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REALITY: Road Emission Activity-Link based InvenTorY: A dynamic on-road pollutant emissions model

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1. INTRODUCTION

The objective of this paper is to introduce a new pollutant emission estimation model that has traffic as a source of emission, Lebacque (2010). The two main elements of traffic as source of pollution are the road network and the traffic pattern. A road network consists of a collection of roads that are characterized by their capacity and speed limit. Traffic refers to a collection of cars on a road. Cars are differentiated by their use, by their size and by their age. To make accurate estimates of pollutant emission, it is imperative to have accurate emission rates (gr/km/pollutant). REALITY calculates pollutant emissions taking into account the characteristics of the pollution source, and employs statistical techniques to improve emission rates that are taken from COPERT (2004).

REALITY calculates hot emissions. These are pollutants emitted while a vehicle is running on hot engine. The model is considered dynamic since the estimates change with respect to changes in the network and traffic. Pollutant emissions are estimated for each road type in the network, and as a function of the volume of traffic that is differentiated by vehicle class and age, and average speed on each road. The volume of traffic and the average speed are estimated on a real time basis using dynamic modeling. The dynamic nature of REALITY makes this model a new generation of pollutant emission estimators. Time dependant variables of traffic (volume, and speed) are estimated using network equilibrium dynamic assignment models, Taylor, (2003), Lu,C.-C. et al., (2007), Lebacque et al. (2009) Aguiléra,Lebacque, (2010).

The idea behind network equilibrium dynamic assignment modeling is to distribute origin-destination traffic volumes among network links in a way that all links have the same travel costs.

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Two supplementary models are introduced in this paper. DYNABURBS and APOLARIS. The first model calculates cold emissions, and the latter calculates micro scale (road or a segment of a road) concentration of pollutants. The main feature in DYNABURBS is trip chaining and parking information that are either user furnished or are extracted from the web. APOLARIS introduces micro scale pollutant concentration estimation. In this model the chemistry transport equation is modified to reflect new elements such as the absorption rate of building materials, and human activities.

2. INPUT DATA

There are five basic types of input data files. The network data file has the list of links (roads) of the entire network. These links are identified by link identification number, the longitude and the latitude of the entry and the exit points of a link, the traffic volume which is the output of a network equilibrium dynamic assignment model, and average speed which is the mean of the speeds of vehicles on the road. Vehicle fleet composition data is a matrix of size (27 x 21). The 27 rows are the years from 1984 to 2010. For each year, the number of vehicles by class registered is given. There are 13 vehicle classes in general. These categories match the categories in COPERT IV.

The categories are: private cars running on gasoline, private cars running on diesel, light duty vehicles (gasoline, diesel), heavy duty vehicles (diesel), bus (gasoline, natural gas), LPG, 2-stroke, hybrid, mopeds, and motor cycles. In the fleet data eight out of thirteen categories are included. LPG, 2-stroke, hybrid and bus (natural gas) are omitted, mainly because of the lack of data. The fraction of each car class over the total number of cars is calculated. These fractions are used to calculate the volume of each car class in the total volume on each road. The coefficient files are matrices of size (13 x 12). 13 is the number of age categories, and 12 is the number of car classes. There are 11 coefficients for each car class by age category.

These coefficients are speed coefficients in speed functions that are used in calculating basic emission rates (gram/km). There are several user input files. In the user specified network file, user specifies those vehicle classes by their age categories which are of interest to the user. The user input file used in emission estimation is a matrix of size (13 x 22) which gives the percentage of each car class by age category for each link of the network. For now, the percentage of car class by age category is taken as constant for all links.

Data needed for DYNABURBS is trip chaining data from cell phone communication and travel survey data. This data should at least give the number of trips per day, trip purposes, number of stops, and the duration of each stop. Parking data should be extracted from the Web. This data should provide parking capacities of garages, the rate of enter and exit from garages and on street parking. Data needed for APOLARIS is the usual wind speed, temperature, and humidity data. Additional data are the materials used in buildings and their rate of particle absorption. Other relevant data are: building heights, the density of buildings around a link, Sprin, A. (1986), the density of human activity, and the type of activities on a link,

2. REALITY: on- road pollutant hot emission estimation

The algorithm that calculates pollutant emissions has several sub-programs. The first sub-program calculates volume and average speed by vehicle type per unit of time per link, and link distance. The next sub-program calculates Basic Emission Rates (BERs) per pollutant and per link. BERs are assumed to be nonlinear functions of average link speeds. The relationship between average speed and BER is given in equation (1) below.

$$BER = a + bv + cv^2 \qquad (1)$$

The coefficients a, b, and c are from tables in COPERT (2000). Tables of coefficients are setup based on COPERT tables for each pollutant resulting from transportation activities. These coefficients are then adjusted based on findings from published case studies. The variable (*v*) represents the average link speed. The next sub-program calculates pollutant emissions per link by vehicle class per unit of time as is shown below:

$$e^t_{hot,l} = BER \times \upsilon^t_{c,l} \times d_l \qquad (2)$$

e^t_{hot} is hot emission on link (l) at time (t). Hot emission is calculated by multiplying the basic emission rate (BER) by traffic volume by vehicle class ($\upsilon^t_{c,l}$) at time (t) and link distance. Traffic volume is estimated from the application of a dynamic assignment model. An example of CO emission for the Paris area is given in figure 1 below. Dark blue represents very low emissions. Lighter blue indicates higher emissions and red indicates maximum emission levels.

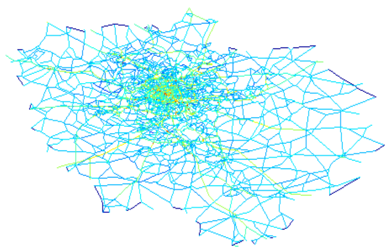


Figure1. Shows CO emissions in grams per link of gasoline operated private vehicles – Paris area – between 6:00 a.m. and 7 a.m.

A program divides the network into square grids. The size of the grid is specified by the user. Each grid contains a number of network links. Pollutant emission per grid is calculated in the subsequent sub-program. The calculation is simple; either link emissions for links in each grid are added together or it is directly calculated from equation (2) as is shown below:

$$e^t_{hot,i} = \sum_{l=1}^{N} BER \times \upsilon^t_{c,l} \times d_l \qquad (3)$$
$$\forall\, i = 1,\ldots,M \;;\; \forall\, t = 1,\ldots,T$$

$e^t_{hot,i}$ is the emission per grid (i) at time (t). (N) represents the total number of links in a grid. The following two figures (2) and (3) show CO emissions of private vehicles and trucks by grid cell.

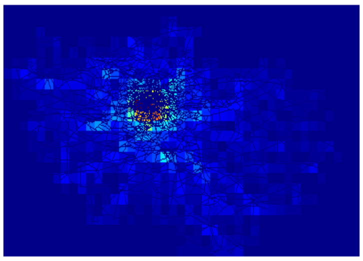


Figure 2. CO emissions per grid cell of gasoline operated private vehicles- Paris area- – between 6:00 a.m. and 7 a.m.

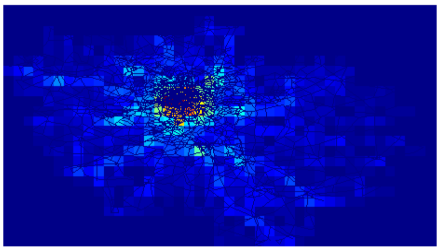


Figure 3. CO emissions per grid cell of diesel operated heavy duty vehicles- Paris area- – between 6:00 a.m. and 7 a.m.

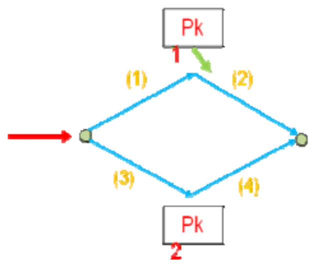
3. DYNABURBS: DYNamic Assignment for suburbs: cold emission estimation

Cold emission refers to emission of pollutants from cars running on cold engine. Engine is cold when a car is started and for a short time afterwards when a car is running. In order to calculate cold engine emission, it is necessary to know the number of cars parked, the of entry and exit rate from parking garages or on street parking, and know the distance cars run on cold engine. Parking is a function of trip chaining. Trip chaining is defined as the number of stops a road user makes between an origin and destination due to non-work activities (example: dropping kids to school, shopping, doctor's appointment, or cultural and recreational activities).

Cold emission per link is calculated similar to hot emission with the exception that the volume is the volume of cars running on cold engine. To find this volume it is assumed that trip chaining information is a user generated information. This means that user relays his daily itinerary using his cell phone or web tools such as Twitter, or other chat programs. Information on parking garages can also be found online. The enter and exit rates of on street parking and the duration of on street parking can be calculated from satellite pictures of urban streets. BERs and dynamic average volumes and speeds are calculated as before.

An example of the application of DYNABURBS is given for a small network below in figure 4

Figure 4 a simple two paths network



There is an origin (a) and a destination (b). 2 alternative paths connect origin (a) and destination (b). There are parking facilities (garages or on street parking) on both paths. Network equilibrium is calculated as a function of the number of cars that enter and exit the mainstream traffic after parking. Cold emissions given dynamic parking patterns (variables entry and exit rates into and out of the main stream traffic) are calculated. Cold emissions evolve in a smooth manner. These emissions are then compared with cold emission calculated from static parking rates. These emissions are piecewise continuous. Flows in the static case do not change within a time slot which means that during a time interval traffic flows stay constant. The two cold emission patterns are shown in figure 5 below.

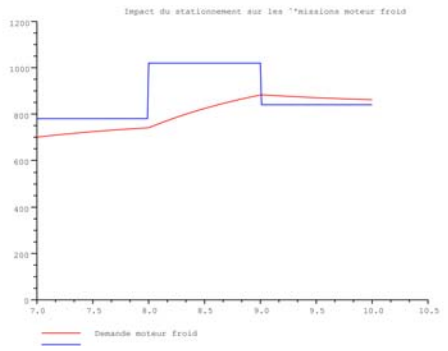


Figure 5. The impact of time varying parking pattern on cold emission estimation vs an static case

The x-axis is time and the y-axis is cold emission levels. The blue line represents cold emissions based on link flows which are piece wise constant functions of fixed parking rates. The red line represents cold emissions calculated from time varying parking rates. The red line has a smoother evolution than the blue line. This advantage stays even when traffic flows are considered as linear functions of static parking rates. This is shown in figure 6 below:

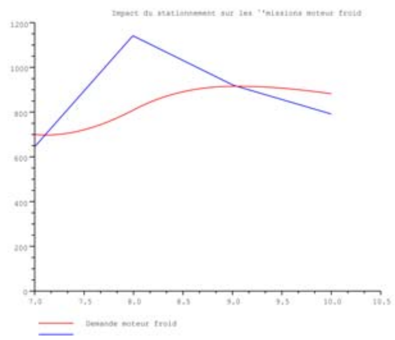


Figure 6. The impact of time varying parking pattern on cold emission estimation vs a linear case

The x-axis is time and the y-axis is cold emission levels. The blue line represents cold emissions based on link flows that are piece wise linear functions of fixed parking rates. The red line represents cold emissions based on variable parking rates. DYNABURBS was tested on the Paris network. Figure 7 shows cold emission of CO by link between 6:00 a.m. - 9:00 a.m. in the Paris metropolitan area.

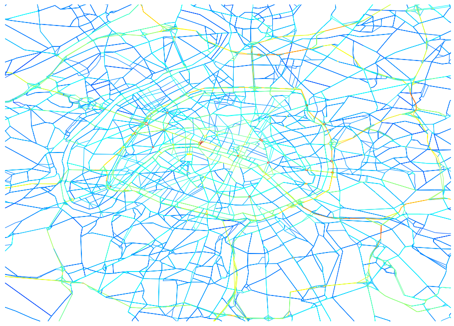


Figure 7 Cold emission of CO by link period 6:00 a.m. - 9:00 a.m. Paris

Compare figure 7 with figure 8 which gives a graphical representation of cold emission of CO in the city of Paris for the period between 9:00 a.m. and 12:00 noon. Naturally, cold emission is higher as is shown with light yellow and red colored links.

Figure 8 cold emission levels of CO for Paris metropolitan area between 9:00 a.m. and 12:00 noon

4. APOLARIS: Atmospheric Pollution Activity-Road Initiated Source

APOLARIS calculates pollutant concentration on a micro scale, namely street level. Urban streets are the focus of analysis. The major characteristic of these streets is that they are surrounded by buildings. These buildings can be different in height and shape and the construction materials used. A typical urban street is demonstrated in figure 9.

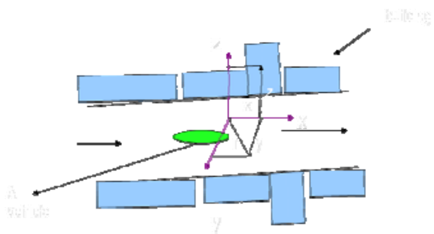


Figure 9 a typical urban street

A car is considered to be a linear source of pollution. It is assumed that pollutant concentration level is different in different directions (X), (Y), (Z). This is due to many factors. The level of concentration depends on the level of absorption of pollutant particles in the environment. In the (X) direction, the main absorption factor is the street surface. It is assumed that the surface is laminated and therefore absorption is negligible. The chemistry transport equation is split into three separate PDE equations in (X), (Y), and (Z) directions.

$$\frac{dC}{dt} + U\left(\frac{dC}{dx}\right) = \frac{d}{dx}\left(k_h \frac{dC}{dx}\right) + R + Q \qquad (4)$$

C = pollution concentration
U = wind in the east-west direction
K_h = horizontal turbulent diffusion
R = speciation
Q = pollutant emissions from traffic = pollutant emissions on the links of a network

In the (Y) direction, pollutant particles are absorbed by the surrounding buildings (street level isolation) and human activities.

$$\frac{dC}{dt} + V\left(\frac{dC}{dy}\right) = \frac{d}{dy}\left(k_h \frac{dC}{dy}\right) + R + Q + \Psi + (\alpha \times \Phi) \qquad (5)$$

V = wind in the north-south direction
Φ = the quantity of pollutants absorbed by the street isolation level,
α = the absorption rate, and
Ψ = the quantity of pollutants absorbed by humans.
Ψ is a function of the density of activities.

In the (Z) direction, the main absorption factor is the street isolation level.

$$\frac{dC}{dt} + W\left(\frac{dC}{dz}\right) = \frac{d}{dz}\left(k_z \frac{dC}{dz}\right) + R + Q + (\alpha \times \Phi) \qquad (6)$$

W = wind in the vertical direction
K_z = vertical turbulent diffusion

Solutions to equations (4), (5), and (6) are constructed from the eigenfunctions $C_\ell^{i*}(x)$, $C_m^{i*}(y)$, and $C_n^{i*}(z)$ of the three equations, which represent pollutant concentration levels in directions (X),(Y), and (Z). Total link concentration is then calculated as a combination of the product of the three solutions (the $\lambda_{\ell mn}$ are the eigenvalues):

$$C_t^{total} = \sum_\ell \int^t e^{-\lambda_{\ell mn}(t-s)} R_\ell(s) ds \; C_\ell^{i*} C_m^{i*} C_n^{i*}$$

5. Conclusion

REALITY is a new pollution emission estimation model. It is new because it integrates the dynamic aspect of traffic, which is variable traffic volumes and speeds. Another new feature is the integration of coefficient matrices used in speed functions. Basic emission rates are calculated from these speed functions. The main advantage of the model is that all parameters used can be updated or modified. Therefore, the model is flexible, and can be a useful tool when conducting studies in hot emission estimation.

The other two models: DYNABURBS, and APOLARIS are still at the preliminary stages of development and need to be fine tuned.

References

Aguiléra, V., Lebacque, M., 2010. Dynamic Estimation of Traffic Emissions in Metropolitan Road Networks. Proceedings of the WCTR confrerence, July 11-15, 2010, Lisbon

Kouridis, C., Ntziachristos, L., Samaras, Z., 2000, COPERTIV Computer Programme to calculate emissions from road transport - user manual. EEA European Environmental Agency.

Lebacque, M., 2010, REALITY - Road Emission Activity-Link based InvenTorY - technical report LVMT/ CEREA, ecole des ponts - paristech.

Lebacque J.P., Ma T.Y., Khoshyaran M.M., 2009. The cross-entropy field for multi-modal dynamic

assignment. TGF'09. To be published in Traffic and granular flow 2009.
Lu, C.-C. et al, 2007. A bi-criterion dynamic user equilibrium traffic assignment. Transportation Research Part C.

Sprin, A., 1986. Air Quality at street level: Strategies for Urban Design. Cambridge: Harvard Graduate School of design, Cambridge, MA, USA.

Taylor, N., 2003, The CONTRAM dynamic assignment model. Journal of Networks and Spatial Economics, 3, 297-322.