed as much as possible reduces the loss of energy and fuel consumption. Maintaining a constant speed can reduce fuel consumption by different percentage (from 7.6 to 35.8%) depending on the type of vehicle and traffic situation according to the work of Orfila, Pierre, and Andrieu [134].This can be explained by the fact that most vehicles requires only 5 kW (about 7 hp DIN) of power in order to maintain the speed of 50 km / h. Similarly, at a constant speed of 120 km / h, power necessary to maintain the speed is about 25 kW (34 hp). The rest of the engine power (about 90% or more) is used only for speeding or driving at high speed (which is contrary to the Highway Code and principles of eco - driving). Speed control or the ACC (Adaptive Cruise Control) is a useful tool for a balanced ride and maintenance of a constant speed, especially on the highway or unladen road. If the vehicle is moving up then down, reducing speed in hills and letting it rising in slopes could be a better mean to reduce energy wastes, compared to stay at a constant speed, since potential energy is adding to kinetic energy (Orfila, Pierre, and Andrieu [134],Deljanin, Berkovic, and Deljanin [45]).

7.4 Eco-driving: least possible regime of the engine speed

Engine speed (RPM) influences rather directly fuel consumption. Every small reduction of engine speed means that less fuel is required. To conserve fuel during deceleration or stopping, the process to execute the proper eco-driving technic is to slow down smoothly by releasing the accelerator pedal, leaving the same gear, and if it is not possible then adjust the speed at which the RPM reduces with the degree of transmission in the neutral position. Diesel and Gasoline vehicles built since 1990 are usually equipped with electronic injection that cuts off fuel to the engine when slowing down (released accelerator pedal downhill, is what is commonly called engine braking). The advantage is that the engine brake can be used to save fuel: for example, by releasing the accelerator in time when the vehicle comes at traffic lights. This also results in reducing the use of brakes and reducing maintenance costs. Engine brake is not only a positive effect on fuel consumption, but also to reduce greenhouse gas emissions, traffic safety, traffic flow and improve passenger comfort.

7.5 Eco-driving: rule to anticipate traffic

It is certainly possible to bring the vehicle to the desired speed but it’s also important to predict the environmental conditions that influence the flow of traffic with the aim to avoid unnecessary braking and acceleration. Some examples are:

- when approaching a traffic light;
- when approaching cyclists or agricultural vehicles (common on rural roads);
- on motorways.

Focusing attention to the conditions that occur in traffic flow leads to better and more effective response to the situation before it happens, and that is all based on the benefits provided by the cruise speed control. Depending on traffic conditions, it is not possible to drive as fast as it's allowed by the speed limit, but by adjusting the speed it is possible to save fuel according to research of Deljanin, Berkovic, and Deljanin [45].

7.6 Eco-driving: rule of vehicle maintenance

Tire pressure plays a vital role in the economy of fuel, driving vehicles whose tires have insufficient pressure leads not only to warming up tires, but creates an excessive fuel consumption up to 8%. It is then very important to save fuel by efficient monitoring of pressure in pneumatics (new vehicles are equipped with TPMS). Tire pressure is recommended by the manufacturer but confort is another part of the manufacturer choice. Indeed, the comfort of the vehicle is mainly based on the depreciation of road damps, with the tires and suspension playing an important role at this level. When the tire pressure increases, the feel of damp on roads is increased.

All tires are marked with data indicating the minimum pressure in them which allow optimum movement point. Most sellers of tires and car manufacturers recommend the use of standard pressure 2.1-2.3 bar. This pressure is a compromise between comfort and safety. Unfortunately, unlike its purposes, this practice does not take into account the life of the tire and fuel consumption over the long term. Some eco-drivers may be tempted to increase the pressure outside the acceptable limits of the tire which can lead to less fuel consumption. However, because of the uncertainty in the quality of the tire, it is necessary to avoid too much inflation which can lead to an explosion of the tire. Green tires (Michelin, for example), will save about 5% fuel or more (it depends primarily on the type of vehicle). The higher resistance and lower rolling index will provide greater fuel efficiency. These tires are generally more expensive, but in the end, with regard to fuel consumption, become economically viable very fast. Tires with low rolling resistance (LRR) are aimed at the highest possible efficiency and CO_2

reduction. Their use can reduce fuel consumption by 1.5 to 4.5%. Tires with low rolling resistance enable the reduction of CO_2 by 4 g/km (Coelho et al. [39]).

Lastly, the motor maintenance is of importance to reduce energy consumptions (filters, oil replacement).

7.7 Four variants of eco-driving feedback technology tailored to four driver segments

Feedbacks are an important aspect in eco-driving as well as training. Schall, Wolf, and Mohnen [147] research were to analyze the existence and persistence of the effects of economic incentives and theoretical training for eco-driving on fuel consumption. The driver segmentation is important to demonstrate the benefits and the difference between each type of drivers (Diekstra and Kroon [53]; fig.29).

Driver segment 1, the egoistic learner:

The egoistic learner will be attracted and influenced by feedback technology. This technology shows his/her personal gains in terms of money saved and that displays his/her progress and performance of eco-driving behaviors relative to own past performance.

Driver segment 2, the altruistic learner:

The altruistic learner will be influenced and attracted by feedback technology that shows self and other different gains in terms of environmental benefits that displays her/his progress and performance of behaviors of eco-driving relative to his/her own relative performance.

Driver segment 3, the egoistic performer:

The egoistic performer will be influenced and attracted by feedback technology that shows her/his personal gains in terms of money saved, and that display his/her progress and performance of eco-driving behavior relative to others past performance.

Driver segment 4: the altruistic performer:

Altruistic performer will be attracted and influenced by feedback technology, this technology shows self and other drivers gains in terms of environmental benefits and that display his/her progress and performance of eco-driving behaviors relative to past performance of others also demonstrated in the work of Brouwer et al. [30].

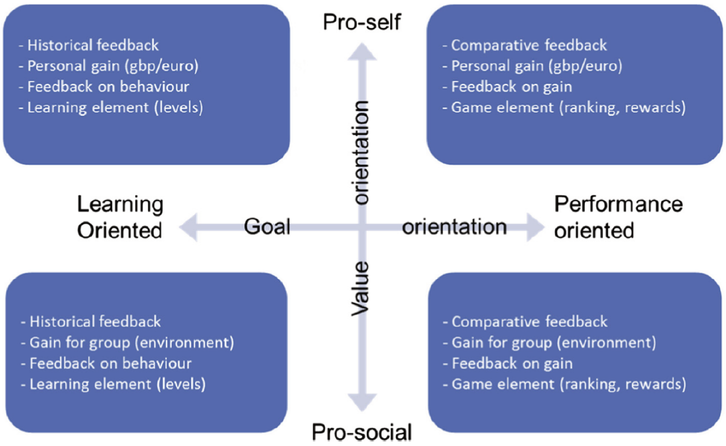


Figure 29: *Feedback strategies adapted to the different driver segments [30]*

In order to instigate a behavior change providing feedback is a powerful tool. There are possibilities to increase the effectiveness of feedback by tailoring the feedback to a person. Stillwater and Kurani [161] found an example that feedback was the reason behind the decrement of fuel consumption, these decrements were dependent on feedback. Different drivers seem to be attracted to different types of information and feedback. Presenting the same feedback all drivers may be inferior in comparison to presenting personalized feedback. A driver segmentation based on driver‘s behaviour (aggressive, defensive, eco-driver) is presented in this thesis. In hope to gather information and use all relevant data of different systems would make a difference in conducting a project in construction/maintenance/rehabilitation of roads. Defining different sign speeds in accordance to previous and this research will have significant impact on environmental and energy use of roads.

PART II

Road eco-potentiality assessment by experimentation, simulation and optimization

Thesis general methodology

The general objective of this thesis work is to assess road eco-potentiality and to bring practical solutions in order to improve it. Road eco-potentiality is the eco-driving potential offered by a road, depending on its design and its management.

More precisely in this objective, this thesis proposes a methodology to optimize speed-sectioning in order to save fuel, speed-sectioning being the layout of successive allowed speed along a given road route. The main lever is to allow eco-drivers to eco-drive. Then, the methodology is called eco-potentiality because its goal is to give the potentiality for each driver to eco-drive.

This methodology relies on the ascertainment that drivers are rather often surprised on their journeys by speed-signs imposing them to brake. In such cases, speed-signs could require high reduction in speed, or could be seen very tardily/late because being placed in a sharp turn, or they could be placed in strong downhill slopes, a situation that limits natural deceleration rate of vehicles.

Combined situation with high reduction speed in a turn or slopes are particularly penalizing, and are not such an exceptional case, as seen in the bibliographical part with an analysis decomposed in a Driver-Vehicle-Environment framework/model. This ascertainment on speed-sectioning is schematized by the "initial situation" part of the methodology diagram, on fig. 30.

For all of these issues about speed-signs (turn, slope, high speed reduction), a common solution may consist on modifying the position of the speed-sign along the route: upstream of the sharp turn, upstream of the slope.

In order to assess the hypothesis of speed-sectioning misplacement, and to evaluate the effectiveness of the sign displacement solution, I have choose to organize my thesis methodology in four steps, schematized on fig. 30.

The first step is the initial situation analysis by means of different criteria aiming to evaluate the level of the inadequacy of the speed-sectioning regarding to slopes, turns and vehicle dynamics (i.e : the level of "misplacement of speed-sign").

Second step is an experimental investigation to identify potentially misplaced speed signs and to record data that will be used in the following simulation and optimization parts. An equipped vehicle is used to get real-data on the initial situation as speed profile, slope, radius of curvature and visibility distances. This experimental part is consolidated with the application criteria presented in the first step.

As a third step, a traffic-flow simulation has been used to evaluate the impact of misplaced speed-sign facing several type of drivers, with more or less eco-driving willing behaviors. Micro-traffic simulation is done in the Trafficware environment, as to evaluate potential gains of the chosen management solution: sign displacement.

The final step is to determine the proper optimization process by using all the elements from the previous steps. As it can be seen in detail in fig. 30, the SUMO micro-traffic model has been used in order to take into account a realistic traffic over digitized real road infrastructures. Here the goal is to evaluate the overall impact of the speed management solution on vehicle consumptions and to be able to extend this evaluation over a whole road network.

Different elements are presented and used in the methodology diagram (Fig. 30). For example in the experimentation part different types of blocks are defined. The white blocks represents all fixed unchangeable factors i.e. equipped vehicle, source code etc. The orange blocks are different variables which can effect the structure on all four levels. The rose blocks represent factors that can be variables and optimized blocks by other elements in the defined structure. Green blocks are representative as they have already proved their value on other already optimized projects in different fields of transportation engineering.

The four following chapters describes the initial situation analysis with the associated criteria of misplacing detection and the three steps of experiments, evaluation and optimization. So, the first chapter proposes simple criteria to analyze a road network for a road manager, within the framework of speed-sectioning assessment for an isolated vehicle. The next chapters describes the various experiments carried out in France and in Bosnia-Herzegovina with equipped vehicles. The extension of results for one car to a full traffic is presented in the third chapter. The mean of this extension is micro-simulation inside the Trafficware framework. The important step of calibration is fully described. The core of the fourth chapter is the optimization methodology. As Trafficware was not appropriate for this purpose, the implementation was carried out by using Sumo and Python. An example of optimization is presented as a proof of concept.

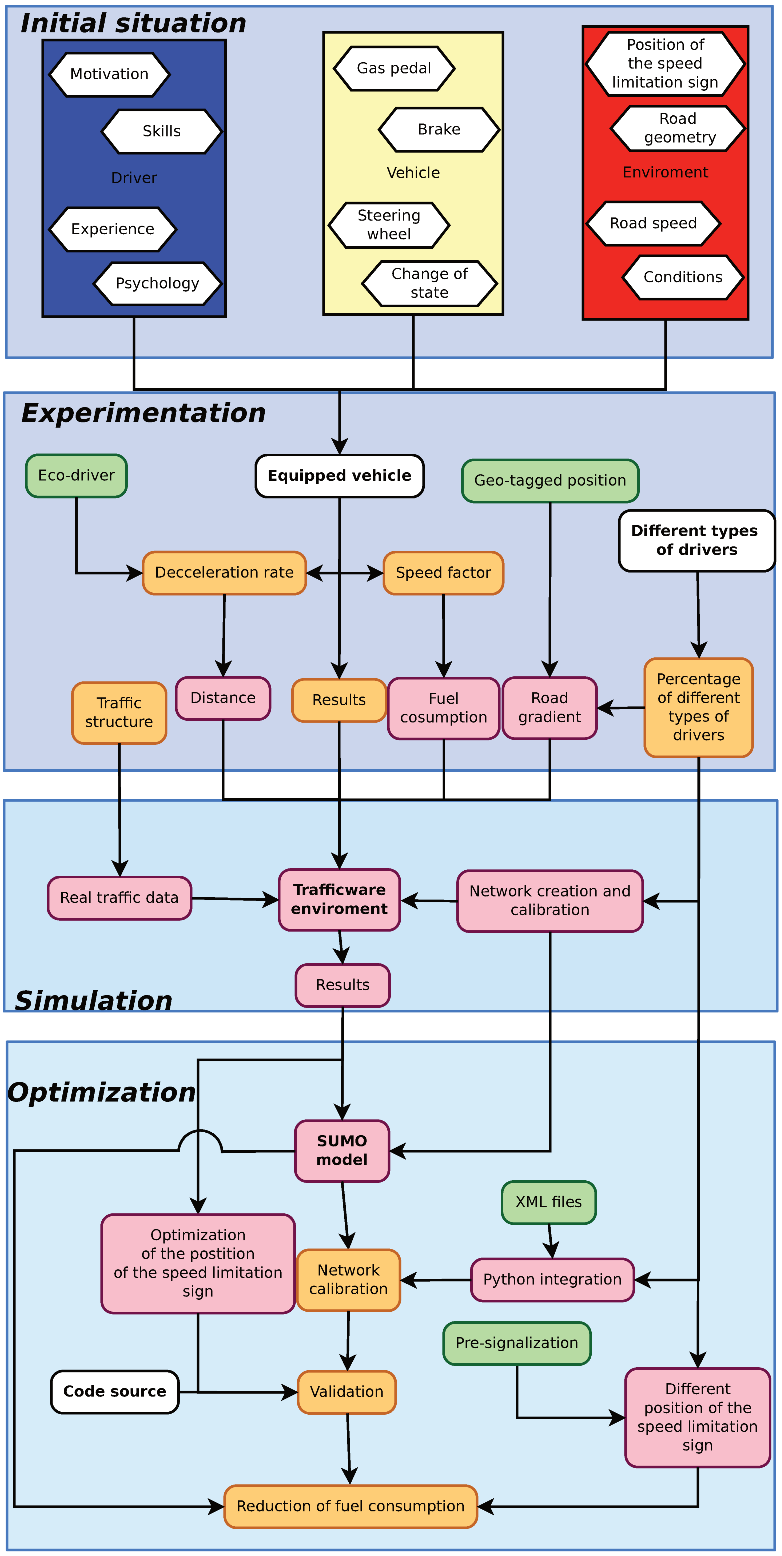


Figure 30: *Methodology on how to improve eco-potentiality of road infrastructures*

CHAPTER 1

ROAD SPEED-SECTIONING: QUALITY STATEMENT AND CRITERIA DEFINITION

1.1 Method for speed-sectioning quality statement

Regarding environmental and economical issues, there are some locations on the road that prevent eco-driving. These locations are considered here, for which drivers apprehend a speed-sectioning change without having the necessary distance to decelerate. Then they have to hard brake which is contrary to eco-drive, since anticipation could have led to lower upstream speed and energy consumption.

Only speed-sectioning resulting of a road sign presence will be retain in this thesis work, among the variety of speed-sectioning cases as roundabouts, crossings, speed bumps, that will be the opportunities of thesis perspectives.

This type of locations preventing eco-driving will be called MSP for Misplaced Speed-sectioning Point locations in the following. Similarly the SPD position, which stands for Starting Point of Deceleration, is defined by the associated position where the driver has apprehended the speed sign and has applied an effective command to decelerate, i.e releasing the gas pedal.

In a more rigorous way, there is a delay between the perception of the sign and the decelerating manoeuvre, linked to the reaction time, which is of the order of one or two seconds [1]. Distance traveled during this reaction time is denoted d_{reac} and it accounts indirectly in SPD position.

Fig. 31 illustrates this concept of MSP/SPD. A transition between two constant-speed sections of a route is presented. The sectioning is represented by the vertical solid line at the MSP abscissa. Before this limit, the authorized speed is $\mathrm{V}_{\mathrm{SPD}}$. After that, it becomes $\mathrm{V}_{\mathrm{MSP}}$.

Cyan and green curves both represent the trajectories of an eco-driver, who releases the gas pedal as soon as he sees the speed limit sign, thus initiating its decel-

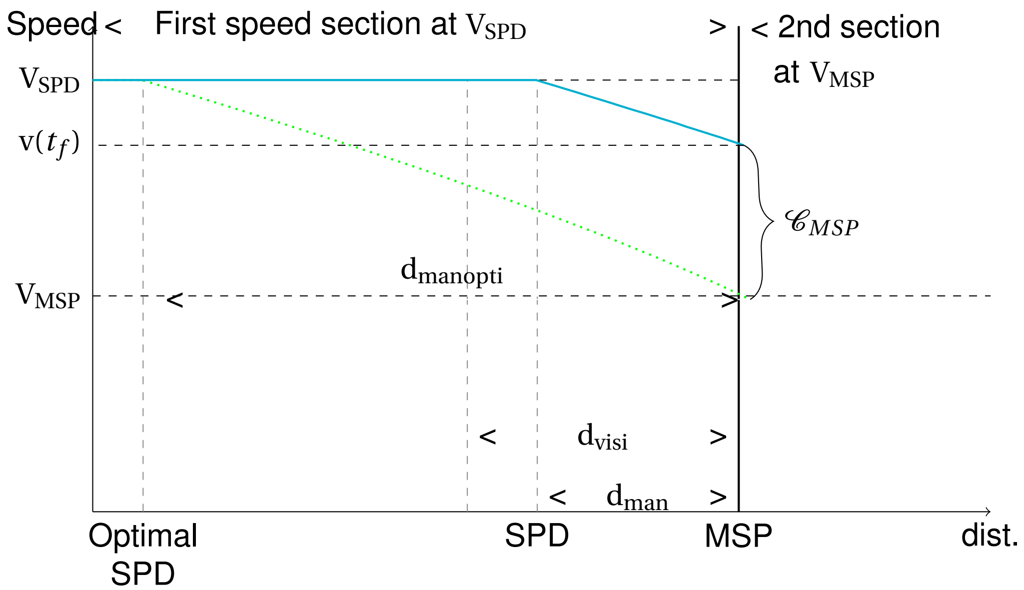


Figure 31: *Ecodriving trajectories through a well- (dotted green) and poorly- (cyan) designed speed-sectioning*

erating maneuver at the SPD point. In the green curve case the speed sign is ideally placed since the vehicle reaches it at the exact V_{MSP} regulation speed. It is the configuration aimed by the optimization work of this thesis. On the contrary, in the cyan curve case, the driver, although being an eco-driver, has to apply mechanical braking while reaching the MSP point.

1.2 Simple criterion for easy to use speed-sectioning assessment

If it is relatively simple to understand that fig. 31 settles two situations, one allowing eco-driving and one implying fuel waste by braking, it is more difficult for a road manager to know in which of these two categories are the speed-signs of his network.

The aim of this section is to provide him/her a simple criterion which will quantify how much eco-driving friendly are his/her speed-sign, without discerning the type or size of concerned vehicles.

Technically, the criterion is based on inconsistency evaluation between speed-sectioning and other most influencing parameters: road longitudinal profile, drivers perception of signs and general vehicle dynamics.

On a given route, to detect if a speed sign is not consistent with eco-driving, vehicles dynamical situations are evaluated at the MSP and SPD predefined points (supposed to be misplaced). Between these two points the dissipated energy by rolling without braking nor accelerating, called natural deceleration, is compared with the energy to be dissipated to reach the regulatory speed at MSP, V_{MSP}, from the speed of the vehicle at SPD, V_{SPD}. In the following, we suppose that the difference in mechanical energy between the SPD and MSP points is positive which is a consistent assumption in the case of MSP.

The energy to be dissipated for a given vehicle of mass m between the SPD and MSP points is the difference in mechanical energy:

$$\Delta E = \Delta Ek + \Delta Ep \tag{17}$$

Kinetic and potential energies to be dissipated are

$$\Delta Ek = \frac{1}{2} \cdot m \cdot (V_{SPD}^2 - V_{MSP}^2) \tag{18}$$

and

$$\Delta Ep = m \cdot g \cdot (h_{SPD} - h_{MSP}) \tag{19}$$

with h_{SPD} and h_{MSP} the altitudes at SPD and MSP points.

This difference in mechanical energy should have to be compensated by dissipating forces without mechanical braking as it will be detailed in the next section, but intrinsically, its amount is already a criterion since it is fixing the level of dissipating forces that will have to be worked out.

This first level criterion aims to be vehicle-independent for a convenient use by road managers. However dissipation forces are car-specific. They derive mainly from rolling and air resistance and are then linked to the weight, mg, directly for the rolling resistance and indirectly for the aerodynamic drag. Moreover by noticing that this energy is an integration of power along the maneuver distance d_{man}, a dimensionless criterion is proposed χ_{EASM} (EASM = Energy Alert Speed Management):

$$\chi_{EASM} = \frac{\Delta E}{m \cdot g \cdot \log_{10} \cdot (d_{man})} \tag{20}$$

Where d_{man} is the driver maneuvering distance, which separates SPD and MSP

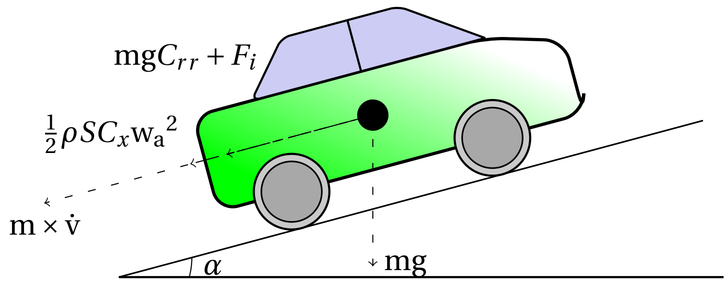


Figure 32: *Vehicle model*

points.

This distance is active through a logarithm function because an important part of the dissipation is the aerodynamic drag which decreases as the vehicle decelerates along the maneuver distance. This diminishing return of the distance is mathematically best fitted by the logarithm function. We assume that $log_{10}(\mathrm{d_{man}}) > 0$.

This criterion summarizes thus the energy interpretation. By developing this equation, the criterion is independent of vehicle parameters:

$$\chi_{\mathrm{EASM}} = \frac{1}{2}\frac{\mathrm{V_{SPD}^2 - V_{MSP}^2}}{\mathrm{g\log_{10}(d_{man})}} + \frac{\mathrm{h_{SPD} - h_{MSP}}}{\mathrm{\log_{10}(d_{man})}} \tag{21}$$

Road managers have therefore a convenient criterion to evaluate rapidly the speed transitions of their networks and to detect easily transitions where χ_{EASM} is important and for which eco-driving is consequently not favored. After having detected these transitions they could move the speed limiting sign in a nearby site with a better eco-driving potential i.e. a better visibility of the sign or without a road slope. Validation of the new sign position is done by calculation of the criterion at this new position.

1.3 Enhanced energy criterion to evaluate route speed-sectioning

The simple criterion χ_{EASM} defined in the previous section is improved here towards an energy cost denoted $\mathscr{C}_{MSP}$ which takes into account more explicitly vehicle dissipating forces. This cost $\mathscr{C}_{MSP}$ associated to the misplaced speed sign will be determined in this section in terms of energy for each single car, before being determined for a traffic on a road in a dedicated chapter by using traffic simulation.

As for the first step criterion, naturals deceleration from V_{SPD} to V_{MSP} is considered.

The vehicle is modeled by a point model to which are applied the following forces (Fig. 32):

- the aerodynamic drag: $\frac{1}{2}\rho S C_x {w_a}^2$, with ρ the air density, S the front vehicle area, C_x the drag forces coefficient, w_a the apparent wind (temporary assumed to be equal to the speed v)
- rolling resistance: mgC_{rr}, with m the vehicle mass, g the acceleration of gravity, C_{rr} the coefficient of rolling resistance,
- internal forces of the vehicle : F_i which sums frictions and motor resistance, according to the engaged gear and auxiliaries components,
- the gravity forces: $mg\sin(\alpha_r)$, with α_r the angle of the slope in radian.

The following equation is obtained

$$\dot{v} = -(\frac{1}{2}\rho C_x S_x v^2 + (mg(C_{rr} + \sin(\alpha)) + F_i))/m \tag{22}$$

And so:

$$\dot{v} = av^2 + c \tag{23}$$

with $a = -(\frac{1}{2}\rho C_x S_x)/m$ and $c = -g(C_{rr} + \sin(\alpha)) - F_i/m$

The solution of this differential equation provides the trajectory, i.e. the position of the vehicle and its speed as a function of time.

In the case of the simple, but usual, configuration without variation in slope, these calculations can be done analytically. It is then possible to calculate very quickly the energy cost of a misplaced speed sign. For more complex spatial configurations digital computations are needed.

The analytical solution of the ordinary differential equation 23 is:

$$v(t) = -B\tan(A(t+K)) \tag{24}$$

with $B = \sqrt{c/a}$, $A = \sqrt{ac}$, $K = -\arctan(V_{SPD}/B)/A$.

The analytical calculation of the travelled position x as a function of time:

$$x(t) = E \times \left(\log(\cos(A \times (t+K))) - \log(\cos(A \times K))\right) \tag{25}$$

with $E = 1/|a|$.

By setting the boundary condition $\mathrm{x}(t) = \mathrm{d_{man}}$ and by inverting Equation 25, it yields that the time t_f taken by the vehicle to travel the distance $\mathrm{d_{man}}$ is given by the following equation.

$$t_f = \arccos\left(\mathrm{e}^{\mathrm{d_{man}}/E} \times \cos(AK)\right) / A - K \tag{26}$$

The cost of the misplaced speed sign $\mathscr{C}_{MSP}$ is as follows:

$$\mathscr{C}_{MSP} = \frac{1}{2}\mathrm{m}\left(\mathrm{v}^2(t_f) - \mathrm{V}_{\mathrm{MSP}}^2\right) \tag{27}$$

$\mathscr{C}_{MSP}$ represents the energy to be dissipated by the brake system. It is the difference between the kinetic energy of the speed $\mathrm{v}(t_f)$ and that of the target speed $\mathrm{V_{MSP}}$. $\mathrm{v}(t_f)$ is the speed at which the vehicle arrives at MSP if the driver releases the gas pedal and does not break mechanically when he sees the speed sign ($\mathrm{v}(t_f)$ displayed on fig. 31).

Then the road managers could move the speed limiting sign. In order to help him/her treat this MSP, the distance travelled by a vehicle from $\mathrm{V_{SPD}}$ to $\mathrm{V_{MSP}}$ without applying tractive force nor mechanically braking is computed analytically in the following and is noted, $\mathrm{d_{manopti}}$. The starting point of this distance is called Optimal SPD. Both are presented on fig. 31 where the dotted green curve is the ideal trajectory of an eco-driver. By using warning sign or speed limiting sign, the road manager has to encourage drivers to follow this trajectory.

First, the time t_d required for this deceleration is computed by inverting Equation 24 with $\mathrm{v}(t) = \mathrm{V_{MSP}}$:

$$t_d = \arctan(-\mathrm{V_{MSP}}/B) / A - K \tag{28}$$

And the solution provided by Equation 24 is presented as:

$$\mathrm{d_{manopti}} = \mathrm{x}(t_d) \tag{29}$$

$\mathrm{d_{manopti}}$ is the optimal distance from the MSP where the eco-driver has to start his/her deceleration as displayed on fig. 31. It gives directly the Optimal Starting Point of Deceleration (DSP) and furthermore the optimal position of panel knowing the visibility distance.

1.4 Discussion

We affirm that the criterion, χ_{EASM} is practical for the manager but the calculation of this criterion requires knowing the manoeuvre distance. In this work, we experimentally evaluated this one. It is the core of the next chapter. This experimentally procedure may be too complicated for the manager of a large road network. This step can be avoided by using road design standards and rule-book on guidance for design, building, maintenance and supervision of the roads of each country as i.e [159] and [142].

From that, the distance L_z to decrease the speed to the speed limiting sign is calculated according to:

$$L_z = (V_p^2 - V_k^2)/(26 \times (a_z + 0.1 \times s_i)) \tag{30}$$

where V_p represents the initial speed and V_k is the final speed, a_z (m/s^2) is the natural deceleration value linked to usual friction coefficients, and s_i is the level of the longitudinal slope.

Assuming that this distance is verified, the manager has all the data to calculate χ_{EASM} without conducting the experimental part.

These results are valid for one vehicle driven by an eco-driver. The road managers benefits both to the knowledge of energy waste implied by a given speed-sign (cost) and to the knowledge of the optimized position which minimize this cost.

In order to extent this punctual result to the traffic, different types of vehicle, drivers and the interactions between them (car-following models) have to be taken into account. Previous equations can be applied to different vehicles, but to take into account different drivers and their interactions, a traffic model is required. It will be the core of a following dedicated chapter, but before that, experiments are presented in order to support this theoretical analysis.

CHAPTER 2

EXPERIMENTAL EVALUATION OF A ROUTE SPEED SECTIONING

Thanks to the co-direction of my thesis work, by the IFSTTAR institute (France) and the Sarajevo University (Bosnia-Herzegovina), and in order to emphasis road network differences between the two countries, experiments have been done on two road routes, in Bosnia-Herzegovina and France.

The aim of these experiments is to verify the consistency between vehicle dynamics, road longitudinal profile and speed sectioning, in term of eco-driving capabilities. Considering the amount of needed mechanical braking, of perception distance, these experiments are first a way to evaluate the pertinence of the two developed criteria and results have been published in that sense (Coiret, Vandanjon, and Cuervo–Tuero [40] and Deljanin et al. [51]). Secondly, they are a mean to acquire data for the simulation and optimization steps of the next chapters.

2.1 Experimental setup

Both test campaigns consisted of :

- browse the road network to identify locations where a speed sectioning change seems to impede eco-driving considering vehicle dynamics and road geometry. In the usual case such a location is the emplacement of a speed limiting sign placed in a strong descent or a sharp turn, for which drivers have to apply mechanical braking, instead of simply decelerating;

- run through these locations with a test vehicle, while recording vehicle route with a NMEA GNSS (acquisition frequency of 1 Hertz; punctual imprecision smoothed by signal interpolation);

- test driver is instructed to comply with the speed limits and to simply decelerate as soon as he/she realizes that a speed limit informs him/her that he/she has to decelerate. He/She is instructed to maintain speed if he/she reaches the speed limit before reaching the speed sign and to brake mechanically only if he/she reaches the speed sign with an excessive speed;

- two geo-tagged pictures of the scene are captured from a high resolution camera: one when the driver is perceiving the speed limiting sign, one when he/she reaches effectively this sign. Geo-tagging is realized on a linux-based laptop with the help of a time correlation procedure between the GNSS device and the image capture device, both of them being time-synchronized by the computer;

- complementary, continuous recordings are done: longitudinal wind speed by a roof anemometer, Bus-Can instantaneous fuel consumption, central inertia unit angles, engine throttle angle.

Experiments are intended to detect and evaluate the energetic cost of a speed sectioning sign, which is then computed according to equation 27. However, this equation is based on equation 23, including vehicle parameter: a and c. These parameters are identified by using dedicated experiments. When coasting, the observed deceleration is compared with the deceleration computed with equation 23. The parameters are optimized so that the computed deceleration is as close as possible to the measured deceleration.

2.2 First experimentation in France

As detailed in Coiret, Vandanjon, and Cuervo–Tuero [40], experiments have been done while crossing the French small village "La Brossière". The village is represented in grey on the map (Fig. 33) and the blue elevation graph gives first information on the fact that this village is in a "bowl" situation: both of the two villages entrances present rather high downhill slopes. The yellow dot on the blue route represents the village entrance.

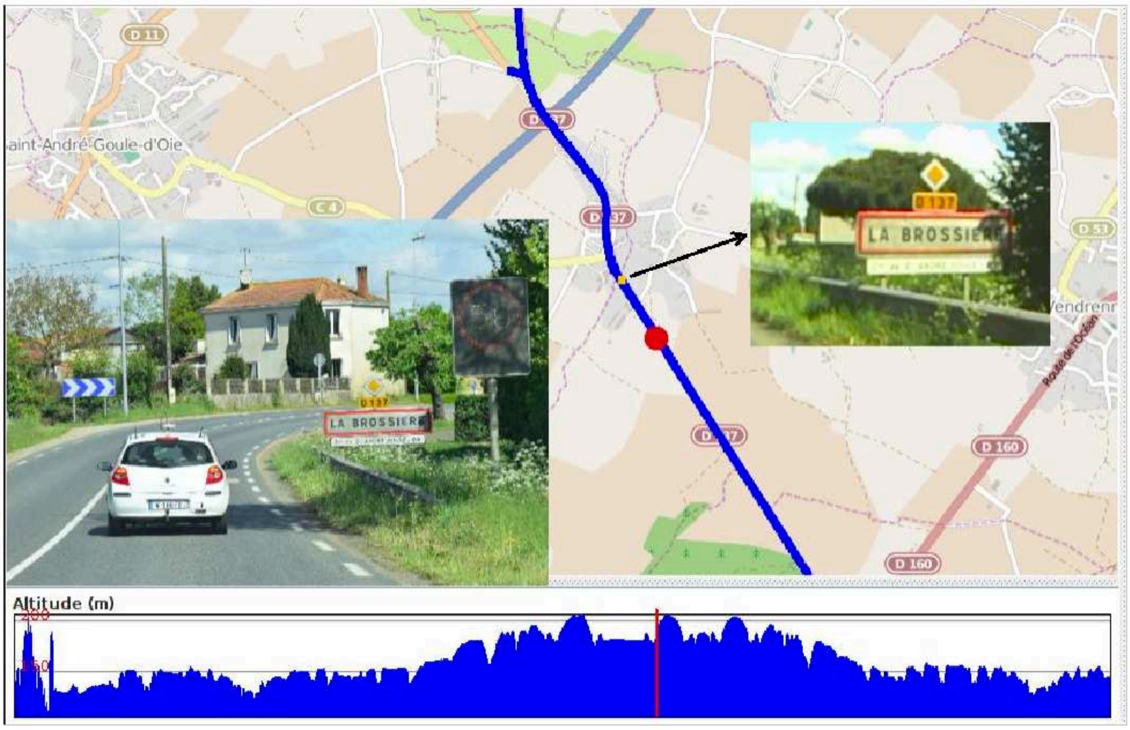


Figure 33: *Experimental car reaching the limiting speed sign at "La Brossiere"*

For this situation case, positions of viewing and passing the road sign are considered:

- distance between the two positions is 300 meters;
- respective altitudes are 189.7 m and 178.7 m (difference of 11 meters);
- speed has to be reduced to 50 km/h from 90 km/h (reduction of 11.11 m/s).

The test vehicle is a Renault Clio III, which weighs 1064 kg, has an average consumption of 4.6 l/100km, an aerodynamic frontal surface of 2.06 m^2 and a C_x drag coefficient of 0.30.

This case is then associated to a high potential energy equal to 49.9% of the kinetic energy, both energy having to be cut down for decelerating appropriately. Alert criterion is then unsurprisingly high (given by equation 20 and equation 21).

As a first experimental case, the energetic cost has been firstly investigated (cost criterion): balance between potential and kinetic energy and speed to reach lead to a mechanical braking need of 246.9 kJ. With a road sign placed 700 m upstream, this requirement would be lowered to 139 kJ.

Considering standard daily traffic data (approximately 5500 veh/day) mainly light vehicles, theses two braking energies can be converted in fuel equivalent costs of respectively 44.7 and 30.7 liters, respectively, per day. Practically, in this case, the displacement of a simple road sign could lead to a daily gain of 14 liters of fuel and roughly 34 kg CO_2 emissions, without penalizing the primary safety function because the low-speed section is stretched over the high-speed section.

2.3 Experiments conducted in Bosnia-Herzegovina

Experiments in Bosnie-Herzegovina have been carried out on the roads M-5 (Mostarsko raskrsce-Kiseljak-Busovaca) and M-18 (Vogosca-Olovo-Stupari). Out of the 140 km of the tested roads, 9 speed limiting signs have been found to be problematic in the sense of eco-driving capabilities.

In these experiments a Peugeot 308 has been used. It has an average fuel consumption of 6.1 l/100km, an aerodynamical frontal surface of 2.19 m^2 and a C_x-drag coefficient of 0.32. The Peugeot and Renault vehicles are very similar which is a advantage to state that the two experimental cases are comparable.

Two acquisition systems were carried out: the same light acquisition system that has been use for the French experiment and another more complex system.

This last complex system was based on a raspberry architecture, with several sensors linked to it:

- a GNSS/Glonass/Sbas Receiver RTK (NV08C -RTK GNSS) and a 3G Modem to receive the corrections from a fixed basis. This localization system includes accelerometers;
- an anemometer (miniair6-64).

This main system delivers speed, altitude, apparent wind which are the inputs of the equation of E_b. Then, the energetic cost of the panel is computed.

However, we have not been able to use the RTK functionality of the GNSS during the experiments, due to lack of a good 3G connectivity. Wind measurement have nor

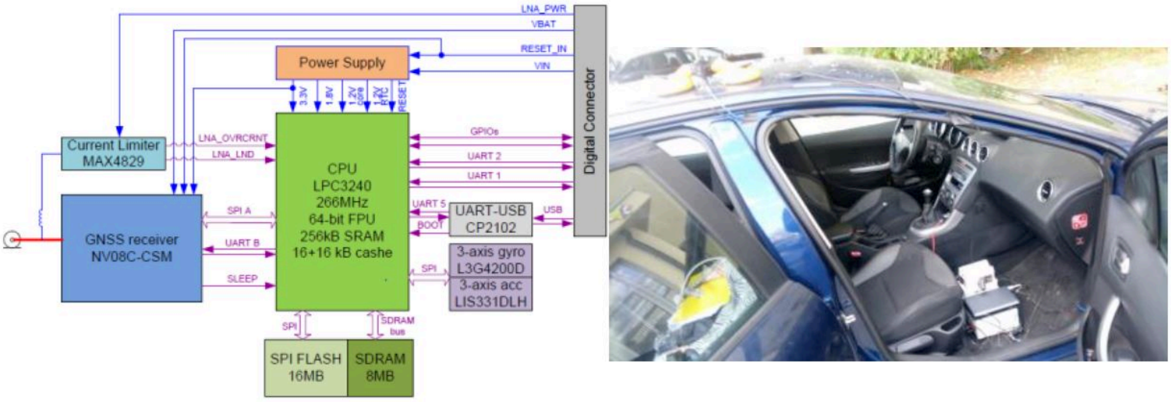


Figure 34: *Instrumentation schema and in-car layout*

been much profitable since wind was relatively small compare to the vehicle speed and its influence has been found to be very low.

With this instrumented car, different roads of B&H displayed on fig. 35 were analyzed.

Suspected "negative" example of a sign layout has been found at the exit of the village "Kobiljača",on the R442 ; M-5 and in the south-north direction. At this point drivers have to decelerate from 80 km/h to 40 km/h without having a sufficient maneuver distance of the speed limiting sign, and this leads the driver to brake mechanically.

Here the constraint is the curve which limit the sign visibility, on contrary to the French experimental case, for which a descent was limiting the deceleration capability. The road sign has probably been implemented here urgently to protect nearby population, without considering drivers visibility on it too much; the design is nevertheless sufficient to ensure road safety, but insufficient to allow eco-driving.

For this situation case, just after a turn, positions of viewing and passing the road sign are considered:

- distance between the two positions is of 50 meters;
- respective altitudes are 625 m and 629 m (difference of 4 meters);
- speed has to be reduced from 80 km/h to 40 km/h (reduction of 11.11 m/s).

This case is then associated to a low potential energy, a high kinetic energy and a short maneuver distance. Alert criterion is then unsurprisingly high (given by equation 20 and equation 21).

Figure 35: *Roads analysed - source google maps a) M-18 (Vogosca-Olovo-Stupari); b) M-5 (Mostarsko raskrsce-Kiseljak-Busovaca)*

Fig. 36 presents the apparent wind (Wspeed), the speed and the acceleration (Speed, Acc) of the vehicle and the longitudinal profile of the road (Alt) during the acquisition duration. The vertical bar at 4 seconds corresponds to the instant when the pilot sees the speed limiting sign. It can be clearly observed that the driver is surprised by the sign: he/she has to brake almost immediately after seeing the panel (the acceleration curve fell just after the vertical bar).

With these data, the energetic cost of the panel is computed with the $\mathscr{C}_{MSP}$ criterion. Its value is of 140 kJ, less than the 247kJ value of the French experimental case, but the present situation is much variable, with a visibility distance which is short (50 meters) but that could even be shorter in case of driver inattention (and thus a much higher energetic cost).

The results found confirm the interest of the method. However, there is a difference with the French case. While in France, it was easy to find signs that involved disk braking. This type of situation is less frequent in Bosnia (only 9 problematic panels on 140 km). This difference can be explained by difference in legislation, in traffic, in geography.

The speed limitation on national highways in France was 90 km/h and on some

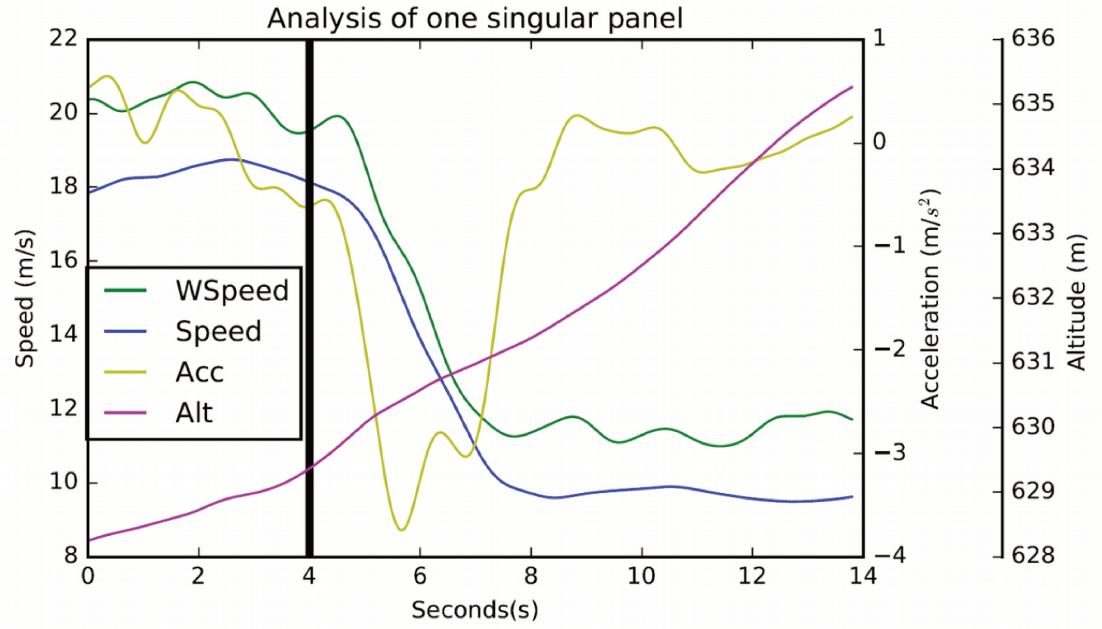


Figure 36: *Measurements from the test vehicle: exit of the "Kobiljača" village*

roads 110 km/h when the experiments were carried out (in 2017). In 2018, this regulation changed. In Bosnia-Herzegovina the roads are limited to 80 km/h on the most parts of the national road network. Moreover, the city/village entrances are not properly marked in Bosnia-Herzegovina and the speed limitations at theses entrances are not unique: 50 or 60km/h in the different villages or cities. In France those problems are not even posed and the legislation strictly defines the entrance in agglomeration is 50 km/h. These facts imply the difference in speed differentiation are not the same: 40-60 km/h in France and 30-40 km/h in Bosnia-Herezgovina.

Another interesting point of view is the traffic: this is comparable on one point where the French network of roads represents approximately 1 million km on 40 millions vehicles this represents 40 veh/km and the Bosnia-Herzegovina road networks represents approximately 24.796 km on 1 million vehicles on the year 2018, from the statistic department of vehicles of Bosnia-Herzegovina; this represents also 40 veh/km. This rough comparison induces a similar traffic in Bosnia-Herzegovina and in France. As a consequence, the operating speeds are similar in both countries.

One of the important factors is that the mountainous terrain of Bosnia-Herzegovina constrains the drivers operating speeds.

2.4 Complementary experimental phase

In this part, complementary experimental investigations have been worked out in order to taken into account various road geometries which can impede eco-driving. For convenience, French road locations have been used, in complement to the previous "La Brossiere" site.

Moreover, fuel costs related to these French road design have been evaluated for two approaching speed cases: 90 and 80 km/h, because allowed speed in French secondary roads has been lowered from 90 to 80 km/h in 2018. It was then a opportunity to state on the environmental effect of this new regulation, in addition to our investigation field and to the road safety as a primarily aim of this measure.

Investigating the new speed case is not limited to regulation evaluation: approaching speed is a key point of the misplaced signs issue, since the speed reduction to achieve is directly linked to kinetic and dissipative energies.

So, experiments have been renewed at the previous French test location, "La Brossière", and have been strengthened by new experiments with the "VERT" vehicle dedicated to fine localization (Fig. 37; [170]), in three other locations of interest:

- location 1: "La Brossière", long, straight line downhill slope;
- location 2: similar straight line downhill slope, but with a shorter sight distance due to the presence of trees masking the road sign;
- location 3: slope in a short radius curve leading to a very short sight distance;
- location 4: combined slope and curves; leading to a short sight distance.

Respective latitudes and longitudes for the four locations are: (46.828805,-1.154361), (47.126944,-1.422222), (47.132222,-1.422916) and (47.143833,-1.403694).

For each situation, the speed limitation sign is considered to be misplaced in an eco-driving potentiality meaning, at the MSP, position and the position where the test driver begin to slow down is considered as the SPD point.

The previous test procedure has been used again, but with three repetitions for each tested location. Table 1 summarizes the experimental parameters of decelerating phases for 3 repetitions for each of the 4 situations points. These parameters are computed from the GNSS positions of the MSP and SPD points.

Distances are computed from in-plane projections of GNSS positions, while assuming straight vehicle movement and earth spherical form by:

Figure 37: *Vert vehicle*

Table 1: *Experimental data for 4 road sites*

Location	Repetition	Maneuver Duration (s)	Height (m)	Distance (m)	G_{ratio}
Location 1	test 1	14	8.3	297.1	0.028
	test 2	15	9.3	316.7	0.029
	test 3	14	8.4	302.7	0.028
Location 2	test 1	8	4.5	159.6	0.028
	test 2	7	4.3	150.4	0.028
	test 3	8	4.8	169.6	0.028
Location 3	test 1	7	5.5	108.0	0.051
	test 2	6	5.0	98.9	0.051
	test 3	6	5.0	98.8	0.051
Location 4	test 1	6	5.7	113.6	0.050
	test 2	5	4.7	95.0	0.050
	test 3	6	5.6	112.7	0.050

$$Dist = \arccos\left(\sin(\mathrm{lat_{SPD}})\cdot\sin(\mathrm{lat_{MSP}}) + \cos(\mathrm{lat_{SPD}})\cdot\cos(\mathrm{lat_{MSP}})\cdot\cos(\mathrm{lon_{MSP}} - \mathrm{lon_{SPD}})\right)\cdot 6.371\cdot 10^{6}(m) \quad (31)$$

With $\mathrm{lat_{SPD}}$, $\mathrm{lat_{MSP}}$, $\mathrm{lon_{SPD}}$, $\mathrm{lon_{MSP}}$ latitudes and longitudes in radians at SPD and MSP points.

The geometrical ratio G_{ratio} of height over distance between the SPD and MSP points gives first indications about the constraint in speed imposed by the speed sectioning:

- location 1: large sight distance but high altitude lowering, leading to a high geometrical ratio G_{ratio} of 0.028;

- location 2: smaller sight distance but similar slope intensity leading to a the same geometrical ratio G_{ratio};
- location 3: sharp turn leading to a very short sight distance, associated with a 5 meters lowering in altitude and so a very high geometrical ratio G_{ratio} of 0.051;
- location 4: similar turning case as for the location 3 case.

2.5 Experimental results: four sites and two approaching speeds

The developed criterion and cost evaluation will be used to assess the environmental impact of speed sectioning of the four experimental locations. In order to model a full traffic, both a passenger car and a heavy vehicle are considered to travel these locations before being constrained to slow down at the speed of 50km/h required by the road sign, while being alone in a free flow situation.

The passenger car and the heavy vehicle have respectively the following characteristics: mass of 1.539 and 29.333kg ($= \frac{2}{3} \times$ 44.000, mean weight of Heavy Goods Vehicle is assumed to be the two thirds of maximum weight), C_d drag coefficient of 0.32 and 0.65, S aerodynamic frontal surface of 2.25 and 8 m^2, C_{rr} rolling resistance coefficient of 0.01 and 0.0057.

Moreover, both French former and new speed regulations of respectively 90 and 80km/h are taken into account.

Table 2 displays the results for the χ_{EASM} criterion, the $\mathscr{C}_{MSP}$ energy cost, linked to the presence of speed sectioning at the four selected sites, for a passenger car and a heavy vehicle while approaching speeds were 90km/h.

Straight line cases such as location 1 and 2 are leading to criterion of around 12, and fuel over-consumption of around 8.8 ml for passenger cars (pc) and around 215ml for heavy vehicles (hv).

Locations situated in sharp turns, as location 3 and 4 are showing higher criteria of 13 and 14, with mean over-consumption of 10.3 ml for passenger cars and 219 ml for heavy vehicles.

Table 3 gives the criterion, energy cost and over-consumption for approaching speeds of 80km/h, consistent with the new French speed regulation case.

Straight line cases such as location 1 and 2 are leading to criterion of around 9 and 10, and mean fuel over-consumption of 6.1 ml for the passenger car and 159.4ml for the heavy vehicle. These values are smaller than for the former speed regulation case.

Table 2: *Criterion and Cost results for the four sites: 90km/h case*

			$\mathscr{C}_{MSP}$ (kJ)		fuel over-consumption (ml)	
Location	Repetition	χ_{EASM}	pc	hv	pc	hv
Location 1	test 1	12	289	7,477	8.5	219.4
	test 2	13	293	7,675	8.6	225.3
	test 3	12	288	7,481	8.4	219.6
Location 2	test 1	12	309	6,970	9.1	204.6
	test 2	12	311	6,951	9.1	204.0
	test 3	12	308	7,015	9.0	205.9
Location 3	test 1	14	352	7,467	10.3	219.1
	test 2	14	350	7,362	10.3	216.1
	test 3	14	350	7,363	10.3	216.1
Location 4	test 1	13	352	7,500	10.3	220.1
	test 2	14	348	7,293	10.2	214.0
	test 3	13	351	7,476	10.3	219.4

Table 3: *Criterion and Cost results for the four sites: 80km/h case*

			$\mathscr{C}_{MSP}$ (kJ)		fuel over-consumption (ml)	
Location	Repetition	χ_{EASM}	pc	hv	pc	hv
Location 1	test 1	10	202	5,670	5.9	166.4
	test 2	10	207	5,877	6.1	172.5
	test 3	10	201	5,577	5.9	166.6
Location 2	test 1	9	216	5,110	6.3	150.0
	test 2	9	218	5,088	6.4	149.3
	test 3	9	215	5,159	6.3	151.4
Location 3	test 1	10	257	5,586	7.5	163.9
	test 2	10	254	5,479	7.5	160.8
	test 3	10	254	5,478	7.5	160.8
Location 4	test 1	10	257	5,623	7.5	165.9
	test 2	10	252	5,407	7.4	158.7
	test 3	10	256	5,596	7.5	164.2

Locations situated in sharp turns, as location 3 and 4 are showing criteria of 10, with mean over-consumption of 7.5 and 162.2 ml for the car and heavy vehicle, which are again much smaller than the 90km/h speed case over-consumption.

This experiment demonstrate that energy can be saved by allowing eco-driving while informing drivers they have to decelerate in a place enough upstream that mechanical braking could be entirely avoided. Comparison between real speed-sectioning and this optimal situation leads to define energy wastes related to misplaced speed signs (MSP). Considering the French new regulation speed, this over-consumption is of only 6 ml of fuel for a passenger car which can be seen as being very little. It is much more for an heavy vehicle with around 160 ml.

Nevertheless, fuel over-consumption can be seen to be much more sensible if a daily traffic is considered at a given misplaced panel. On the considered roads the mean traffic is around 2000 veh/day, with a 8% proportion of heavy vehicles and 92% of light vehicles.

Fig. 38 summarizes the over-consumption for such a traffic composition at the considered speed sectioning points.

For the two approaching speed cases and for the two main geometrical situations of slopes in straight line (locations 1 and 2) and sharp turns (locations 3 and 4). It can be seen that the new speed regulation case of 80km/h is implying fuel over-consumption, of 36.38 and 39.37 liters a day for respectively the straight slope and sharp turn cases (with standard deviations of 1.44 and 0.46). The former speed regulation case of 90km/h where implying even more fuel over-consumption, of 50.26 and 53.69 liters for the same cases (with standard deviations of 1.15 and 0.46).

These results show that speed sign implantations at the four chosen experimental cases are very poor in terms of energy use.

The high amount of modeled over-consumption should therefore encourage road designers and managers to take into account eco-driving potentialities of infrastructure in their policies.

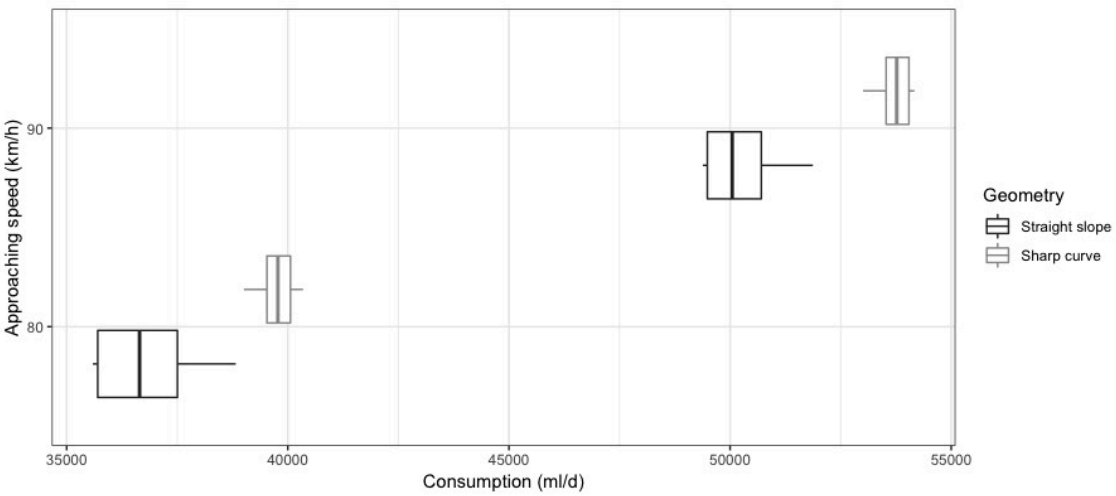


Figure 38: *Daily traffic over-consumption*

Chapter 3

Simulation

This section aims to evaluate the energy cost of the previous detected critical speed-sectioning in the Bosnian experiment. In order to represent the energy impact of the original and modified speed-sectioning we have choose to run traffic flow simulations, with real local traffic data, real road geometry and with realistic vehicles and drivers models.

Synchro Trafficware constitutes the simulation framework. It is based on HCM2010 methodology [26] and its has about one hundred parameters which take into account our experimental conditions on road geometry, traffic structure (vehicles) and driver behaviors. This simulation framework is designed to be flexible enough that we could correctly calibrate the network and vehicle/drivers diversity to match the local real world conditions at a reasonably accurate level.

Synhro Trafficware was chosen because it is used by Professionals. It means that Road managers can carry out our methodology without changing their usual tools. Trafficware is very common in North America and in Bosnia-Herzegovina.

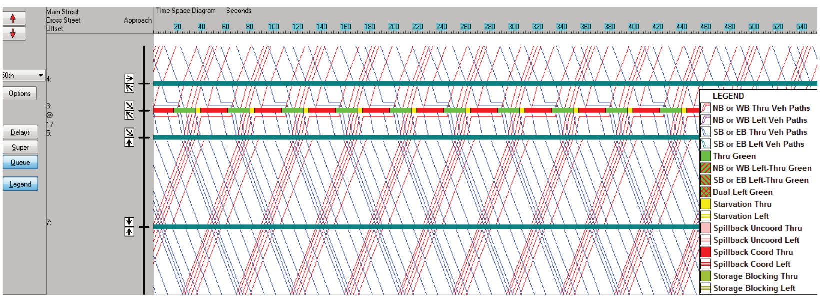


Figure 39: *Time space diagram of the reference point 585 shown on Fig. 42*

Figure 40: *3D view in Trafficware simulation environment*

3.1 Calibration

3.1.1 Basic calibration

The simulation model trafficware is an American/USA simulation model which has default features of American/USA 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.

A time space diagram of one approach on a intersection which is commonly used to number of transportation related problems is displayed on fig. 42. A 3D simulation was also executed in the simulation framework as the real time visualization of the route is possible: it was useful to get a qualitative comparison between experiment and simulation.

3.1.2 Drivers modeling

Modeling the driving conditions is definitely not an exact science. Experiments have shown that speed-sectioning modifications could lower energy consumption for drivers who are following a strict eco-driving strategy: drive at the restricted speed, decelerate as soon as speed limit is perceived, brake only if restricted speed is exceeded.

In real world, driving behaviors are varied in a very complex manner and an evaluation of the energy cost of a speed-sectioning should embrace that variety. However, only 4 types of drivers would be considered in the following, due to modeling complexity feasibility and to the lack of information on the behaviours of drivers in the considered traffic:

- Type 1 (aggressive) where the deceleration rate is 1.4-3m/s^2;
- Type 2 (defensive) where the deceleration rate is 0.7-1m/s^2;
- Type 3 (eco-drivers) where the deceleration rate is 0.3-0.4m/s^2 based on the research of Cantisani, Serrone, and Biagio [34];
- Type 4 (combination of all types (30% of type 1, 40% type 2, 30%type 3)) in accordance to their manoeuvre distance.

Nevertheless, a better knowledge of the traffic structure could have led to a higher number of driver types.

When a driver encounters a change in the speed-sectioning, the situation constitutes an "analyse/action event" with the following parameters:

- entry parameters: initial speed, local slope and turn, visibility;
- action parameters: speed sign detection, starting position of decelerating, braking duration and intensity choices;
- consequences parameters: be at the designed speed before reaching the speed sign or not, necessity of braking or not.

The simulation framework models the driver with a proportional speed law i.e the cruise speed of the driver is proportional to the regulatory speed. Therefore in order to simulate the parameters of the complex defined "analyse/action event" it has been choose to compensate shifts in decelerating positions by a speed factor parameter.

Statistically, speed factor can be used by traffic models to compensate fine real variabilities in driving behaviors, variations in initial speed and deceleration rates compensating variations in instant decision of decelerating and braking.

Values of speed factor and deceleration rates are fixed for the four simulated types of drivers (Table 4).

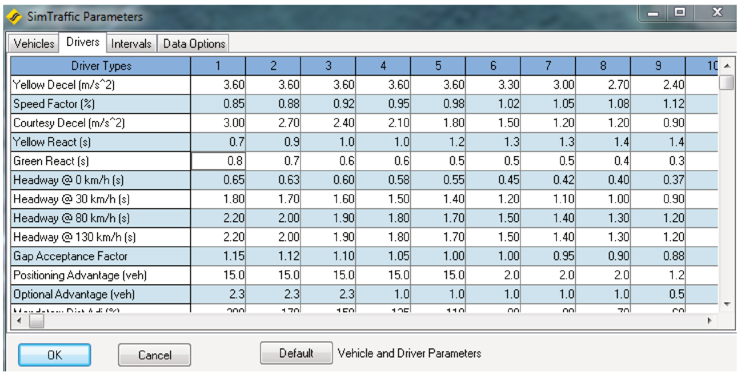
Speed factor aims to take into account a sufficient variety of driving behaviors facing the evaluation gain of speed-sectioning optimization. It allows for the concerned driver to adapt to the current link speed by this factor, which has a range of variation from 0.70 to 1.35. It alters directly the road design speed.

At last, types of drivers will be associated to several types of vehicles in the simulations, without specific link between types of drivers and vehicles.

Driver types	Type 1	Type 2	Type 3	Type 4
Behaviour	Aggressive	Defensive	Eco-friendly	Combination of behaviours (30% Type 1; 40% Type 2; 30% Type 3)
Speed factor	1.15-1.35	0.70-0.85	1.00	0.70-1.35
Deceleration rate (m/s^2)	1.40-3.00	0.70-1.00	0.30-0.40	0.30-3.00

Table 4: *Calibration of drivers speed factor on road characteristics*

Figure 41: *Calibration of drivers reaction time on road characteristics*



Driver Types	1	2	3	4	5	6	7	8	9	10
Yellow Decel (m/s^2)	3.60	3.60	3.60	3.60	3.60	3.30	3.00	2.70	2.40	
Speed Factor (%)	0.85	0.88	0.92	0.95	0.98	1.02	1.05	1.08	1.12	
Courtesy Decel (m/s^2)	3.00	2.70	2.40	2.10	1.80	1.50	1.20	1.20	0.90	
Yellow React (s)	0.7	0.9	1.0	1.0	1.2	1.3	1.3	1.4	1.4	
Green React (s)	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.3	
Headway @ 0 km/h (s)	0.65	0.63	0.60	0.58	0.55	0.45	0.42	0.40	0.37	
Headway @ 30 km/h (s)	1.80	1.70	1.60	1.50	1.40	1.20	1.10	1.00	0.90	
Headway @ 80 km/h (s)	2.20	2.00	1.90	1.80	1.70	1.50	1.40	1.30	1.20	
Headway @ 130 km/h (s)	2.20	2.00	1.90	1.80	1.70	1.50	1.40	1.30	1.20	
Gap Acceptance Factor	1.15	1.12	1.10	1.05	1.00	1.00	0.95	0.90	0.88	
Positioning Advantage (veh)	15.0	15.0	15.0	15.0	15.0	2.0	2.0	2.0	1.2	
Optional Advantage (veh)	2.3	2.3	2.3	1.0	1.0	1.0	1.0	1.0	0.5	

Implementation in Trafficware : To be able to execute this manoeuvre properly, the simulation model reused drivers features as we calibrated them to the reaction time of a eco-drivers shown in fig. 41. So the reaction time of each driver types was different. From the type 1 to 5 we decided to call them defensive type of drivers and from 6 to 10 we decided to call them aggressive type of drivers. The types from 1 to 5 are more eco-friendly drivers.

3.1.3 Speed-sectioning modeling

In order to evaluate speed-sectioning optimization within the simulation framework the three following scenarios are taken into account:

- Scenario 1: in the simulation the speed-sectioning changing point is exactly at the same location as in the experimental situation;
- Scenario 2: speed-sectioning changing point is implanted in the simulation in an upstream optimized placement for eco-driving;
- Scenario 3: an advance warning is simulated by adding an intermediate speed reduction upstream in the simulated road section (80 km/h to 60 km/h then to 40 km/h), thus enhancing eco-driving opportunity for most driver types.

3.1.4 Model inputs: road and traffic data

The simulation is done with a flow of varied vehicles and it is based on the experiment conducted in Bosnia-Herzegovina. Considered experimental road is a bidirectional with very few intersections with local unpaved roads that will be neglected.

The analyzed trajectory is the same as the one used in experiment part (Kobiljača/ R442/ M-5). Associated traffic data has been provided by the road survey service of the Federation of Bosnia-Herzegovina. This road section has an average annual daily traffic (AADT) of 12452 veh. Data are provided by using STERELA counters and QLD-6CX i QLTC 10 (marked as yellow and purple triangles on the map, fig. 42).

Figure 42: *Map of the Main Roads Network of the FB&H with special reference to the 523 and 585 counters*

3.1.5 Set up of the simulation traffic flow

OpenStreetMap is used to apprehend the simulated road environment, enriched with the Bosnian case experimental data (fig. 43). Route length is of 1189 meters and speed-sectioning is defined by the effective positions of road signs. Each simulated segment has its own speed limitation regarding to experimental data. Moreover, speed limits used in the simulation model are the same as in real-life Bosnian experiment.

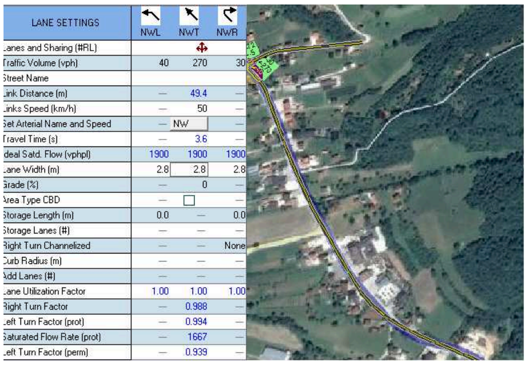


Figure 43: *Road calibration on trafficware platform*

Counterpoint number	Place	Road	AADT 100%	Vehicle categories								
				A1	A2	A3	A4	B1	B2	B3	B4	C1
523	Gromiljak-Blazuj	M5	12452 100%	0 0.0	11644 93.5	0 0.0	0 0.0	84 0.7	356 2.9	153 1.2	150 1.2	65 0.5

Table 5: *Calibration of vehicles structures*

The daily distribution of the traffic used for the simulations is given in table 5 according to the following vehicle classes: A1-motorcycle; A2-personal car; A3-private car with trailer; A4-van with or without trailer; B1-small truck; B2-medium truck; B3-heavy freight vehicle; B4-heavy freight vehicle with trailer; C1-Bus. There is a large predominance of the personal car class (A2).

3.2 Simulation running conditions

The micro-traffic simulation has been run with combinations of measured traffic, simulated drivers and measured road infrastructure. Drivers are apprehending road geometry and speed restrictions and then are consequently applying commands to vehicles.

Vehicles dynamics depends on drivers commands, including individuals speed factors and deceleration rates, on road gradient and turns, and of course on particular vehicle characteristics. Moreover each vehicle is interacting with others in case of non-free flow conditions. As an example the interaction between different vehicles-drivers couples is shown in fig. 44.

In the general case of constrained traffic, the traffic flow simulation relies on the

Figure 44: *Example of the routes followed by different types of vehicles*

following general flow equation:

$$q(k) = k \times v(k) \tag{32}$$

Where: q - flow (vehicles/hour), v - speed (kilometers/hour), k - density (vehicles/kilometer).

Simulations are conforming to HCM2010 equations and regulations [26].

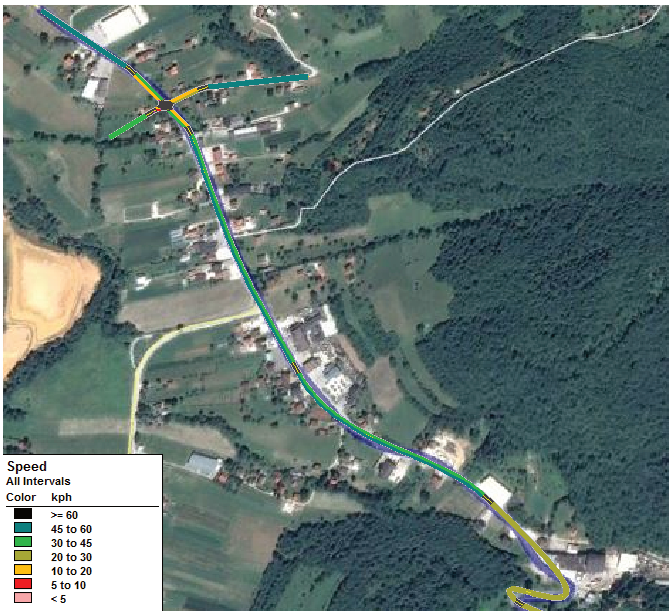


Figure 45: *Segment of our route and representative average speeds*

However, in adverse situation with misplaced speed signs or regulations, the traffic simulation is able to point out traffic congestion, as it can be seen on fig. 45 where average speeds are traced.

In the next section, simulations will help to quantify the impact of speed section's alterations on traffic fluidity and fuel consumption. Within each simulation step, fuel consumption is determined for the vehicle fleet displacements (car, truck, or bus) over the whole calculation area.In the retained simulation framework fuel models are derived from both empirical studies and theoretical equations. Final form of the consumption model used in this work is of:

$$F_i = K_{i1} \times TT_i + K_{i2} \times TDi \times K_{i3} \times TSi \quad (33)$$

where:

- F_i = fuel consumed on link i, in liters per hour;
- TT_i = total travel in veh-km per hour;
- TD_i = total delay in veh-hr per hour;
- TS_i = total stops in vph; and
- K_{ij} = model coefficients which are functions of cruise speed (V_i) on each link i.

$$K_{ij} = A_{j1} + A_{j2} \times V_i + A_{j3} \times V_i^2 \quad (34)$$

where A_{jk} - regression coefficients.

Fuel consumption expression is done here in its general form, however in practice it takes into account each vehicle characterized by its class, its dynamics and associated driver behavior.

3.3 Results and Discussion

A set of simulations has been carried out in order to evaluate the mean fuel consumption over a one kilometer section, for three speed-sectioning configuration and four driver types. Results are presented in fig. 46. The Y axis represents different types of drivers according to table 4. The X axis is the fuel consumption on defined route in a simulation of 10 minutes defined by the traffic data presented in table 5. Inside the one kilometer section of simulation, there is only one speed change, from 80km/h to 40km/h. The three scenarios are differing only by the longitudinal position of the corresponding speed change sign as defined in section 3.1.3.

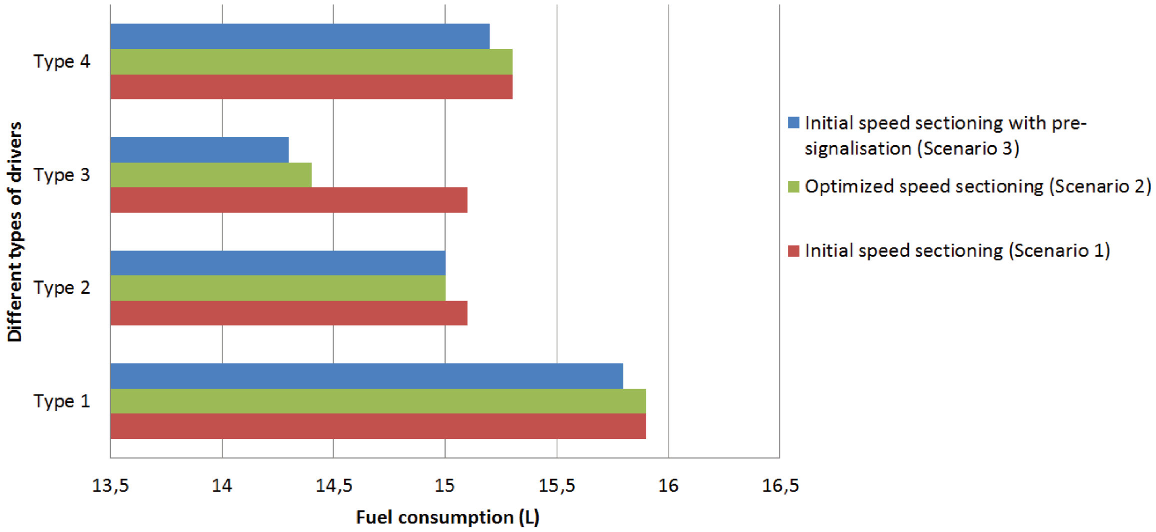


Figure 46: *Fuel consumption for 3 scenarios and 4 driver types over the simulation section*

The results underline the specificity of our three scenarios. The main difference between the three scenarios on fig. 46 is shown for the type 3 driver (eco-driver). This is explained by the fact that the actual infrastructure does not allow eco-driving. On the other hand, the other two scenarios allow eco-drivers to apply eco-driving rules, with a 4.8%(15.1l-14.4l) gain on fuel consumption with the scenario 2 (14,4 l) compared to the scenario 1 (15,1 l) by optimizing the placement of the speed limiting sign, and 5.5%(15.1l-14.3l) with the scenario 3 (14,3 l) by adding an advance warning sign.

These results are important as an improvement to an ecological potential of road infrastructure without lowering safety requirements. This shows that the best values can be used and implemented in the conception phase by simulating before the final project is done.

In this example, an eco-driving friendly infrastructure does not reduce significantly fuel consumption for drivers who do not have such an eco-driving behavior. On fig. 46, the fuel consumption of the driver types 1,2,4 is about the same between the initial speed-sectioning (Scenario 1) and the optimized speed-sectioning and the initial speed-sectioning (Scenario 2) with advance warning signs (Scenario 3). The objective of the scenario 3 was to force the trajectory of the normal drivers to become a soft trajectory, near to an eco-driving trajectory. This objective is not reached for non eco-driving drivers. The reason is that the drivers brake mechanically even along this soft trajectory. The conclusion is that gains are becoming increasingly important as the number of eco-driver increases.

However, we cannot draw general rules from this particular example where the traffic is not dense. In the case of dense traffic, trajectories of eco-driver could influence trajectories of others drivers and then lower their consumption. By using traffic simulation, our methodology takes into account this influence.

Limits and Hypotheses

- The simulation model has potential to assess the traffic locally on a defined route, however it has also some disadvantages. Driving behavior is modeled by automatized base-acceleration phases (speed adaptation factor), without the perception value of a human driver. We can say that even by adjusting the type of the driver, deceleration and acceleration phases does not represent accurately human successive driving processes. This weak point is addressed in the following chapter on Optimization where another simulation framework is carried out.

- Nevertheless simulations show that fuel consumption gains are significant (5.5 % - 15.1l-14.3l) for eco-drivers while being inexpensive for the infrastructure manager, because it is enough just to move a speed limiting sign. A risk for the manager is that moving a speed sign may cause congestion. This can increase greenhouse gas emissions contrary to our goal. Traffic simulations are then useful 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 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 [175] where a model of number of replications is explained and needed in a micro-traffic simulation to obtain reliable results, we checked that the number of replications was sufficient: we obtained very similar results every time, conducted for each type of driver, because of the environment of trafficware 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.

Applicability: The frequency of misplaced panels depends on various factors: geography, traffic sign norms, regulations... Resulting gains according to the displacement of a misplaced speed sign depends also of numerous variables: traffic, percentage of eco-drivers, compliance with regulations. In Bosnia-Herzegovina, we detected 9 misplaced panels over 140 km. In France, we detected 8 panels over 100 km of secondary roads. However, this frequency has decreased recently as the legal speed on these roads has been managed from 90 km/h to 80 km/h. Despite this variability, the most fruitful result should be reached for secondary roads in rural and mountainous area. In the other hand, our methodology should not bring significant improvements to motorways because slopes and turns are moderated and visibility distances are higher.

We can conclude that using this simulation model we have been able to see an eco-driving approach, and have realistic data. The simulation is important to have a global view of eco-potentiality of the infrastructure in correlation to energy parameters. The data gathered helped us evaluate different situations in dependence to drivers structure.

CHAPTER 4

OPTIMIZATION

4.1 Methodology

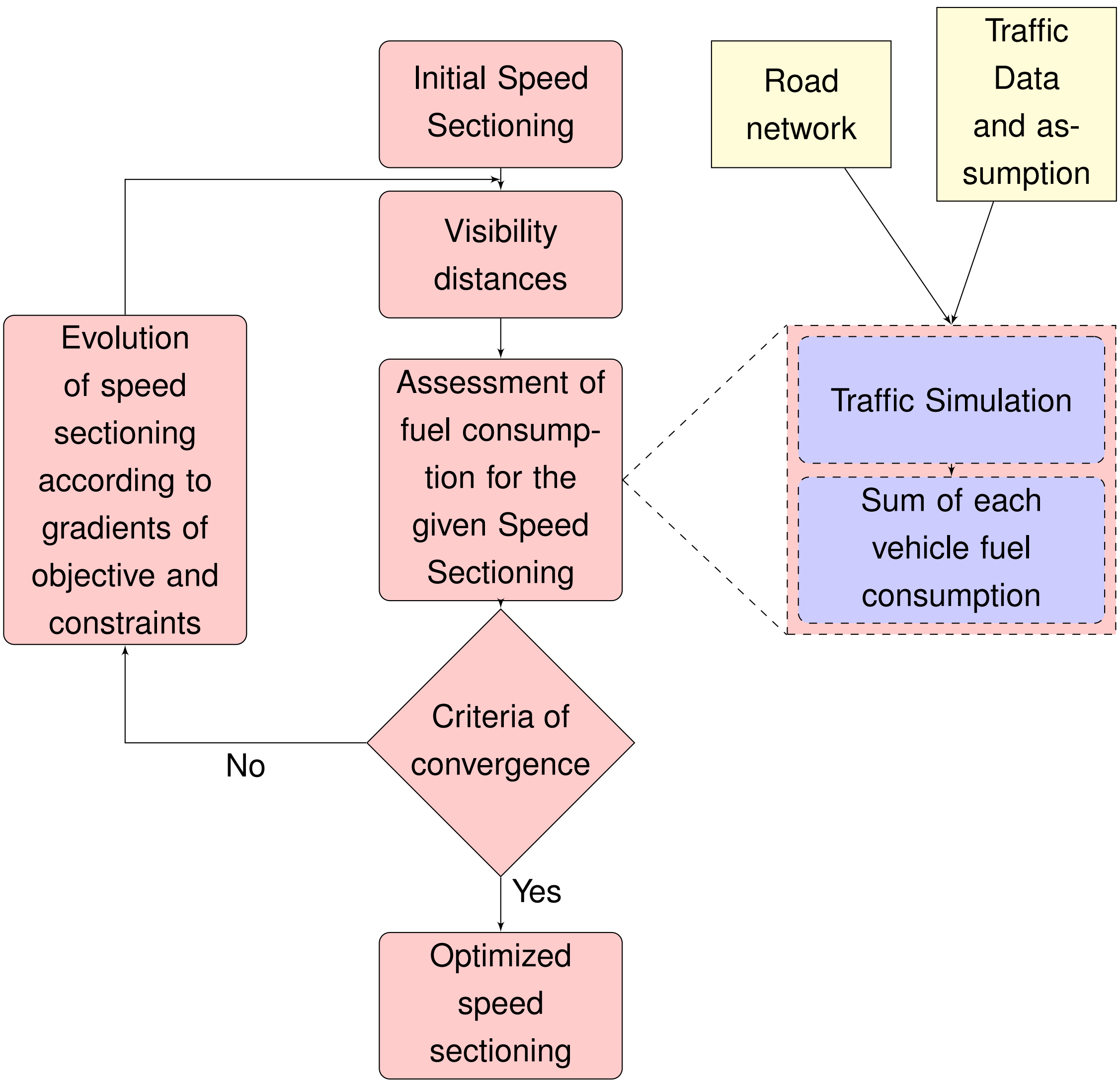


Figure 47: *Optimization methodology*

The objective of the optimization process is to find a speed sectioning which minimizes the fuel consumption while meeting the safety constrains. We assume that this optimization process is applied on an already detected MSP.

Fig. 47 displays the proposed methodology. Starting from the initial speed sectioning, visibility distances associated with this initial speed sectioning are computed. The assessment of this information is the fuel consumption. This fuel consumption is computed by simulating traffic on the road network based on traffic data and assumptions on traffic, e.g, assumption on drivers behaviors. The output of this simulation is the sum of each vehicle fuel consumption. Criteria of convergence are then computed. As it is the first assessment, values of criteria are negative. The optimization algorithm proposes a new speed sectioning while taking into account safety constrain. The algorithm enters in a loop until criteria of convergence are fulfilled. The output of the algorithm is the speed sectioning which minimizes the fuel consumption while meeting the safety constrains.

The outline of the chapter is as follows. The next part is the implementation of this methodology. The methodology was applied on a real example, described in the 3rd section of this chapter. This example is rather simple but proves the applicability of the method. It is a proof of concept for the proposed methodology. The last section is the discussion of these preliminary results.

4.2 Implementation

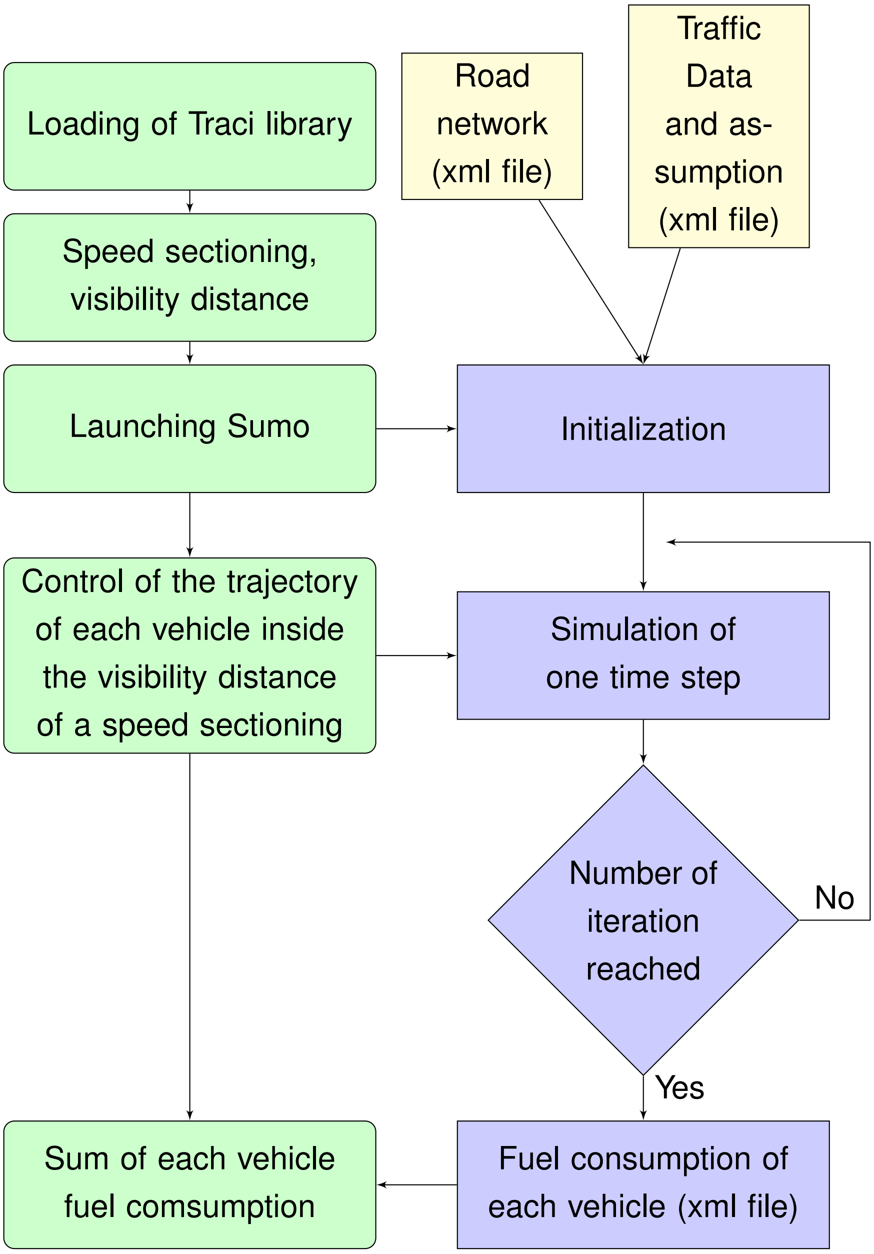


Figure 48: *Interaction between Python (green color) and Sumo (blue color) to control trajectory of vehicle approaching speed sectioning*

The previous methodology implies that the traffic simulation is carried out inside a loop. However with trafficware, a change of speed sectioning was made manually at each loop of the optimization algorithm. It was not feasible. It is the reason why, the simulation tool was changed. Open source software Sumo is used on the ongoing research. Its crucial feature for this study is thaht Sumo can be launched and controlled from Python by using the Python library Traci.

This feature is illustrated by fig. 48. This figure displays the implementation of the traffic simulation (blue blocks of fig. 47) 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 iteration 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. We do not have to change manually the configuration file as it is the case with Trafficware. 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 more accurate than with Trafficware. In Trafficware, various behaviors of drivers were controlled with two parameters: the speed factor and the minimum deceleration. With this interaction between Sumo and Python, we cast each trajectory according to the type of driver. 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.

Some Words on Sumo: Sumo is an agent-based traffic simulation approach. Agents are individual traffic participants moving in an artificial environment. This concept is appropriate to model different kinds of traffic participants and to have them interact with each other in different scenarios. Experiences with implementation and usage of the agent model within the universal multi-agent simulation framework is used by means of several application examples which also support discussion about validation of concept and implementation.

The typical procedure is to build models for various components of a particular (type of) traffic system. Often general purpose programming languages are used, together with more or less universal development environments or frameworks, most of which are open source too. These systems can be adapted to the requirements of the model or class of models under consideration. This approach requires a high level of computer science expertise. Traffic planners and other practice-oriented users prefer the application of specialized, mainly commercial tools. Any adaptation of such a tool is restricted to representing the real-world target system with the available features. However in the scientific community open-source coding is preferred as more variables are programmable; in this case in Sumo. Often an integration with analytic methods and real-world traffic control systems are used.

4.3 Proof of concept

The optimization algorithm was carried out at the end of my thesis. Due to lack of time, the proposed methodology was not applied on an entire road network. It was applied to a MSP detected during the experiment campaign in Bosnia-Herzegovina. This ecologically present black spot is 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). For each virtual position of the speed limitation sign, an experimental determination of the visibility distance is conducted by using satellite tools on open-source platforms.

4.3.1 Geographical and Traffic Data

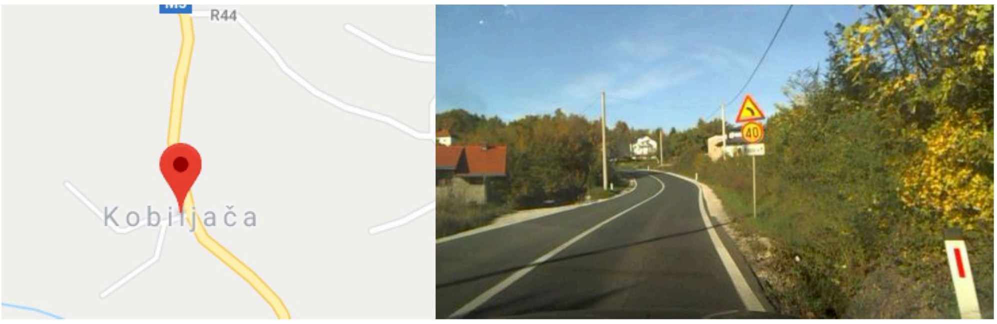


Figure 49: *Plan of situation on the R442 (source google maps) and real-world positioning of the speed limitation sign*

Fig. 49 represents the misplaced speed limitation sign in Bosnia-Herzegovina at its location. 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.

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

Table 6: *Visibility distance according to the position of the virtual panel*

4.3.2 Sumo setup

As already mentioned, several prerequisites for model abstractions when designing a simulation framework is needed. This concerns the precise modeling of real-world details, but also sufficiently large scenarios that can be modeled and computationally simulated in a reasonable length of time. The abstractions which we have used will be described in the following, not neglecting the peculiarities of a simulation in continuous space and the necessary geometric operations within the software.

In any case, two components of traffic simulation with characteristic features can be identified:

- a model of an environment as a network or a landscape, i.e. a topography with typical static entities such as streets, sidewalks, static obstacles;

- a representation of the traffic flow within the modeled environment where attributes are the geometric forms and sizes of moving entities, and motion obeys physical laws (either macroscopically as flows or microscopically as individual entities).

In detail, the model of environment is imported in Sumo by using openstreet map and the software Net-edit was used for calibration purposes. Configured XML files were built and integrated as well. The simulation is conducted primarily on diesel vehicles with EURO 4 standards and HBEFA 3.2 protocols; which are also in correlation to the simulation framework used by SUMO. 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).

Type	C-eco	C-agg	C-def	T-eco	T-agg	T-def
Max dec ($m.s^{-2}$)	0.40	1.00	1.00	0.30	0.90	0.90
Max acc ($m.s^{-2}$)	0.60	1.00	0.60	0.50	0.90	0.50
Speedfacor	1.03	1.10	0.90	1.03	1.10	0.90
Max Speed ($m.s^{-1}$)	30.00	38.00	30.00	22.22	27.00	22.22
Percentage	55.00	15.00	15.00	8.00	5.00	2.00

Table 7: *Drivers characteristics for the Sumo simulation*

The time period of the simulation is 3600 sec. where 100 vehicles are simulated. The effects of variations in speed and in increasing fuel consumption are clearly presentable, they provide another measure of economy of vehicular operation where traffic flow is smoothed out by improved road infrastructure. These measures are presented in the results.

4.3.3 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 vehicle.

- 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 are described.

Interaction between Sumo and Python when a vehicle is approaching the village

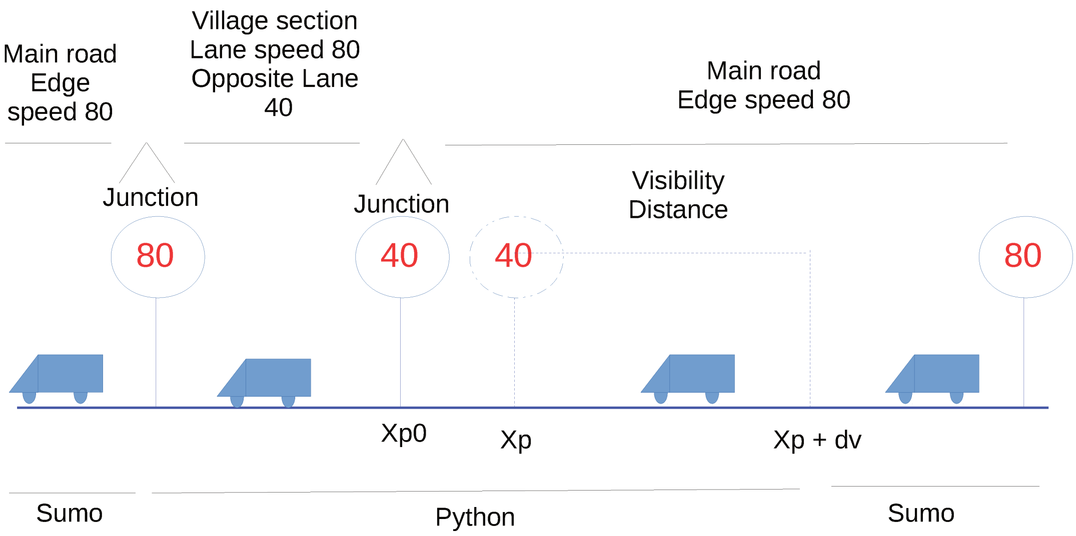


Figure 50: *Interaction between Sumo and Python when a vehicle is approaching the village*

Fig. 50 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. X_{p0} is the actual speed limiting sign position along the road. X_p is the virtual position, d_v 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.

Deceleration types

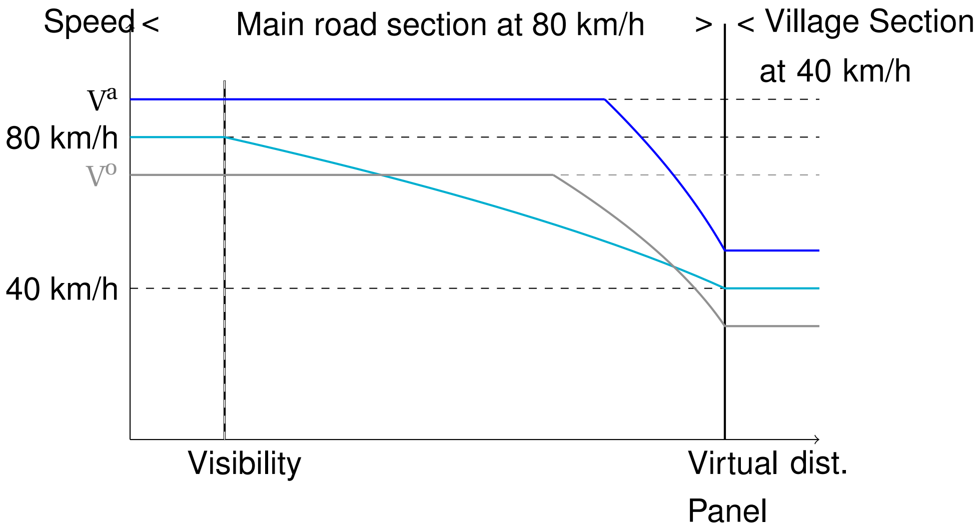


Figure 51: *Three types of trajectory when approaching the virtual panel*

The drivers trajectories approaching the virtual panel were cast according to three types of drivers for each vehicle type here are the values for a car vehicle type:

- Type 1 (aggressive) where its desired deceleration rate is 1.00 m/s^2;
- Type 2 (defensive drivers) where its desired deceleration rate is 1.00 m/s^2;
- Type 3 (eco-drivers) where its desired deceleration rate is 0.40 m/s^2 based on the research of Cantisani, Serrone, and Biagio [34].

Fig. 51 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 type 1 driver. The drive'r speed, V^a 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 type 2 driver who will drive slower, at the speed V^o, than the regulatory speed and with a longer reaction delay. The deceleration is still important because he wants to comply with the speed limit although its longer reaction delay. This grey curve is mostly representative for defensive drivers.

The cyan curve represents the idealized eco-driver (type 3), who will release the gas pedal as soon as 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. 51 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.

The Python implementation of these trajectories is given in Annex.

4.3.4 Results

The degree of freedom of the algorithm is the position of the virtual panel between the initial position of the panel and 300m upstream. The criteria to minimize is the fuel consumption of all the traffic. The considered traffic is based on real traffic data; the number of vehicle on this route is approximately 200-500 veh/h on both lanes and 100-250 veh/h on one lane. We simulate 100 veh/h on one lane. The time period of the simulation is 3600 sec or 1h realized on SUMO simulation framework.

The algorithm proposes to reposition 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. It should be noted that the number of vehicle present on the route are gathered by real traffic data on a free-flow hour. 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. 1 liter of diesel weighs 835 grammes. Diesel consist for 86.2% of carbon, or 720 grammes of carbon per liter diesel. In order to combust this carbon to CO_2, 1920 grammes of oxygen is needed. The sum is then 720 + 1920 = 2640 grammes of CO_2/liter diesel.

One optimized single speed limitation sign could save up to 5250 kg of CO_2 not emitted in the atmosphere by year.

This result is significant.

On this simple example, we did not try to tune finely the algorithm because our objective was to demonstrate that the proposed methodology can be applied on a real example.

4.4 Discussion

- The optimization of an isolated panel could be done " by hands-manually" with an analysis of the visibility distance and of the desired deceleration. We can set up the panel at the position where the visibility distance is maximum. It has to be checked with a traffic simulation that this new position does not create traffic congestion and has the potential to lower the fuel consumption. The problem becomes more complex when several speed sectioning follow one another. In this case, optimization by computer is mandatory. This configuration will be address at short term.
- 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. This drawback can be overcome by monetizing the fuel and the driving time. This improvement can be carried out in short term. The step further is to address multicriteria optimization: algorithm are available under Python but it will take more time to carry them out.
- In this chapter, the methodology is applied on one road by optimizing the location of one panel by taking into account three types of drivers. There is no theoretical limit to apply the methodology on a more complex network where close successive speed sectioning interact, by taking into account more types of drivers, by simulating a longer duration, peak time and off peak-time. The limit is the computation burden. In the following, we discussed these points.
  - Our methodology is oriented to secondary/rural roads. It means that the networks complexity should remain under control.
  - We got information on different types of driver, and their division presented in the work of Garcia-Castro et al. [75] and Cantisani, Serrone, and Biagio [34]. However to our knowledge, the shares of drivers according to the different types of drivers are not well known. Moreover a driver can change its behavior sometimes: an eco-driver can become an aggressive driver if he runs out of time for various reasons. It is the reason why, there is no reason to multiply the number of drivers type. On the other hand, it could improve our simulation by introducing a variety of behaviors inside each type of drivers. For example, it is common in traffic studies to add a standard deviation to

the maximum deceleration acceptable for a driver. This can be done in short term in our work.

- It would be fruitful to simulate peak time in order to detect a possible traffic congestion due to the displacement of a panel. We are processing the traffic data to get this piece of information.
- A model of number of replications is explained and needed in a micro-traffic simulation to obtain reliable results. Indeed in this research the number of replications were sufficient: we obtained very similar results every time, conducted for each type of driver, because of the environment of Sumo model.

CONCLUSION

A four-step methodology is developed in this work in order to provide progressive means of road energy demand reduction. This methodology is dedicated to road managers since it is focused on optimization of route speed sectioning, which consists of the succession limiting speeds along the route. Some misplaced speed changing points do not allow drivers to eco-drive.

The first step is to propose a criterion, EASM, rapidly usable by road managers to detect these points, named Misplaced Speed-sectioning Position (MSP), in relation to the Starting Deceleration Point (SDP) of approaching vehicles and road characteristics as slopes and turns. The second step gives further information to road managers by quantifying the energetic cost of a MSP-type speed change.

The first step provides a vehicle independent criterion. The second yields an energetic cost of a misplaced sign for any given vehicle.

As the third step a traffic flow simulation has constituted the frame of an enhanced energetic evaluation, while considering a full flow of vehicles, based on real traffic data, and modeling several driver behaviors.

The fourth step is an optimization process which integrates the previous step to find the optimized speed sectioning.

Experiments have been carried out in rural area in Bosnia-Herzegovina and France to demonstrate the feasibility of the methodology. MSP were detected in both countries but not for the same reasons. In France, MSP were located downhill. In Bosnia-Herzegovina, the visibility distances of MSP were too short. Complementary experiments were performed in France in order to evaluate the recent change on national road in speed regulation from 90km/h to 80km/h for MSP. As expected, the energy dissipated in braking system is less important with this new regulation.

The complete methodology was applied on a rural road in Bosnia-Herzegovina. Fuel gains depend on the assumptions of the simulation. The rate of Eco-Driver is a key factor in this spare area. The optimization process was applied on a single MSP.

The next step is to apply the optimization code on a sounder case study. At short term, assessments of MSP 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.

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APPENDIX A

CODES IN SUMO

In SUMO, road network can be created in three ways:

- manually by creating our own node, edge, route, connection files;
- using net-generate command;
- importing road network from external sources such as OSM, VISSIM, VISUM etc.

The Appendix A is divided in three sub-sections as following:

- Manual node, edge and route assignment;
- From OSM to network, random trips simulation and output files;
- Origin-Destination to trip simulation.

Manual Node, Edge and Route assignment

A road network consists of nodes (junctions) and edges (i.e. roads that connect various junctions with each other). (-350, 0) (-600, 0) (0, 0) (-350, 400) (350, 400) N1 N2 N3 N4 N5.

Creation of a network consists of the followings:

- Node file creation (.nod.xml);
- Edge file creation (.edg.xml);
- Edge type file creation (.type.xml);
- Network creation from the node, edge and type files;
- Route file (.rou.xml).

Each step and code to create the needed file is explained below. As the file would be too long to directly insert it in the appendix an example of each code is given as followed:

- Node file creation code:

```
<nodes>
<node id="n1" x = "-350" y="0" type="priority"/>
<node id="n2" x = "-600" y="0" type="traffic_light"/>
<node id="n3" x ="0" y="0"/>
<node id="n4" x = "-350" y="400" type="traffic_light"/>
<node id="n5" x ="350" y="400" />
</nodes> (-350, 0) (-600, 0) (0, 0) (-350, 400) (350, 400) N1 N2 N3 N4 N5

File name: my_nod.nod.xml - node file (.nod.xml)
```

- Edge file (.edg.xml); is defined by connecting nodes together to form links:

```
<edges>
<edge from="n1" to="n2" id="1to2" type="3L45"/>
<edge from="n2" to="n3" id="2to3" type="2L15"/>
<edge from="n3" to="n4" id="3to4" type="3L30"/>
<edge from="n4" to="n5" id="out" type="3L30"/>
<type id="highway.pedestrian" priority="1" numLanes="1" speed="2.78"
allow="pedestrian" oneway="1" width="2.00"/>
</edges>

File name: my_edge.edg N1 N2 N3 N4 N5
```

- Type file (.type.xml); include road priority, the number of lanes, speed limits, type of vehicles allowed on the roads:

```
<types>
```

```
<type id="highway.motorway" priority="13" numLanes="2" speed="36.11"
allow="private emergency authority army vip passenger hov taxi bus coach
delivery truck trailer motorcycle vehicle custom1 custom2" oneway="1"/>
</types>
File name: my_type.type.xml
```

The created files are merged together by a command in cmd.exe to create a network from the PATH where the files are located as followed:

```
netconvert --node-files my_nodes.nod.xml -- edge-files my_edge.edg.xml
-t my_type.type.xml -o my_net.net.xml
```

- Route file (.rou.xml); a route file is created in the network to define the movement of each vehicle in the network:

```
<routes>
<vType id="passenger-eco" guiShape="passenger/sedan"
emissionClass="HBEFA3/PC_D_EU4" accel="0.6" decel="0.4" sigma="0.5"
length="5.0" minGap="7" maxSpeed="30" speedFactor="1.03"
color="0,255,0"/>
<vType id="passenger-agg" guiShape="passenger"
emissionClass="HBEFA3/PC_D_EU4" accel="1" decel="1" sigma="0.5"
length="5.0" minGap="7" maxSpeed="38" speedFactor="1.1"
color="255,0,0"/>
<vType id="passenger-def" guiShape="passenger/hatchback"
emissionClass="HBEFA3/PC_D_EU4" accel="0.6" decel="1" sigma="0.5"
length="5.0" minGap="7" maxSpeed="30" speedFactor="0.9"
color="255,255,255"/>
<vType id="truck-eco" guiShape="truck/semitrailer"
emissionClass="HBEFA3/HDV_D_EU4" accel="0.5" decel="0.3" sigma="0.5"
length="12.5" minGap="2.5" maxSpeed="22.22" speedFactor="1.03"
color="0,255,0"/>
<vType id="truck-agg" guiShape="truck/semitrailer"
```

```
emissionClass="HBEFA3/HDV_D_EU4" accel="0.9" decel="0.9" sigma="0.5"
length="12.5" minGap="2.5" maxSpeed="27" speedFactor="1.1"
color="255,0,0"/>
<vType id="truck-def" guiShape="truck/semitrailer"
emissionClass="HBEFA3/HDV_D_EU4" accel="0.5" decel="0.9" length="12.5"
minGap="2.5" maxSpeed="22.22" speedFactor="0.9" color="255,255,255"/>
<routes>
File name: od_route_file.odtrips.rou.xml
```

- Lastly, the Sumo configuration file (.sumocfg) is created with defined time values and interactions between the network file and route file:

```
<configuration>
<input>
<net-file value="my_net.net.xml"/>
<route-files value="my_route.rou.xml"/>
</input>
<time>
<begin value="0"/>
<end value="3600"/>
</time>
</configuration>
File name: my_config_file
```

After the creation of a .sumocfg file it can be launched directly from the file or in cmd.exe with the following command:

```
sumo -c my_config_file.sumocfg Or sumo-gui -c my_config_file.sumocfg
```

From OSM to network, random trips simulation and output files

Previously, we manually built this network (nodes, edges), and manually defined the route, the vehicle types and parameters. However, what if we have a large set of network?

The process to implement is presented below:

- Open Street Map (OSM) or any available map source explorer
- Convert the Map into SUMO Network

```
netconvert --osm-files map.osm -o test.net.xml
```

- Add trip and route to the network using build-in Python scripts randomTrips.py python

  "randomTrips.py" generates a set of random trips for a given network (option -n).

  By default, it does so by choosing source and destination edge uniformly at random distribution. The resulting trips are by default stored in an XML file trips.trips.xml. The trips are distributed evenly in an interval defined by the beginning time –b (default 0) and end time -e (default 3600) in seconds.

```
PATHrandomTrips.py -n test.net.xml -r test.rou.xml -e 50 -l
py PATHrandomTrips.py -n test.net.xml -r test.rou.xml -e 50 -l
```

Setup of the configuration file is next and the process to run the Network is completed.

Lastly, the Sumo Configuration file (.sumocfg):

```
<configuration>
<input>
<net-file value="Blazuj.net.xml"/>
<route-files value="Blazuj.rou.xml"/>
</input>
<time>
<begin value="0"/>
<end value="3600"/>
</time>
</configuration>
File name: Blazuj.sumocfg
```

After generating the configuration files and by placing the network and the routes; the next step is to provides outputs from the model. The first file is the emission file, which generates all data on GHG emissions, fuel, noise etc. This file generates data of each vehicle in the network at each period of time in the network.The code to generate this file is represented below with the example of the elements found inside the emission file.

```
Code:
sumo -c PATHconfig_file.sumocfg --emission-output PATH\my_emission_file.xml

Example:

<emission-export>
<timestep time="0.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1895.56" CO="0.58"
        HC="0.03" NOx="13.18" PMx="0.00" fuel="0.71" electricity="0.00"
        noise="55.94" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="5.10" speed="0.00" angle="307.81"
        x="11851.98" y="4219.78"/>
    </timestep>
    <timestep time="1.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1900.84" CO="0.58"
        HC="0.04" NOx="12.93" PMx="0.00" fuel="0.72" electricity="0.00"
        noise="57.53" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="5.43" speed="0.33" angle="307.81"
        x="11851.72"y="4219.98"/>
    </timestep>
    <timestep time="2.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1916.18" CO="0.58"
        HC="0.04" NOx="12.70" PMx="0.00" fuel="0.72" electricity="0.00"
        noise="57.91" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="6.15" speed="0.72" angle="307.36"
        x="11851.13"y="4220.39"/>
    </timestep>
    <timestep time="3.00">
```

```
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1990.35" CO="0.58"
        HC="0.05" NOx="12.64" PMx="0.00" fuel="0.75" electricity="0.00"
        noise="59.02" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="7.46" speed="1.31" angle="305.87"
        x="11850.02"y="4221.08"/>
    </timestep>
    <timestep time="4.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1978.36" CO="0.57"
        HC="0.05" NOx="12.22" PMx="0.00" fuel="0.74" electricity="0.00"
        noise="58.62" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="9.21" speed="1.76" angle="303.86"
        x="11848.53"y="4222.02"/>
    </timestep>
    <timestep time="5.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="1989.21" CO="0.57"
        HC="0.05" NOx="11.96" PMx="0.00" fuel="0.75" electricity="0.00"
        noise="58.67" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="11.40" speed="2.18" angle="302.10"
        x="11846.69"y="4223.18"/>
    </timestep>
    <timestep time="6.00">
        <vehicle id="flow0.0" eclass="HBEFA3/PC_D_EU4" CO2="2115.39" CO="0.57"
        HC="0.06" NOx="12.21" PMx="0.00" fuel="0.80" electricity="0.00"
        noise="59.65" route="route0" type="passenger-eco" waiting="0.00"
        lane="10051007#0_0" pos="14.16" speed="2.77" angle="302.10"
        x="11844.34"y="4224.65"/>.........
    </timestep>
</emission-export>
```


File name: Blazuj_emission_file.xml

Another step is to generate all available data on the network at each second of time nevertheless if there is a vehicle present in the network. This file is generally considered as a Big Data file (accessible only by gVim 8.1 or another big data software). The code to generate the big data file is presented below as well as a small part of a big data file too:

```
Code:
sumo -c PATH\config_file.sumocfg --full-output PATH\my_full_output.xml
Big data 17GB file (in this file all the vehicles in each moment of
each edge are represented with data)
```


```
 <data timestep="0.00">
        <vehicles>
            <vehicle id="flow0.0" eclass="HBEFA3/PC_G_EU4" CO2="2624.72"
            CO="164.78" HC="0.81" NOx="1.20" PMx="0.07" fuel="1.13"
            electricity="0.00" noise="55.94" route="route0"
            type="passenger/sedan" waiting="0.00" lane="90826327#2_0"
            pos="5.10" speed="0.00" angle="260.34" x="6965.47" y="8152.31"/>
        </vehicles>
        <edges>
            <edge id=":1001203623_0" traveltime="1.28">
                <lane id=":1001203623_0_0" CO="0.00" CO2="0.00"
                NOx="0.00" PMx="0.00" HC="0.00" noise="0.00" fuel="0.00"
                electricity="0.00" maxspeed="3.65" meanspeed="13.14"
                occupancy="0.00" vehicle_count="0"/>
            </edge>
            <edge id=":1001203726_0" traveltime="1.05">
                <lane id=":1001203726_0_0" CO="0.00" CO2="0.00"
                NOx="0.00" PMx="0.00" HC="0.00" noise="0.00" fuel="0.00"
                electricity="0.00" maxspeed="13.89" meanspeed="50.00"
                occupancy="0.00" vehicle_count="0"/>
            </edge>
            <edge id=":1001203726_1" traveltime="1.73">
                <lane id=":1001203726_1_0" CO="0.00" CO2="0.00"
                NOx="0.00" PMx="0.00" HC="0.00" noise="0.00" fuel="0.00"
                electricity="0.00" maxspeed="8.32" meanspeed="29.95"
                occupancy="0.00" vehicle_count="0"/>
```

```
            </edge>...........
        <vehicles>
```

File name: my_full_output.xml

Another file which could be generated is the trip info file which represents all available data on the position of the vehicle. These data are : the departure time, departure lane, speed, route length to the following edges, the arrival time, arrival lane,speed factor etc. A small part of extracted data are presented below as well as the code to generate it.

Code :

```
sumo -c PATHod_file1.odtrips.xml -n PATH.net.xml -r
PATHod_route_file.odtrips.rou.xml --tripinfo-output PATH\tripinfo_output.xml
```



```
<tripinfos>
    <tripinfo id="flow0.0" depart="0.00" departLane="90826327#2_0"
    departPos="5.10" departSpeed="0.00" departDelay="0.00"
    arrival="555.00"arrivalLane="10051007#0_0" arrivalPos="322.89"
    arrivalSpeed="28.59" duration="555.00" routeLength="13146.84"
    waitingTime="0.00" waitingCount="0"stopTime="0.00" timeLoss="105.58"
    rerouteNo="0"devices="tripinfo_flow0.0" vType="passenger/sedan"
    speedFactor="1.06" vaporized=""/>

    <tripinfo id="flow1.0" depart="4.00" departLane="90826327#2_0"
    departPos="5.10" departSpeed="0.00" departDelay="4.00"
    arrival="577.00" arrivalLane="10051007#0_0" arrivalPos="322.89"
    arrivalSpeed="24.22" duration="573.00" routeLength="13146.84"
    waitingTime="0.00" waitingCount="0" stopTime="0.00" timeLoss="64.91"
    rerouteNo="0" devices="tripinfo_flow1.0" vType="passenger"
    speedFactor="0.94" vaporized=""/>

    <tripinfo id="flow2.0" depart="6.00" departLane="90826327#2_0"
    departPos="5.10" departSpeed="0.00" departDelay="6.00"
```

```
    arrival="597.00"arrivalLane="10051007#0_0" arrivalPos="322.89"
    arrivalSpeed="27.81" duration="591.00" routeLength="13146.84"
    waitingTime="0.00" waitingCount="0" stopTime="0.00" timeLoss="119.53"
    rerouteNo="0" devices="tripinfo_flow2.0" vType="passenger/hatchback"
    speedFactor="1.01" vaporized=""/>...........
</tripinfos>
File name: tripinfo_output.xml
```

Origin-Destination matrix to trip simulation

A Sumo network is already prepared and ready to be used. Previously, a manually process on how to built a network (nodes, edges) is explained. Moreover manually defined routes, vehicle types and parameters are introduced as well. The elements needed to define a O-D matrix and convert it into a trip simulation are propose as follows:

- make/have the network file ready (.net.xml)
- make the TAZ (Traffic analysis zone) file (.xml)
- make the OD (Origine-Destination) Matrix file (.od)
- make the od2trips.config file (.xml)
- make the duarouter.config file (.duarcfg)

Traffic Assignment Zone (TAZ) definition:

```
<additional>
<tazs>
<taz id="1" edges="90826327#2">
</taz>
<taz id="2" edges="10051007#0">
</taz>
<taz id="3" edges="-10051007#0">
</taz>
<taz id="4" edges="-90826327#2">
```

```
</taz>
<taz id="5" edges="-90826327#0">
</taz>
</tazs>
</additional>
 File name: TAZ_file.taz.xml
```

TAZ file:

```
TAZ_file.taz.xml OD_file.od od2trips.config.xml od_file.odtrips.xml + + =
od2trips -c PATHod2trips.config.xml
-n PATHtaz_file.taz.xml -d PATHOD_file.od
-oPATHod_file.odtrips.xml
```

Origin-Destination Matrix:

```
$O;D2
* From-Time To-Time
0.00 1.00
* Factor
1.00
*
* some
* additional
* comments
 1 2 10
 3  4   10
File name: OD_file.od
```

Trip Generation, from OD matrix- first approach:

```
duarcfg_file.trips2routes.duarcfg network_file.net.xml od_file.odtrips.xml
od_route_file.odtrips.rou.xml + = duarouter -c
PATHduarcfg_file.trips2routes.duarcfg - o od_route_file.odtrips.rou.xml
```

```
<configuration>
<input>
<net-file value="network_file.net.xml"/>
<route-files value="od_file.odtrips.xml"/>
</input>
</configuration>
```

Route assignment, using DUAROUTER (shortest length path)- second approach:

```
duarcfg_file.trips2routes.duarcfg network_file.net.xml od_file.odtrips.xml
od_route_file.odtrips.rou.xml + = duarouter -c
PATHduarcfg_file.trips2routes.duarcfg
<configuration>
<input> <net-file value="Blazuj.net.xml"/>
<route-files value="od_file.odtrips.xml"/>
</input>
</configuration> - o od_route_file.odtrips.rou.xml
<output>
<output-file value="od_route_file.odtrips.rou.xml"/>
</output>
```

The output can be specified either in the xml configuration file, or from the command line. By default, duarouter calculates the shortest length path for each trip.

```
duarouter -c PATHduarcfg_file.trips2routes.duarcfg Recap od2trips -c
PATHod2trips.config.xml -n PATHtaz_file.taz.xml -d PATHOD_file.od -o
PATHod_file.odtrips.xml
```

Trips generation

```
<configuration>
<input> <taz-files value="taz_file.taz.xml"/>
<od-matrix-files value="OD_file.od"/> </input> <!--
```

```
<output>
<output-file value="od_file.odtrips.xml"/>
</output> -->
</configuration>
File name: od2trips.config.xml
```

Route assignment configuration -the duarouter configuration file takes as input your network and the OD Trips File and output the route file:

```
</configuration>
<input>
<net-file value="Blazuj.net.xml"/>
<!-- My SUMO Network File -->
<route-files value="od_file.odtrips.xml"/>
<!-- My SUMO OD Trips File -->
</input>
<output>
<output-file value="od_route_file.odtrips.rou.xml"/>
</output>
<report> <xml-validation value="never"/>
<no-step-log value="true"/>
</report>
</configuration>

File name: duarcfg_file.trips2routes.duarcfg
```

The Sumo Configuration file (.sumocfg)

```
<configuration>
<input> <net-file value="Blazuj.net.xml"/>
<route-files value="od_route_file.odtrips.rou.xml"/>
</input>
<time>
<begin value="0"/>
```

```
<end value="3600"/>
</time>
</configuration>
File name: config_file.sumocfg
```

The summary on how to calculate fuel consumption and obtain results of fuel consumption and emissions of each type of vehicle and each type of driver are as followed:

Outputs with the codes are defined to obtain an emission file for each vehicle and each type of driver:

```
sumo -c PATH config_file.sumocfg
--emission-output PATH my_emission_file-vl-eco-v50.xml
```

For each type of vehicle, different types of drivers and different network speeds are presented. The variables and their significations are presented below:

- v50-the speed of the network is 50 km/h
- v80-the speed of the network is 80 km/h
- vl-passenger car
- pl-heavy vehicle (trucks, semi-trailers)
- eco-eco-driver
- agg-aggressive type of driver
- def-defensive type of driver

By extracting data in this research we needed fuel consumption and speeds. Then the python script to calculate the different consumption is launched such as:

```
from lxml import etree
#tree = etree.parse ("PATH/my_emission_file.xml")
tree = etree.parse ("my_emission_file-pl-def-v50.xml")
```

```
fuel = 0;
for user in tree.xpath ("/ emission-export / timestep / vehicle"):
z = user.get ( "fuel")
+ = fuel fuel float (z)

print ("fuel consumption: {0: 4.2f}". (fuel) format)
```

in the cmd we write the following steps:

1. with cd PATH/SUMO100

2. python calcul_fuel.py

my_emission_file-vl-eco-v80.xml- 2.969 l / 100 km

my_emission_file-vl-agg-v80.xml- 3.259 l / 100 km

my_emission_file-vl-def-v80.xml- 2.918 l / 100 km

my_emission_file-pl-eco-v80.xml- 18.381 l / 100 km

my_emission_file-pl-agg-v80.xml- 20.509 l / 100 km

my_emission_file-pl-def-v80.xml- 19.047 l / 100 km

my_emission_file-vl-eco-v50.xml- 2.431 l / 100 km

my_emission_file-vl-agg-v50.xml- 2.746 l / 100 km

my_emission_file-vl-def-v50.xml- 2.257 l / 100 km

my_emission_file-pl-eco-v50.xml- 16.968 l / 100 km

my_emission_file-pl-agg-v50.xml- 19.704 l / 100 km

```
my_emission_file-pl-def-v50.xml- 15.738 l / 100 km

In this example:

my_emission_file-vl-eco-v50.xml
```

The speed of the network is 50 km/h as v50, vl-stands for passenger car and eco-for a eco-driver. The emission file represents all the outputs of each vehicle concerning all emissions, pollutants, speeds and fuel consumption.

This is a parametric verification of the simulation environment, taking into account a straight and flat virtual infrastructure of 100 km, faced with a variety of driver behavior and vehicle characteristics. The simulated vehicles maintain constant speed defined by the network.

Titre: Potentialité d'éco-conduite des infrastructures routiéres selon l'adéquation entre tracé et vitesse d'usage

Mot clés : Dynamique du véhicule, Éco-conception, Consommation d'énergie, Trafic

Resumé : Le lien entre les infrastructures routières et l'utilisation de l'énergie n'a pas été étudié en profondeur, car les attentes de la société en matière de transport sont essentiellement liées à l'efficacité et à la sécurité. Avec l'émergence des enjeux environnementaux, les pistes pour réduire la consommation d'énergie en procédant à des optimisations mineures de l'infrastructure routière sont explorées. Cette thèse vise à développer l'une de ces optimisations en améliorant le potentiel d'éco-conduite des infrastructures routières. Pour cela, l'énergie dépensée par les véhicules sur une route en fonction de leur dynamique, leur géométrie et la section en vitesse est modélisée. L'optimisation du sectionnement en vitesse peut faciliter l'éco-conduite, limitant ainsi l'utilisation nécessaire du freinage mécanique à l'approche d'une section de réduction de vitesse. Une méthodologie en quatre étapes a été mise au point pour évaluer le sectionnement en vitesse. La première étape consiste à proposer un critère utilisable par les gestionnaires pour détecter rapidement un mauvaise position de sectionnement de vitesse (Misplaced Speed-sectioning Position, MSP). La deuxième étape quantifie le coût énergétique d'un mauvais positionnement (MSP) et la position optimale du sectionnement de la vitesse pour un éco-conducteur. Les résultats de ces deux étapes fournissent des informations au gestionnaire qui peut proposer une nouvelle disposition des sections de vitesse en tenant compte du trafic et de la configuration de la route. La troisième étape de notre méthodologie consiste en une simulation des flux de circulation permettant une meilleure évaluation énergétique des nouvelles sections de vitesse, basé sur des données réelles de trafic, et en modélisant plusieurs comportements des conducteurs. La quatrième étape est un processus d'optimisation pour trouver le sectionnement optimisé de la vitesse. Des expériences ont été menées en Bosnie-Herzegovine et en France pour démontrer la faisabilité de la méthodologie.

Title: Ecodriving potentiality of road infrastructures according to the adequacy between infrastructure geometrical characteristics and vehicles speeds

Keywords : Vehicle dynamics, Eco-design, Energy consumption, Traffic

Abstract: The link between road infrastructure and use energy has not been, studied in depth , particularly as the legitimate societal expectations for transportation are primarily related to efficiency and safety. The environmental emergency implies to explore new trends as minor optimization of the road to reduce the energy use. This thesis aims to develop one of these optimization by improving the potential of eco-driving road infrastructure. This will be achieved by modeling the effect on the energy spent by vehicles on a road of the adequacy between their dynamics, geometry and the sectioning in speed of the infrastructure. A four steps methodology has been developed to assess speed sectioning. The first step is to propose a criterion usable by road managers to rapidly detect Misplaced Speed-sectioning Position (MSP). The second step quantifies the energy cost of a MSP for a particular vehicle and the optimal position of the speed sectioning for an eco-driver. The outputs of these two steps yield information to the manager who can propose a new speed sectioning layout taking into account traffic and road configuration. The third step of the methodology involves a traffic flow simulation enabling an enhanced energy evaluation of new speed sectioning, based on real traffic data, and modeling several driver behaviors. The fourth step is an optimization process to find the optimized speed sectioning. Experiments have been carried out in Bosnia-Herzegovina and France to demonstrate the feasibility of the methodology. The benefits are reduced energy consumption, air pollution and noise produced by braking.