TRAFFIC CONGESTION AND ENERGY CONSUMPTION

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REZUMAT. Extinderea aşezărilor urbane, amplasarea activităţilor socio-economice, dependenţa de automobil şi fiabilitatea redusă a serviciilor publice de transport generează congestia traficului în marile aglomerări urbane. Creşterea numărului de cicluri de conducere, viteza redusă de deplasare, comportamentul individual şi caracteristicile infrastructurii sunt factorii determinanţi în asocierea dintre creşterea consumului de combustibil şi congestia urbană. Utilizând simularea numerică pe calculator, lucrarea analizează influenţa acestor factori asupra variaţiei consumului de combustibil.

Cuvinte cheie: trafic rutier, congestie urbană, consum de combustibil, simulare numerică.

ABSTRACT. The spread of the urban settlements, the localization of the socio-economic activities system, the car dependency, the poor reliability of the public transport services generate traffic congestion into the large urban areas. The increase number of driving cycles, the low speed, the individual travel behavior and the infrastructure characteristics are the main factors associating increased fuel consumption and urban congestion. Through computer simulation, the paper investigates the influence of these factors in fuel consumption variation.

Keywords: road traffic, urban congestion, fuel consumption, computer simulation.

1. INTRODUCTION

The spread of the urban settlements, the interaction between the land-use and the socio-economic activities system, the car dependency, the poor reliability of the public transport services generate traffic congestion into the large urban areas, with high influence on energy consumption in the transport system. The growing number of driving cycles, the vehicles low speed, the individual travel behavior and the road infrastructure characteristics are the main factors in increasing energy consumption associated with the urban traffic congestion.

To reduce energy consumption in transport sector, automotive engineers, transport planners and policy makers are urging for different policies and measures:

- ❑ Encouraging fuel intensity and fuel economy through fuel taxes and agreements with industry to improve vehicle fuel efficiency (e.g. smaller vehicles, increasing powertrain);
- ❑ Promoting transport demand and traffic management systems supported by specific taxes, promoting public transport and car sharing/pooling;
- ❑ Using alternative technologies such as hybrid, fuel cells or bio-fuels;
- ❑ Educating local policy makers and the public about the measures taken for reducing energy consumption.

Taxation plays an important role in countries strategies in reducing the transport demand. Congestion charging and access taxation has been experimented in some cities around the world (e.g. London, Singapore, Milan). Also a number of measures have been introduced to urge a shift from individual car use to public transport system by increasing the frequency, convenience and travel speed for public transport (dedicated lanes and preemption at crossings).

2. URBAN CONGESTION

Traffic congestion on streets and highways has grown to critical dimension in many cities of the world and has become a major problem with many detrimental effects including lost time, higher fuel consumption, more vehicle emissions, increased accident risk, and greater transportation costs.

Traffic congestion is relatively easy to recognize: roads saturated with cars, trucks and buses. The definition of term congestion indicate words such as "blocking", "frequent braking" and "excessive agglomeration" which are familiar for every traffic road user.

Taylor [1] defines traffic congestion as "the phenomenon of increased disruption of traffic movement on an element of the transport system, observed in terms of delays and queuing, that is

generated by the interactions amongst the flow units in a traffic stream or in intersecting traffic streams. The phenomenon is most visible when the level of demand for movement approaches or exceeds the present capacity of the element and the best indicator of the occurrence of congestion is the presence of queues."

All the various measures to combat congestion attempt to reduce the transport infrastructure demand/supply ratio, respectively:
- The rearrangement and development of the urban network infrastructure;
- A better use of the existent urban network infrastructure;
- Mobility Management to reduce social mobility (the number of vehicle-km on the existent infrastructure) and also traffic peaks.

Because land is scarce and road infrastructure is expensive to construct, it would be uneconomical to invest in so much capacity to ensure continuous traffic regimes close to the free flow. Indeed, because demand for travel depends on the cost, improvements in travel conditions induce people to take more trips, and it would probably be impossible to eliminate congestion [2].

3. FUEL CONSUMATION IN ROAD TRANSPORT

Fuel consumption is commonly associated with average speed, and researchers often use average speed as a traffic performance measure. These speed-fuel consumption factors (in terms of grams per km) can be drawn by simply taking the accumulated vehicle activity database and its fuel consumption in different traffic situation. Then we can split the trip into smaller segments representing the time spent on streets, and residential streets, and we can then associate a consumption curve with the average speed of that particular trip segment. A"U" shape is the most common form for this curve.

Using statistic data gathered from different research projects, the European Environmental Agency [3] describes the fuel consumption by various generic functions. These functions are dependent of the average speed and are also discriminated by fuel type and vehicle class. Table 1 shows different generic functions for a passenger cars, light duty vehicles and busses which are the most present in urban traffic.

Table 1

Speed (V) dependency functions of vehicles fuel consumption

Vehicle type	Fuel	Vehicle class	Fuel consumption generic function [g/km]
Passenger cars	Gasoline	Pre Euro 1	aV^{-b} $a + bV$ $a + bV + cV^2$
		Euro 1-4	$\dfrac{a + cV + eV^2}{1 + bV + dV^2}$
	Diesel	Pre Euro 1	$a + bV + cV^2$
		Euro 1-4	$\dfrac{a + cV + eV^2}{1 + bV + dV^2} + \dfrac{f}{V}$
	LPG	All categories	$a + bV + cV^2$
Light duty-vehicles	Gasoline	All categories	$a + bV + cV^2$
	Diesel	All categories	$a + bV + cV^2$
Busses	Diesel	Pre Euro I	$e + a\exp(-bV) + c\exp(-dV)$
		Euro I-IV	$c + a\exp(bV)$

(Source: EEA, 2009)

In table 1, the coefficients a-f have distinctive value for each vehicle category, also discriminated by engine capacity and speed range.

This family of fuel consumption-speed curves illustrates several key ideas. Very low average speeds generally represent frequent stop-and-go driving cycles.

Therefore, the fuel consumption per kilometer is quite high. Conversely, when vehicles travel at much higher speeds, they demand very high engine power, which require more fuel. As a result, this fuel consumption-speed curve has a distinctive "U" shape, with high

consumption rates on both ends and low emission rates at moderate speeds.

4. CASE STUDY. FUEL CONSUMPTION UNDER CONGESTION CONDITIONS IN GROZĂVEŞTI AREA

The road intersection Grozavesti-Splaiul Independentei (Grozavesti bridge) was chosen as case study.

In order to build an Aimsun model [4], the following input data are required:

- Network Layout: map of the area, details of the number of lanes for every section, reserved lanes, possible turning movements for every junction, speed limits for every section and turning speed for allowed turns at every intersection;
- Traffic Demand Data: vehicle types and their attributes, vehicle classes (for reserved lanes), flows at the input sections (entrances to the network) for each vehicle type, turning proportions at all sections for each vehicle type;
- Traffic Control: location of signals, the signal groups into which turning movements are grouped, the sequence of phases and, for each one the signal groups that have right of way, the offset for the junction and duration of each phase.

The input data have been obtained through traffic survey (Figure 1). We suppose that the sum of input system flows equals the sum of output system flows $Q_{in}=Q_{out}=Q$.
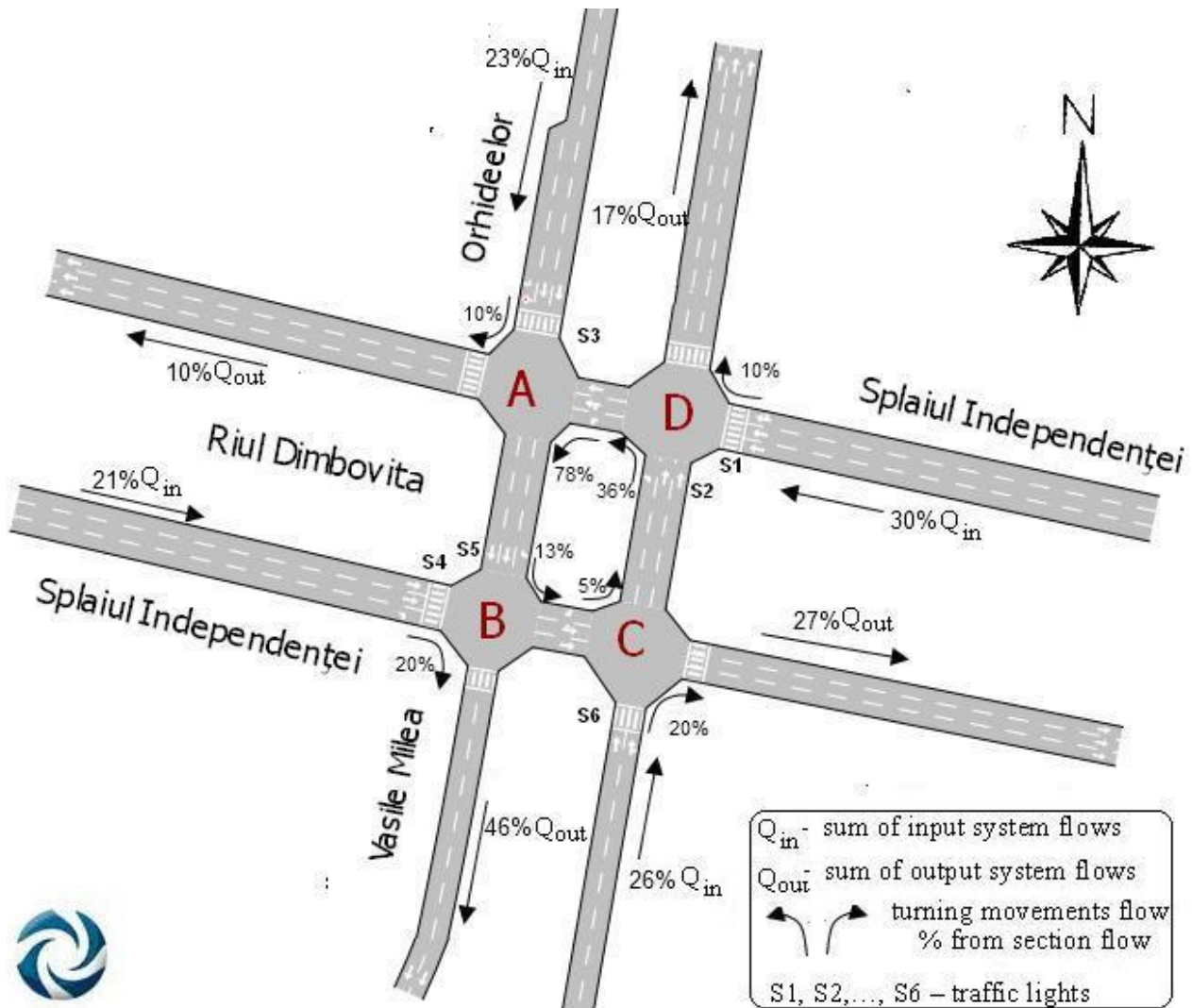

Fig. 1. The pattern of Grozavesti intersection for simulation in Aimsun

Grozavesti intersection can be regarded as consisting of four simple synchronized intersections. These intersections are:

> A – intersection between Orhideelor street and Splaiul Independenței (upstream),
> B - intersection between Splaiul Independenței (upstream) and Vasile Milea,
> C - intersection between Vasile Milea and Splaiul Independenței (downstream),
> D - intersection between Splaiul Independenței (downstream) and Orhideelor street.

For intersection A, we labeled A1 the input stream from Orhideelor and A2 the outflow from Splaiul Independenței to Regie.

Similar notations are used for the other nodes B, C, D. Note that A1, B1, C1, D1 are input flows in the system, A2, B2, C2, D2 are flows out of the system. Simulation experiments have been conducted under the following assumptions:

- Transitory period (warm-up) simulation is one hour, sufficient to limit the effects of initial state and to reach steady [5].
- Simulation time lasts two hours between 8:00 to 10:00, the input system flow is Q_{in} = 3300-4000 veh/h.
- Traffic light cycle T_C=100s, t_{g1}=50s, t_{g2}=40s, t_{g3}=60s (Figure 2)

> t_{g1} - the duration of green and yellow time corresponding groups of traffic lights S3, S6 (Orhideelor Street entrance, respectively Grozavesti);
> t_{g2} - the duration of green and yellow time corresponding groups of traffic lights S1, S4 (Independence-PUB Splaiul entry and Cotroceni);
> t_{g3} - the duration of green and yellow time corresponding groups of traffic lights S2, S5 (Grozavesti bridge exits).
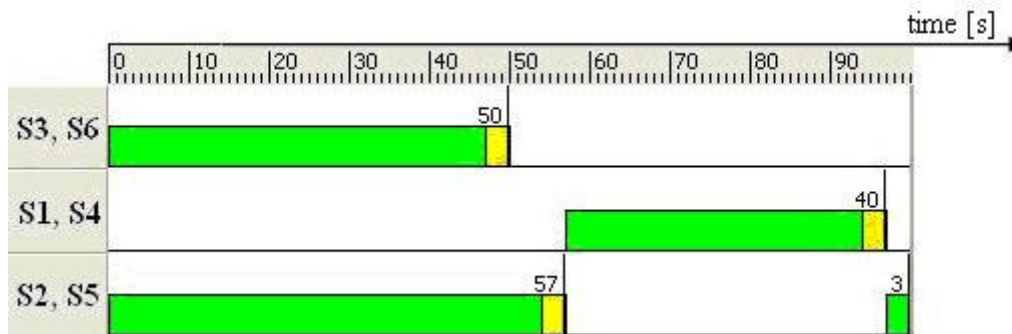

Fig. 2. Lighting system diagram

The statistical traffic measures provided by Aimsun can be specified at different levels of aggregation for the whole system, for each section or for each turning movement. Some of the statistics provided by Aimsun at the section level are the following are mean flow (average number of vehicles per hour that have crossed the section during the simulation period) and mean speed (average speed for all vehicles that have traversed the section).

Table 2

Traffic flows and speeds

Qin [veh/h]	Q [veh/h]				v [km/h]				Q [veh/h]				v [km/h]			
	A1	B1	C1	D1	A1	B1	C1	D1	A2	B2	C2	D2	A2	B2	C2	D2
3318	745	690	857	1026	21,9	19,7	29,3	14,2	340	1503	909	566	48,2	47,8	48,5	47,8
3496	793	719	921	1063	20,2	19,2	28,4	12,6	373	1570	945	608	48,2	47,8	48,3	47,8
3695	846	746	975	1128	15,7	18,8	27,3	8,65	434	1644	976	641	48,3	47,7	48,4	47,8
3918	897	834	1004	1183	11,5	18,3	26,4	3,2	544	1663	1047	664	48,2	47,7	48,4	47,8
4019	910	850	1066	1193	8,6	19,1	24,7	3,6	543	1677	1094	705	48,2	47,8	48,2	47,7

The traffic flows composition, established through traffic survey, is depicted in Table 3.

Table 3

Traffic flow composition

Vehicle	Fuel	Engine
Personal car – 83%	Gasoline – 76% Diesel – 23% LPG – 1%	Pre Euro – 17.46% Euro 2 – 12.56% Euro 3 – 28.16% Euro 4 – 41.82%
Light-duty vehicle – 17%	Gasoline – 43% Diesel – 57%	Pre Euro – 14% Euro 2 – 6.2% Euro 3 – 37.98% Euro 4 – 41.82%

Also, a number of 6 busses/h are entering each input link.

Following the fuel consumption function for each vehicle characteristics and taking into consideration the traffic simulation data (flow-speed dependency), the overall fuel consumption in the study area is depicted in Figure 3.
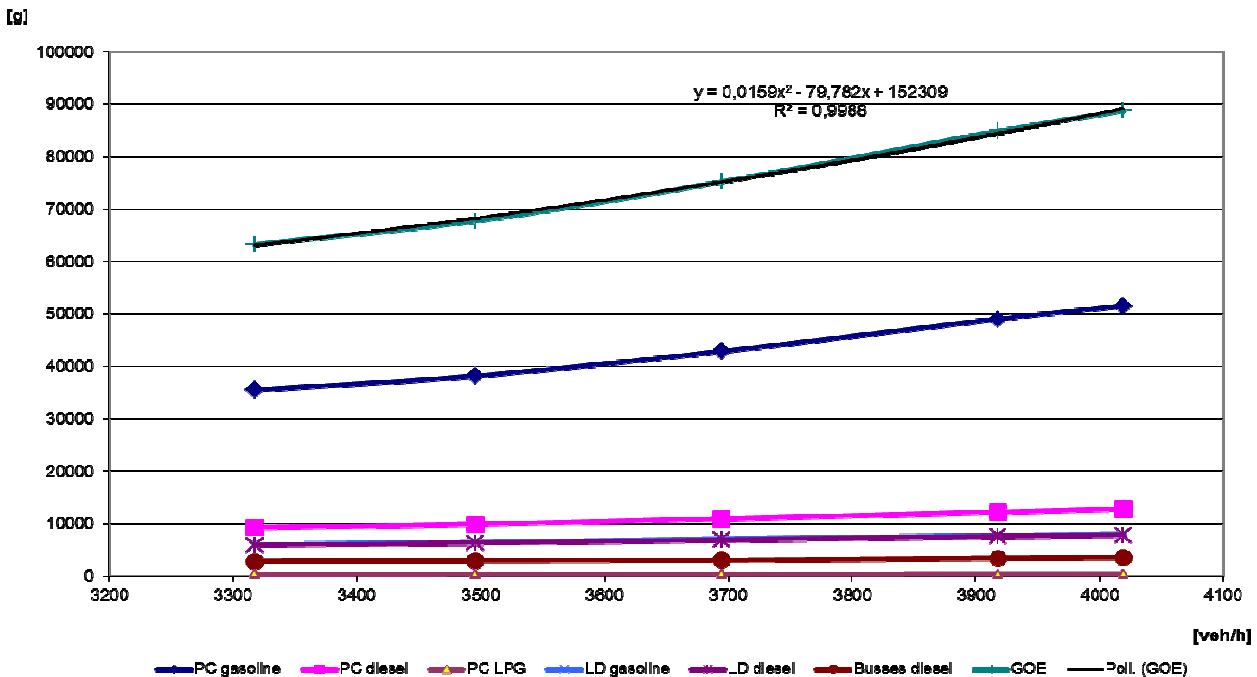

$$y = 0.0159x^2 - 79.782x + 152309$$
$$R^2 = 0.9988$$

Fig. 3. Fuel consumption in the study area

The fuel consumption is computed for each vehicle and fuel type. The overall consumption is expressed in grams of oil equivalent, taking into consideration the conversion factors in table 4.

Table 4

Oil equivalence conversion

Fuel	Oil equivalent coefficient
Gasoline	1.0650
Diesel	1.0344
LPG	1.1263

The grams of oil equivalent function has a quadratic form with a very good coefficient of determination, but taking into consideration the wide range of speeds distribution, the coefficient of the second power is very feeble.

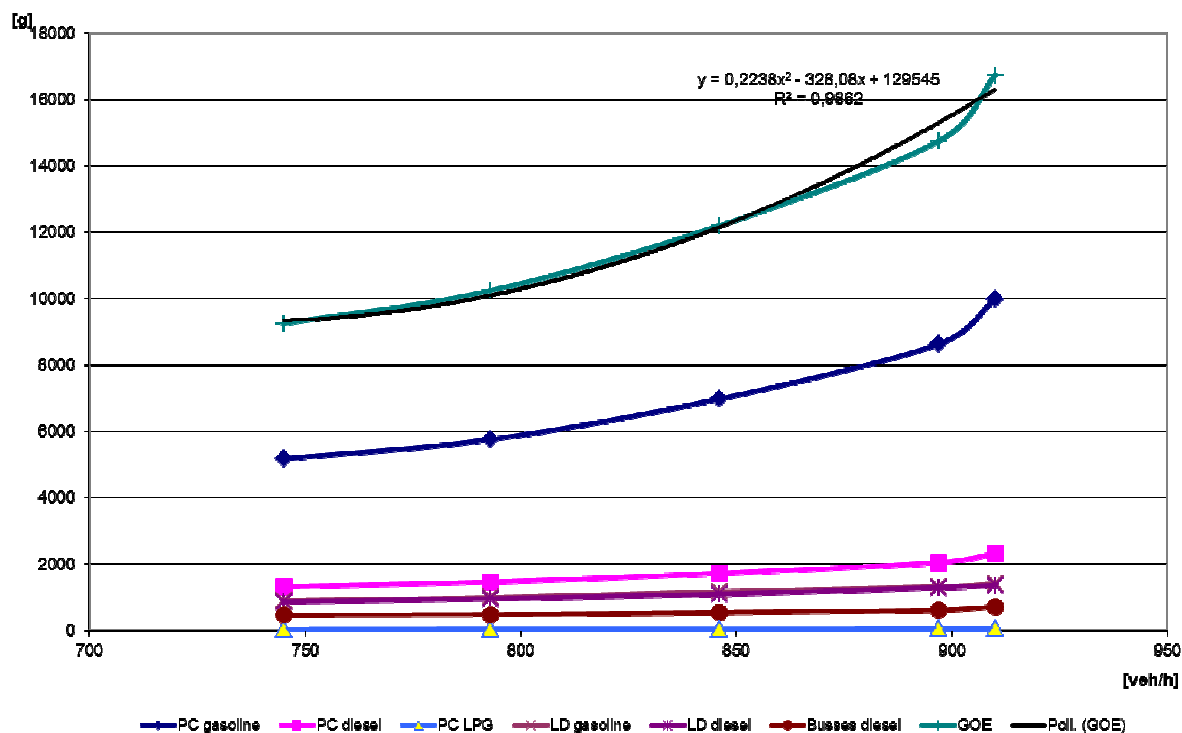Also for the input link A1, the overall fuel consumption is shown in Figure 4.

$$y = 0,2236x^2 - 326,06x + 129545$$
$$R^2 = 0,9662$$

Fig. 4. Link A1 fuel consumption

The A1 link is a higher congested one. The increase in the traffic flow turns into a quick decrease of the vehicles speed which causes higher fuel consumption due to the greater number of stop-and-go driving cycles. Also for this link, the overall fuel consumption function has a quadratic form with a stronger coefficient of the second power compared to the whole study area.

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