Evaluation of traffic gases emissions: the case of the city of Tunis

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Abstract

The purpose of this paper is to show how the operations research techniques can help to evaluate the emissions of polluting gases from road traffic in urban area. Our practical study case is the center of Tunis city.

To evaluate the emissions of several polluting gases (CO, CO2, SO2, NOx, CH4 and VOC), we have combined the traffic assignment model ATESAME [1] with new module implementing the CORINAIR [2] formulas.

The traffic assignment model corresponds to a static User Equilibrium model that can be computed by solving a nonlinear optimization problem (See Sheffi [5]). This nonlinear convex model can be efficiently solved by using the classical Frank Wolfe technique. The CORINAIR formulas give an expression of the unitary emissions, i.e. the emissions per kilometer, as a function of the vehicle speed and of the current temperature.

Several scenarios of traffic congestion and temperature conditions have been simulated for the center of Tunis City. We present here the mains results from the simulations for the center of Tunis city.

1 The emissions model

Let us now briefly describe the functioning of the model evaluating the polluting gases emissions. This model combines a classical *User Equilibrium model* with an implementation of the polluting gases emissions formula. We first recall the definition of an *User Equilibrium.* Then we present the CORINAIR methodology [2] to evaluate the unitary emissions from road traffic.

1.1 The traffic assignment model

We recall first the *User Equilibrium* definition which can be found, for example, in Sheffi [5]. It is assumed that each traveler has for objective to minimize his total travel time, which is the sum of the travel times of all the arcs constituting his route.

Definition 2.1 *An* **User Equilibrium** *will be reached when no traveler can improve his travel time by unilaterally changing his route.*

Mathematically, on can give the following equivalent formulation:

Definition 2.2 *At an* **User Equilibrium,** *for each group of travelers having the same origin point and the same destination point,*

- *the travel times for* **all used paths** *connecting the origin to the destination are* the same.
- *the travel times of* **unused path** *are* **greater or equal to** *the common travel time of used paths for this group.*

Following Sheffi [5], we recall how equilibrium solutions can be computed as solutions of an *equivalent non linear optimization problem.*

The data of the problem are the following.

1. The **supply side** of the traffic assignment model is given by :
   - the *network* which can be represented by a Graph $\mathcal{G} = (\mathcal{N}, \mathcal{A})$ where $\mathcal{N}$ is the *set of nodes* and $\mathcal{A}$ is the *set of arcs* indiced by a.

- the *link performance function* associated to each a, noted $t_a(x_a)$ giving the **link travel time** of arc a as a function of the traffic flow on arc, x_a.

2. The **demand for travel** is represented by an *origins-destinations matrix* q, where element q_{od} is the *number of traveler between the origin node o and the destination node d* for a specific time period (generally the peak hour).

We use p as indice for a particular *path* linking an origin node to a destination node. The **travel time on a particular path** p is noted c_p. It can be computed as the sum of travel times on the successive arcs of the path linking origin node o to destination node d :

$$c_p = \sum_{a \in p} t_a \tag{1}$$

The **variables** of the problem are the *path flows*, noted f_p for the flow on path p. The following *relation between path flows f_p and arc flows x_a* can be established. The flow on an arc is the sum of the flow on all paths using arc a:

$$x_a = \sum_{p|a \in p} f_p, \quad \forall a \in \mathcal{A} \tag{2}$$

We can also establish the following *relation the path flows f_p and the demand q_{od}*. In fact, q_{od}, the total demand between origin node o and destination node d is the sum of path flows for all paths linking o to d:

$$\sum_{p \in od} f_p = q_{od}, \quad \forall od \tag{3}$$

Sheffi [5] show that the solutions of the traffic assignment problem can be founded as solution of the following non linear problem:

$$\begin{array}{ll} \min & z(x) = \sum_a \int_0^{x_a} t_a(x_a) dx_a \\ \text{s.t.} & \left\{ \begin{array}{rcll} \sum_{p \in od} f_p & = & q_{od} & \forall od \\ f_p & \geq & 0 & \forall p \\ x_a & = & \sum_{p|a \in p} f_p & \forall a \end{array} \right. \end{array} \tag{4}$$

The proof is very simple. The *Kuhn Tucker conditions* (See Luenberger [4]) which are necessary satisfied at the optimum of problem (4) are precisely the **User Equilibrium Conditions.**

1.2 The CORINAIR methodology

The CORINAIR methodology is presented in [2]. We summarize here the main principles of this methodology. The European Community group for evaluating the gas emissions from road traffic has established *unitary emission formula for several polluting gases as a function of:*

- the *composition of the fleet of vehicles*;
- the *current temperature*;
- the *average speed* of vehicles.

These formulas can be applied for *speed ranking from 5 to 110 km/h* and for *temperature ranking from -10 Celsius to + 35 Celsius.* The main polluting gases that we consider in this study are the following :

- the *monoxide of Carbon:* CO;
- the *carbon dioxide:* CO_2
- the *sulphur dioxide:* SO_2;
- the *oxides of Nitrogen:* $N0_x$;
- the *methane:* CH_4;
- the *organic compounds volatiles:* OCV.

The basic formula for evaluating the gases emissions is the following:

$$\text{Emissions}[g] = \text{ unitary emission factor}[g/km] \times \text{distance}[km] \qquad (5)$$

The *unitary emission factors* are given *as a function of the fleet composition.* For example, the formula giving the CO unitary emissions (in g/km)

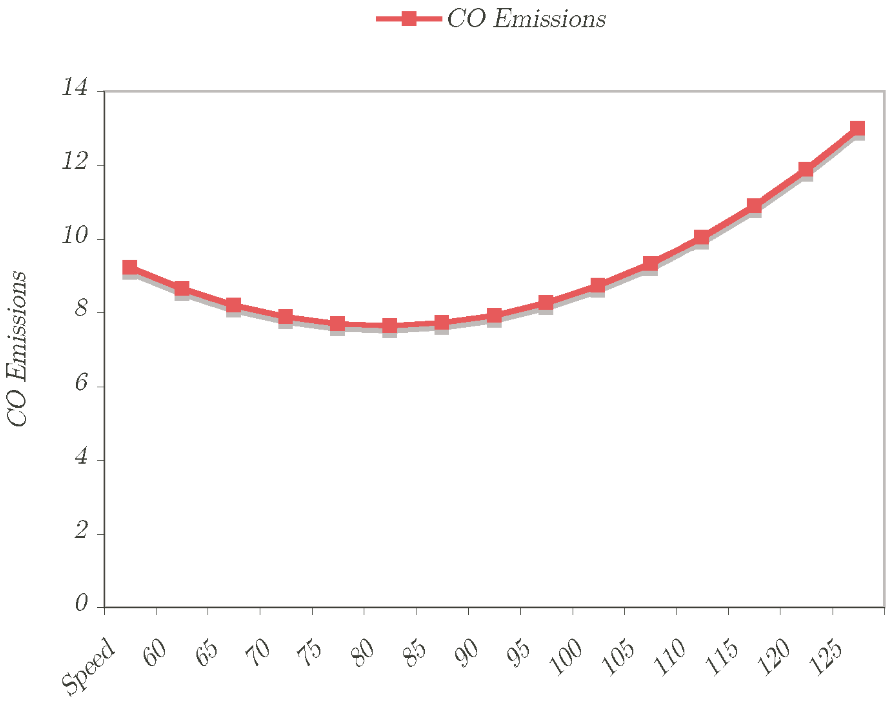

Figure 1: CO emissions as a function of the vehicle Speed

for a benzine car from category EC 15-02 of 1.4 litre with a speed between 60 and 130 km/h is the following:

$$26.260 - 0.440 \times (\text{vehicule speed}) + 0,0026 \times (\text{vehicule speed})^2$$

Plotting this function (See Figure 1), we can see on that the emissions are minimal for 90 kilometers per hour.

For urban area a great proportion of trips are done with a cold motor. This imply a *suremission factor which is function of the current temperature*. For the same example of the CO emissions, the multiplicative factor corresponding to suremissions for cold start is given by the formula:

$$3.7 - 0.09 \times (\text{current temperature})$$

Table 1 presents the evolution of this suremission factor as a function of the current temperature. Remark that for temperature greater than 30 Celsius,

Temperature (Celsius)	CO Suremissions Factor
-10	4,6
-5	4,15
0	3,7
5	3,25
10	2,8
15	2,35
20	1,9
25	1,45
30	1
35	0,55

Table 1: Suremission factor as a function of the temperature

the suremission factor is lower than 1, i.e. the suremission factor becomes a reduction factor.

We only consider this suremissions factor for particular cars, the buses and trucks are supposed to travel all the day. For the assignment of the origin-destination matrix on the network,we have used the ATESAME software [1] which provides as results :

1. the *flow* on each arc;
2. the *travel time* for each arc;
3. the *average speed* on each arc.

To calibrate the CORINAIR formulas we have used some technical data given by car manufacturers. Since the only information needed by the CORINAIR formula are:

1. the *average speed* on each arc,
2. the *flow* on each arc,
3. the *current temperature*,

all the relevant information (except the current temperature of course) are **given by the assignment model.**

2 Application to the center of Tunis City

Let us now apply this model to our *practical study case*, namely the *City of Tunis.* The main data of the traffic assignment model, are,

1. the *network description* thought its graph representation;
2. the *link travel time functions* thought their road performance functions;
3. the *demand* represented by an origin-destination matrix.

2.1 Study area

Our study area is thus the **center of Tunis City**. The *network representation* is done with an graph composed of 49 nodes and 114 links (See Figure 2).

The *origin-destination matrix* was computed using public data provided by studies of the National Institute of Statistics (such as the number of cars per hour).

The *link travel time functions* were calibrated using also public data (such the average speed or maximal speed).

2.2 Traffic composition

On this network, on can observe the *traffic composition* given in Table 2.

68 %	Particular cars running on benzine
18 %	Particular cars running on diesel
4 %	Particular cars running on gas
8 %	Buses running on diesel
2 %	Trucks running on diesel
100 %	Total traffic

Table 2: Traffic composition

Figure 2: The center of Tunis City

2.3 Considered Senarii

Four scenarios (See Table 3) were tested:

- *Scenario 1:* the first one corresponds to monday 6 february 2006 between 7 and 8 hours, which is the peak hour, the temperature was 17^0C,
- *Scenario 2:* the second one corresponds to the same congested traffic condition, but with a current temperature of 34^0C,
- *Scenario 3:* the third scenario corresponds to a fluid traffic and a temperature of 17^0C,
- *Scenario 4:* the last scenario corresponds to a fluid traffic with a temperature of 34^0C.

	Current temperature 17^0C	Current temperature 34^0C
Congested traffic	Scenario 1	Scenario 2
Fluid traffic	Scenario 3	Scenario 4

Table 3: Considered Senarii

3 Numerical results

3.1 Polluting gases emissions

The implementation of the CORINAIR formulas gives the following results.

- Figure 3 gives the **total emissions of Monoxide of Carbon** (CO). Recall that this gas is very dangerous since it can not be detected and can be lethal in closed conditions. We can observe a *diminution of CO emissions* from Scenario 1 (low temperature) to Scenario 2 (high

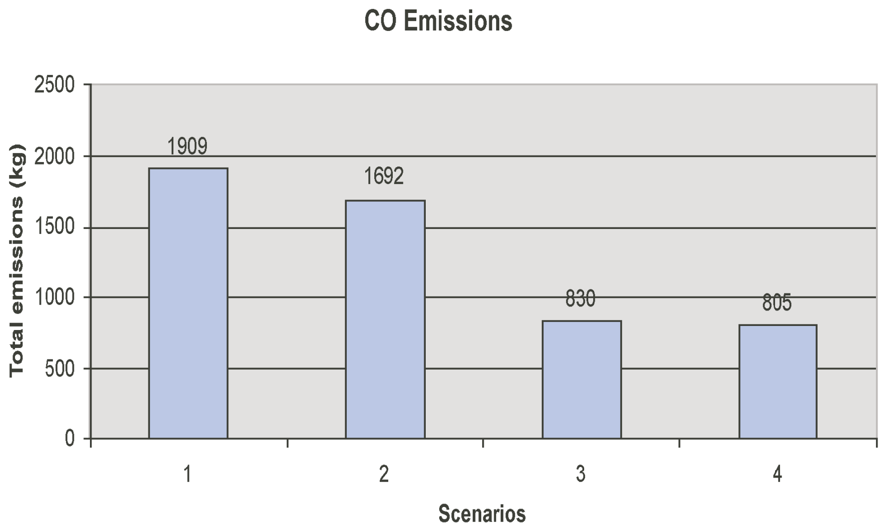

Figure 3: CO Emissions

temperature). Thus a *greater temperature means lower CO emissions*. This can be explained by the better combustion of the motor. The same conclusion can be done with the comparison of the two last senarii. The fact that the emissions are lower in the two last senarii is not surprising since the total demand is lower is this two scenarios. This directly imply lower emissions.

- Figure 4 gives the **total emissions of Carbon Dioxide (CO_2)**. Recall that this gas is the *main factor for the climatic warming*. Note also that the scale has totally changed. We compute here the emissions in kg and not in g and the total emissions in Scenario 1 are of the order of magnitude of 350 tons. This is the **main emission of road traffic**. We can obverse the same phenomena that for the monoxide of carbon, namely that *emissions are lower at an higher temperature* but this reducing effect is lower here.

- Figure 5 gives the **Oxides of Nitrogen (NO_x) emissions**. This is an odorous gas which is factor of acid rains. The emissions are lower than the CO emissions. The great difference with the two oxides of carbon is the fact that *the NO x emissions increase with the temperature* (from

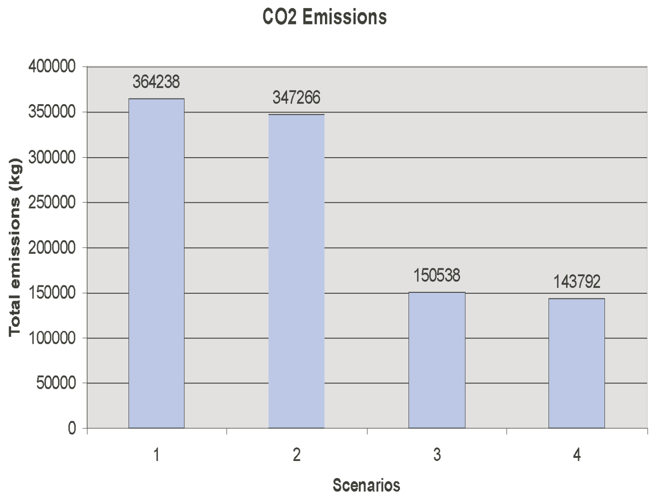

Figure 4: CO2 Emissions

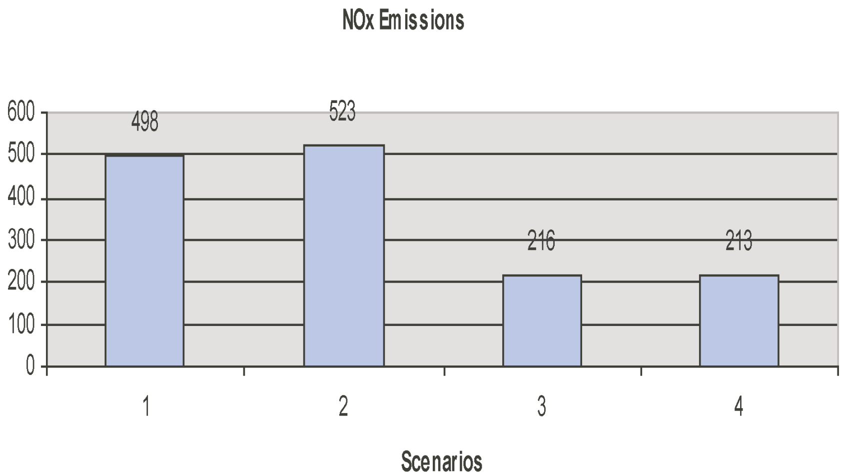

Figure 5: NOx Emissions

Scenario 1 to Scenario 2). This can be explained by the fact that the NO_x are emitted by a reaction that takes place at an high temperature.

- Figure 6 gives the **Methane (CH_4) total emissions**. This gas is also an *important factor for the climatic warming*. The *CH4 emissions also increase with the temperature.*

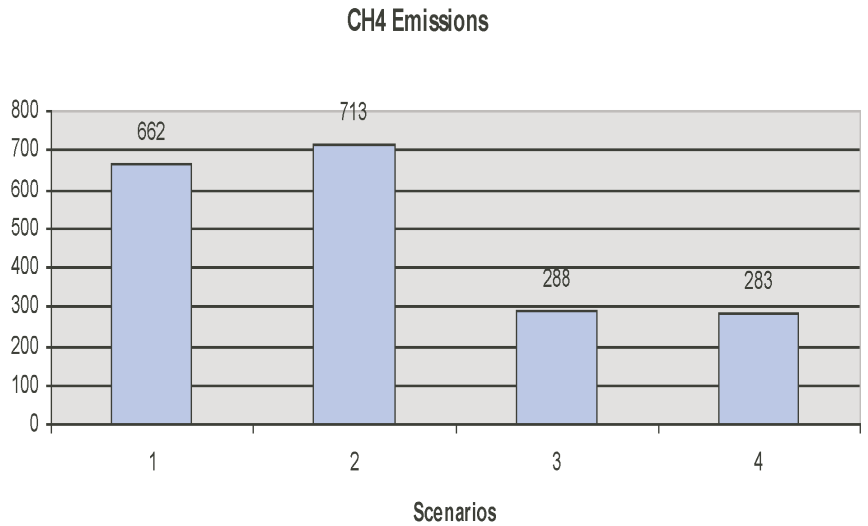

Figure 6: CH4 Emissions

- Finally, Figure 7 gives the **total emissions of Organic Compounds Volatiles:** OCV. These very toxic gases can be carcinogenic. These emissions *decreases with the temperature.* This is not surprising if we recall that the combustion is better at an higher temperature and the fact that the Organic Compounds Volatiles are the subproducts of an incomplete reaction.

3.2 Emissions as a function of the vehicle types

Our model also determine the quantity of gas emitted by each category of vehicles (See Figure 8). Some conclusions can be given.

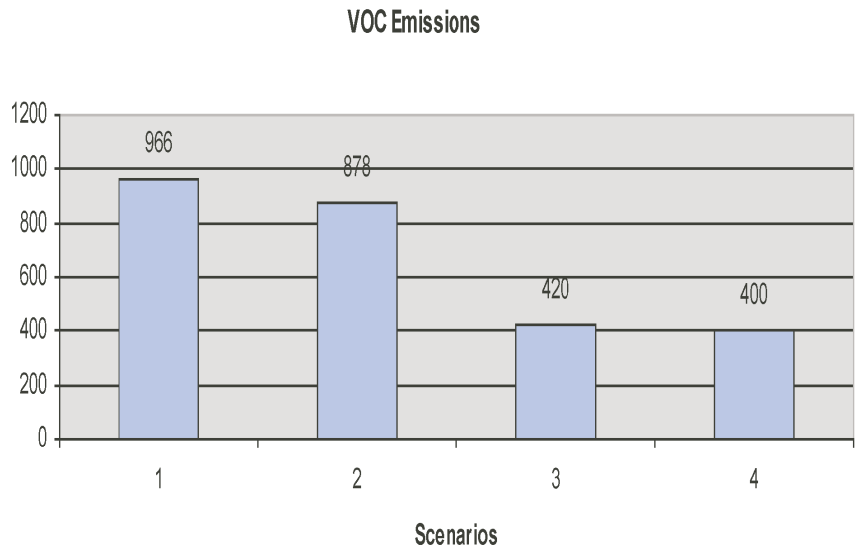

Figure 7: VOC Emissions

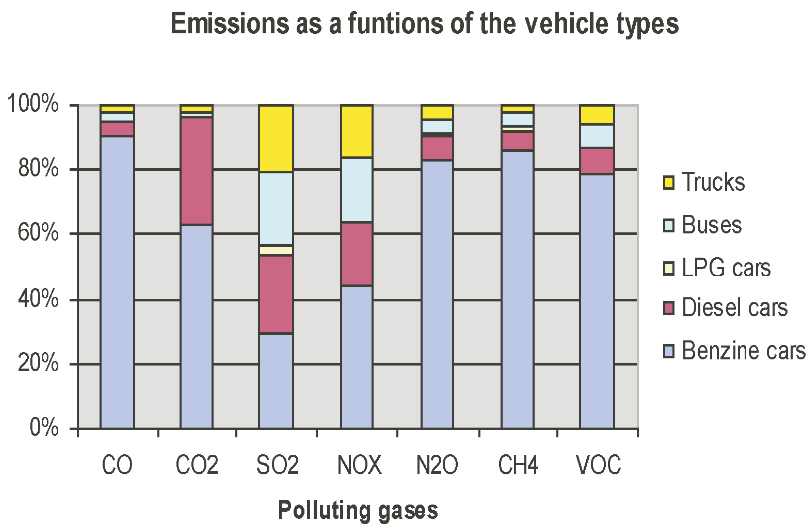

Figure 8: Emissions as a function of the vehicle types

- First, the *particular cars running on benzine, are the main factor of Carbon Monoxide emissions*. Recall that theses cars represent 68 % of the total fleet but they cause 90 % of the total CO emissions.

- The *cars running on diesel are responsible for greater CO_2 emissions*. In fact, the particular cars running on diesel represent 18 % of the fleet but 30 % of the emissions.

- Note also that for the more toxic gasses, namely the dioxide of Sulfur (SO_2) and the oxides of Nitrogen (NO_x), the trucks and the buses which only represent 2 % and 8 % of the fleet are responsible of 40 % of their total emissions. This is due to the fact that these emissions are increasing with the power of the motor.

4 Conclusions

This model can thus be used to *evaluate the gas emissions* in a variety of *traffic conditions, temperature conditions* and *fleet composition*.

The **limits of the model** are the following:

- The traffic level and the unitary emissions remain approximate,

- The car fleet composition frequently changes,

- The vehicles counting used to define the origin-destination matrix are often incomplete or inaccurate.

Future research will be devoted to compute a monetary evaluations of these traffic externalities.

Acknowledgement

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