Evaluating vehicles emissions through traffic simulation

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Abstract: - The dynamic of the human activities due to the globalization and to the extension of the free movement of persons and goods involve the increasing of traffic flows crossing transport sensitive areas, generating great negative externalities (air, soil pollution, noise, vibrations). The paper deal with a method to assess the vehicles exhaust emissions combining traffic survey, traffic simulation and emission factors proposed by the European Environment Agency. A computer simulation model is conceived to record individual movement of cars and computing emissions based on their activity (traveled distance, speed), technical features, emissions standard. The case study investigates the exhaust emissions process on Prahova Valey in the Carpathians, a transport sensitive area bordering protected natural areas. The presence of tourist and cultural heritage attraction points, combined with the specific topography of the road network generate, during weekends and holidays, congestion phenomena associated with great externalities, mainly noise and exhaust emissions. Comparison among emission during congested periods and traffic calming are outlined.

Key-Words: - computer traffic simulation, vehicles exhaust emissions, road congestion

1 Introduction

The EU enlargement, the economic growth in the European space, the free movement liberties (capitals, goods, services and persons) in the common space generate the increasing of trade relations and the traffic flows between European regions. The dynamic of transport flows determine the socio-economic restructuring of the territory and also negative externalities. The greenhouse gases, the acidification of air and soil, the noise and vibrations, the land fragmentation, and the accidents are threatening factors affecting ecosystems, natural heritage and human life.

The EU legislation promoted political, administrative and financial instruments for supporting local, regional or national authorities to include environmental impact analysis in planning the transport infrastructures development (Environmental Impact Assessment Directive 85/337/EEC, Strategic Environmental Assessment Directive 2001/42/EC, Flora-Fauna-Habitat Directive 92/43/EEC, Transport Environment Reporting Mechanism etc.). At European level, have been identified and recognized the existence of special zones where the transport and traffic impact exceeds the general preservation frame [1]. These zones are delineated as transport sensitive areas. The research project Mountain Areas in Europe [2], outlines the taxonomy of mountain areas according to five altitude levels, inside each one mentioning the specific conditions (slope, temperature variation).

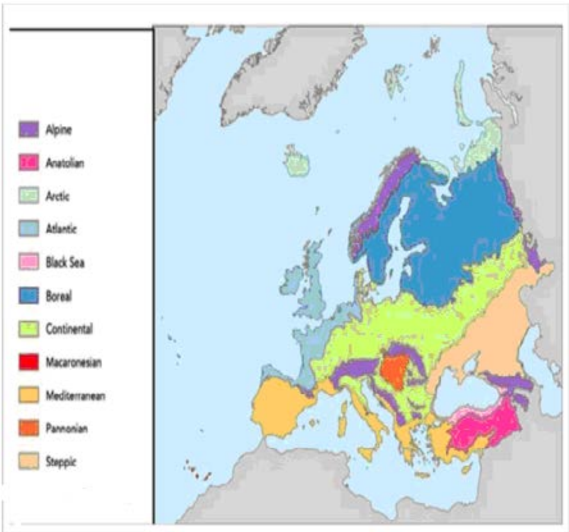

Fig. 1 Bio-geographical European regions
(Source: European Environmental Agency, 2002)

According to this study, 40% of the European territory was declared as mountain areas. At national level, the largest mountain areas are in Swiss and Norway (90%), Greece (78%) and Austria (73%).

The impact factors generated by human activities are evaluated by their spread area, magnitude, frequency, and reversibility. Because the effects are different among transport modes, a modal discrimination is allays necessary [3], [4]. The negative externalities due to road traffic that affect the most mountain areas are depicted in table 1.

Table 1 Externalities of road traffic

Indicator	Impact
Land use	▪ Soil/water quality ▪ Land fragmentation
Noise level	▪ Loses on fauna ▪ Disturbing tourist and leisure activities
Air quality	▪ Negative effects on receptors (human beings, fauna, flora)
Adjacent effects	▪ Natural hazards ▪ Transport network vulnerability

Road vehicles were responsible for around 33% of NOx, 14% of VOC, 29% of CO emissions, 14% of PM10, and 15% of PM2.5 (including non-exhaust emissions) in EU Member States in 2012 [5]. Road transport remains the most polluting transport mode with respect to NOx, CO and VOC emissions. Urban areas are the main zones where the exhaust emission limits are broken, but this can also occur in transport sensitive areas like mountain valleys where the atmospheric air layers inversion reduces the emissions dissipation. The mountain valleys, due to their seen-sights, or because the transport connection role could attract important traffic flows, turning into congestion during some periods. The models for assessing the negative externalities generated by traffic plays a major role in evaluating new traffic scenarios that could occur by taking actions to limit the traffic (e.g. transit limitations for some vehicles, taxation, speed limit). The paper develops a model to evaluate vehicles emissions, using traffic computer simulation and emission factors proposed by the European Environment Agency. For small areas, the proposed model exceeds the limits of the COPERT 4 system, by recording the individual movement of vehicles in different traffic patterns.

2 Vehicles exhaust emission factors

The European Environmental Agency (EEA), in Emission Inventory Guidebook 2013 [6] proposed three tiers for counting car exhaust emissions:

- Tier 1 uses fuel as activity indicator combined with average fuel-specific emission factors. The method is suitable in the absence of more detailed data than fuel consumption;
- Tier 2 approach considers the fuel consumption for different vehicle categories, running regime (urban, rural, highway) and their emission standards;
- Tier 3 uses a combination of vehicle activity data (average speed, mileage) and technical data (emission factors).

While Tier 1 method has a macroscopic view (used at national or regional level), the Tier 3 approach is more appropriate to be implemented for smaller administrative units or links in road networks. The Tier 3 method is further used in evaluating pollutants emissions correlated to car traffic (outlining the influence of congestion). The COPERT IV system implements the EEA Tier 3 assessing methodology, but it uses the average speed on the network links despite the vehicles individual speed.

The exhaust emissions for gases like CO, NOx and VOC are speed dependant and could be computed using the general equation:

$$E_{i,k,r} = N_k \times M_{k,r} \times e_{i,k,r} \quad (1)$$

where:

$E_{i,k,r}$ is the exhaust emission for the pollutant *i* [g], produced by the vehicle of technology *k* driven on a road of type *r*;

N_k - the number of vehicles [veh] of technology *k*;

$M_{k,r}$ - the mileage per vehicle [km/veh] driven on road *r* by vehicle of technology *k*;

$e_{i,k,r}$ - the emission factor [g/km] for pollutant *i* by vehicle of technology *k* on road type *r*.

For passenger cars, the generic function used for carbon monoxide (CO), nitrogen oxides (NOx) and volatile organic compounds (VOC) emissions is:

$$e_{i,k,r} = \left(a + cV + eV^2\right) / \left(1 + bV + dV^2\right) \quad (2)$$

where V is the average car speed [km/h] and the coefficients a-e are provided for each pollutant, car technology (Euro 1-5) and engine capacity. For pre-Euro cars, polynomial and power functions are also available.

The emission factors for pre-Euro and Euro1 light-duty vehicles are described by a quadratic form:

$$e_{i,k,r} = a + bV + cV^2 \quad (3)$$

where the coefficients a-c are also provided for each pollutant and technology. For post-Euro 1 vehicle, the emissions are calculated by (3) and a specific reduction factor.

For coaches/buses and heavy-duty trucks, the most common generic functions for exhaust emissions are:

$$e_{i,k,r} = (a + bV) + (c - b) \times (1 - \exp(-dV))/d \quad (4)$$

$$e_{i,k,r} = e + a\exp(-bV) + c\exp(-dV) \quad (5)$$

where the coefficients a-e are provided for individual engine technology, road gradient and loading factor [6].

3 The use of road traffic simulation in assessing vehicles emissions

Advances in computer science along with the need for traffic management models have urged for the use of the microscopic simulation models as useful tools for traffic planners. Microscopic simulation can be applied for assessing traffic outputs that are difficult to be quantified through the field measurements, such as fuel consumption, exhaust emissions, air quality impacts and accident risk factors.

An outstanding property of micro-simulation traffic models is the tracing of the individual vehicles activity over a series of short time intervals or run distances. Boulter et al. [7] and Barceló [8] provide useful guide-lines to the principles of traffic simulation. Tate et.al [9], Panis et al. [10], Jayaratne et al. [11], Xia and Shao [12] present examples for integrating traffic simulation and vehicles exhaust emission models.

Figure 2 depicts the proposed methodology for evaluating cars exhaust emissions, combining traffic data, computer traffic simulation using VISSIM software and emission factors estimated through European Environmental Agency (EEA) models.

Using real world coordinates through Geographic Information System (GIS), the transport infrastructure topology is described in terms of links, lanes, connections, roundabouts, speed limit areas, traffic calming elements, priority rules, signaling. The car traffic flow and input data are provided separately for each vehicle type (passenger car – PC, light duty vehicle – LDH, heavy duty vehicle – HDV, bus/coach, motorcycle). The vehicles should be classified according to their fuel type (gasoline, diesel, LPG, CNG, hybrids), technology/standards (e.g. pre ECE, Euro 1-5) and engine capacity.

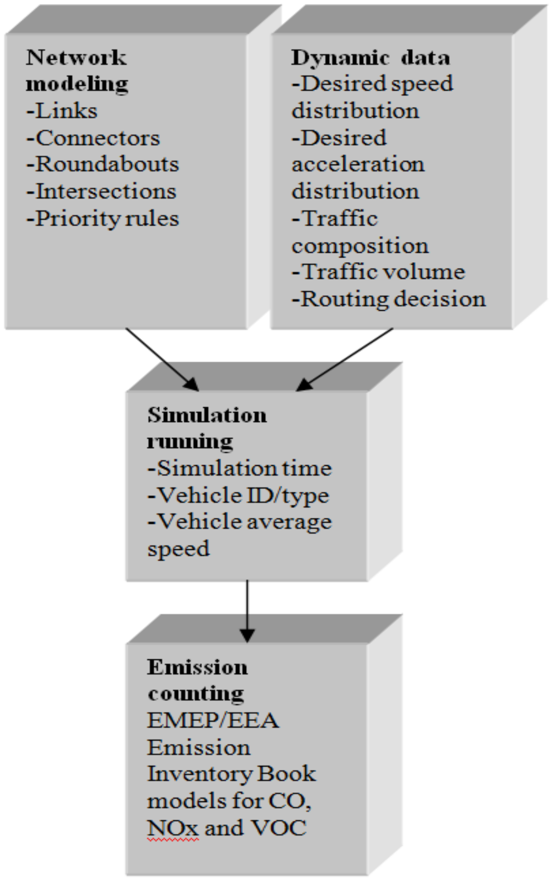

Fig. 2 Vehicles emission assessing using traffic computer simulation

The VISSIM traffic simulation software implements the psycho-physical car-following model developed by Wiedemann [13]. Vehicles are the main objects in this modeling approach. The class of vehicles contains the following default attributes:

- current speed,
- current acceleration,
- desired speed,
- maximum negative acceleration,
- maximum positive acceleration,
- current position on a path,
- current state.

There are only discrete values for the current state attribute. The state of a vehicle describes different behavioral patterns of vehicles, as depicted in table 2.

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Table 2 States of a vehicle during simulation

State	Kind of drive	Acceleration
Free Driving (I)	not influenced	depending on the current speed and the desired speed
Free Driving (II)	direct influenced	positive acceleration until the desired distance is reached and the difference in speed is zero
Approximating (I)	direct influenced	negative acceleration until the desired distance is reached and the difference in speed is zero
Approximating (II)	direct influenced	negative acceleration until the risk distance is reached and the difference in speed is zero
Following	indirect influenced	keeping acceleration until the desired distance is reached and the difference in speed is zero

The state will be changed if defined limits for distances to the predecessor or differences in speed are crossed. The acceleration of the vehicle will be newly recalculated and shall then be constant until the driver has to react to new traffic conditions.

4 Case study

Prahova Valley, crossing the Central Carpathians, is one of the most transited mountain routes connecting the southern and the central parts of Romania. The proximity of great socio-economic urban areas (Ploiesti and Brasov), the tourism attraction and the leisure facilities generate important traffic flows, which during some periods (weekends, holidays) cause congestion and therefore an increase in car exhaust emissions.

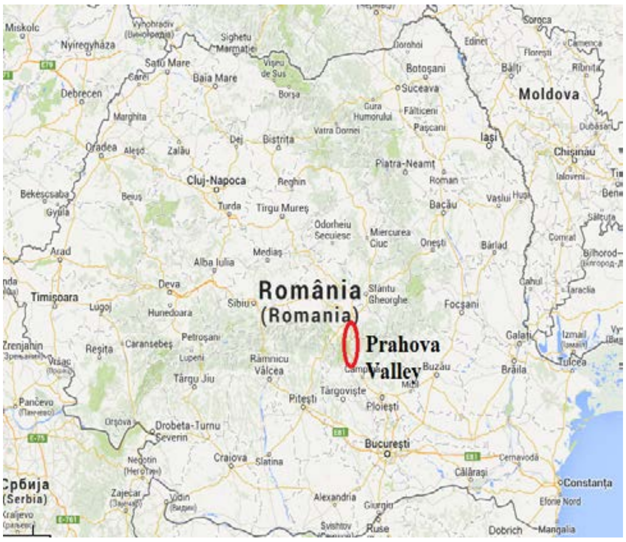

Fig. 3 Prahova Valley geographic position

The observed daylight vehicles traffic data by field survey is shown in table 3.

Table 3 Traffic data

Vehicle type	Traffic flow [veh/h]				
	Time interval				
	5:00-7:00	7:00-11:00	11:00-16:00	16:00-19:00	19:00-22:00
Passenger cars (PC)	52 - 190	235 - 246	496 – 1105	468 - 602	286 - 393
Light-duty vehicles (LDV)	14 - 48	15 - 66	48 - 62	42 - 58	36 - 52
Heavy-duty vehicles (HDV)	34 - 66	12 - 14	2-6	6 -12	18 - 22
Busses & Coaches (B/C)	2 - 4	4-12	6-12	4 -8	2 - 4

The lower values are specific for working days, while the highest values are recorded during weekends. The vehicles discrimination based on fuel and technology/standards is depicted in table 4.

Table 4 Vehicles traffic composition

Vehicle type	Fuel	Technology/ Standards
Passenger cars (PC)	Gasoline 76.85% Diesel 19.89%	Pre-Euro - 54% Euro2 - 10% Euro3 – 17% Euro4 – 19%

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	LPG 3.26%	
Light-duty vehicles (LDV)	Gasoline 43.65% Diesel 56.35%	Pre-Euro - 34% Euro2 - 17% Euro3 – 30% Euro4 – 19%
Heavy-duty vehicles (HDV)	Diesel 100%	Pre-Euro - 49% Euro2 - 18% Euro3 – 21% Euro4 – 12%
Busses/ Coaches (B/C)	Diesel 100%	Pre-Euro - 51% Euro2 - 7% Euro3 – 35% Euro4 – 7%

The traffic simulation is built-up using VISSIM software. An instant of the simulation is depicted in figure 4.

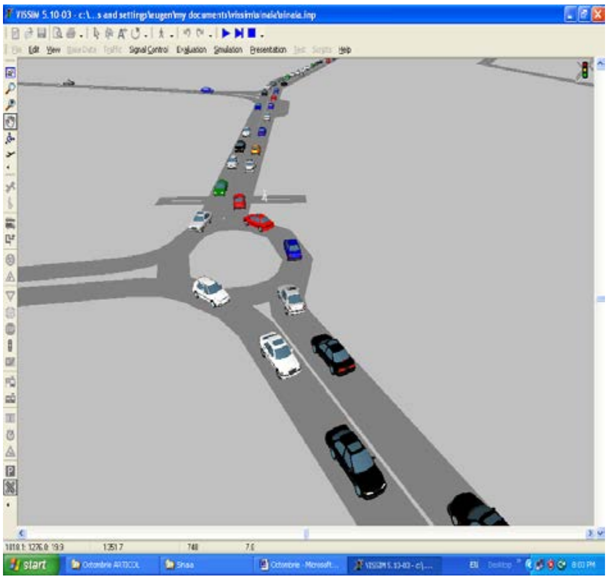

Fig. 4 Traffic simulation 3D instant

Individual vehicle activity and characteristics are traced and the average speed is computed when leaving the area. Based on this data emissions are evaluated. The limits for CO, NOx and VOC emissions during day-time intervals and the day of the week are shown in figures 5-7.

During working days, the intervals 7:00-11:00 and 19:00-22:00, and respectively 11:00-16:00 and 16:00-19:00 are quite similar, expressing similar equivalent traffic volumes. During weekends, a huge increase is recorded between 11:00-16:00, where the amount of emissions is 2.5 times greater than the similar period during working days.

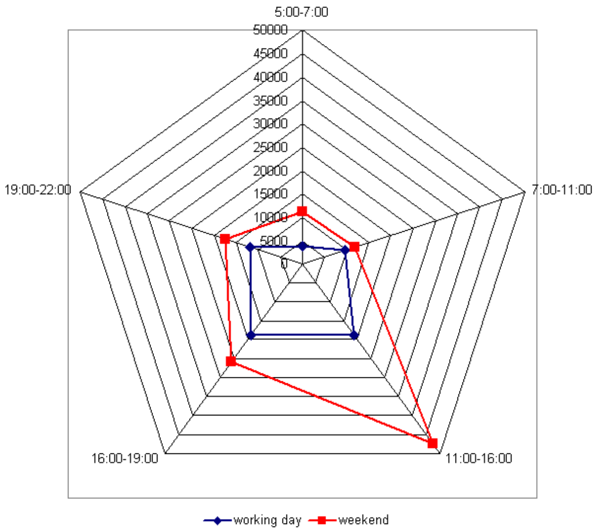

Fig. 5 CO emission [g/h]

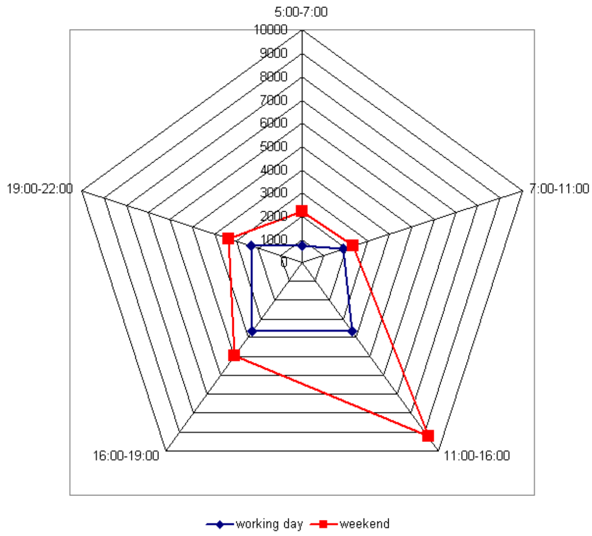

Fig. 6 NOx emission [g/h]

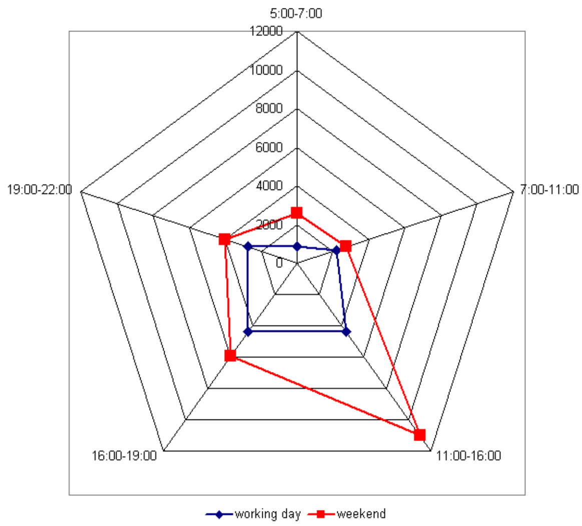

Fig. 7 VOC emission [g/h]

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5 Conclusion

Mountain areas have a special sensitivity concerning transport activities, described through a large category of elements (abiotic, biotic and land-use). These areas act as natural barriers for transportation and allocate traffic flows on a small number of routes, along mountain valley where human settlements are also located.

The concentration of transport activities on narrow spaces on mountain regions generates:

- Increasing sensitivity at air pollution by the phenomenon of air layers inversion due to high altitude, topography and climatic conditions;
- Greater accumulation of chemical pollutants and increasing soil oligotrophy;

The physical features of the mountain transport networks, the natural relief and the traffic conditions generate air pollution emissions that currently overpass the European average levels. The weekend leisure-time and the business tourism are among the most responsible human activities for road traffic congestion and therefore for the growth in vehicle exhaust emissions along mountain valleys in Romania. The rising of car ownership and the land use policies allowing the spread of the residential areas in mountain resorts are translated into an intensive passenger car use in the areas. Most of the new residential areas and the tourist accommodation facilities are developed in zones with feeble or non-existing public transport. At the same time, the modal shift is not well encouraged through national or regional actions towards more efficient transport means.

The awareness of these aspects lead to the inclusion of the discussions on sensitive mountain areas related to transport into the European and regional convention (i.e. Alpine Convention [14], Carpathian Convention [15]), where political, social, economical and environmental frame could provide solutions (administrative, fiscal or technical) for limiting the negative externalities due to car traffic and promoting the requirements of the sustainable development.

Acknowledgment

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