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TRAFFIC EMISSION SIMULATION AND VALIDATION WITH MEASURED DATA IN SOUTH KOREA

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Abstract: Poor air quality in urban areas is often directly related to traffic emissions, especially in the so called hot-spots. Major efforts have been made in recent years to compute emissions in such locations from simulated traffic conditions at microscale level in an accurate way. In this study we focus on a 300m x 300m domain that covers a signalized intersection of two major roads in Seoul (South Korea). The selected location is a traffic hot-spot with more than 8000 vehicles·h^{-1} at weekday peak hours. To validate this modelling techniques on-road air pollutant emissions of Nitrogen Oxides (NO_x) estimated from mobile monitoring laboratory data are compared with the computed concentration results, based on traffic emissions simulations. For the traffic simulation, detailed information of the network (geometry, number of lines and traffic light location) is needed along with traffic light cycles. Traffic volumes, routes and fleet composition are estimated from CCTV cameras. Speed-time profiles for peak and off-peak hours on weekdays are simulated with the traffic microsimulation model PTV VISSIM. Traffic emissions are computed with VERSIT+$_{micro}$ emission models through the TNO ENVIVER interface on a grid of 5m x 5m spatial resolution and temporal resolution of 1-h. This emission results are used as input for CFD model to obtain high resolution concentrations. These predicted spatial concentration distribution are compared to the GPS data measured by the mobile laboratory in real traffic conditions. This comparison is useful to obtain a first approach to the validation of the traffic simulation and the emission computation VISSIM-VERSIT+$_{micro}$/ENVIVER modelling system.

Key words: *Emission model validation, VISSIM-VERSIT+$_{micro}$/ENVIVER, NO_x, on-road pollution data.*

INTRODUCTION

Road traffic is nowadays one of the main factors affecting the air quality of big cities around the world. In urban areas, poor air quality is directly related to traffic emissions, especially in highly polluted microenvironments or hot-spot, where road traffic is the most significant contributor to air pollution (Borge et al., 2014). In recent years, many efforts have been made computing emissions on such locations from simulated traffic conditions at microscale level in an accurate way (Quaassdorff et al., 2016). There is a clear tendency to increase spatial and temporal resolution of air quality models in urban areas, so more accurate answers can be given for specific air quality issues. However, the information needed to feed and validate such microscale approaches is scarce. The main motivation of this study is to improve our understanding of the VISSIM-VERSIT+$_{micro}$/ENVIVER modelling system as a useful method to compute accurate traffic emissions in hot-spots. This is done through the comparison of NO_x traffic computed concentrations and measured on-road data from a mobile laboratory. This constitutes a valuable example of model validation that may help in the harmonization of the application and assessment of microscale modelling tools.

METODOLOGY

Modelling domain

Posco intersection is the crossing of two main roads, Samseong-ro (South-North) and Teheran-ro (East-West). It is located in the district of Gangnam-gu in the south-east part of Seoul, South Korea (**Figure 1**). This is a key intersection for commuters at peak hours to arrive at the city centre. The selected modelling domain covers an area of 300m x 300m with more than 8000 veh·h^{-1} crossing the signalized intersection.

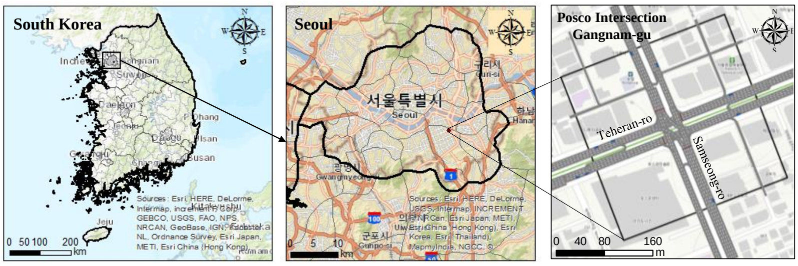

Figure 1. Location of Posco intersection in Seoul, South Korea and the selected modelling domain of 300m x 300m.

Modelling system

The methodology followed in this study consists in the combination of a traffic microsimulation model with a cycle variable emission model and a CFD air quality model as showed in **Figure 2**.

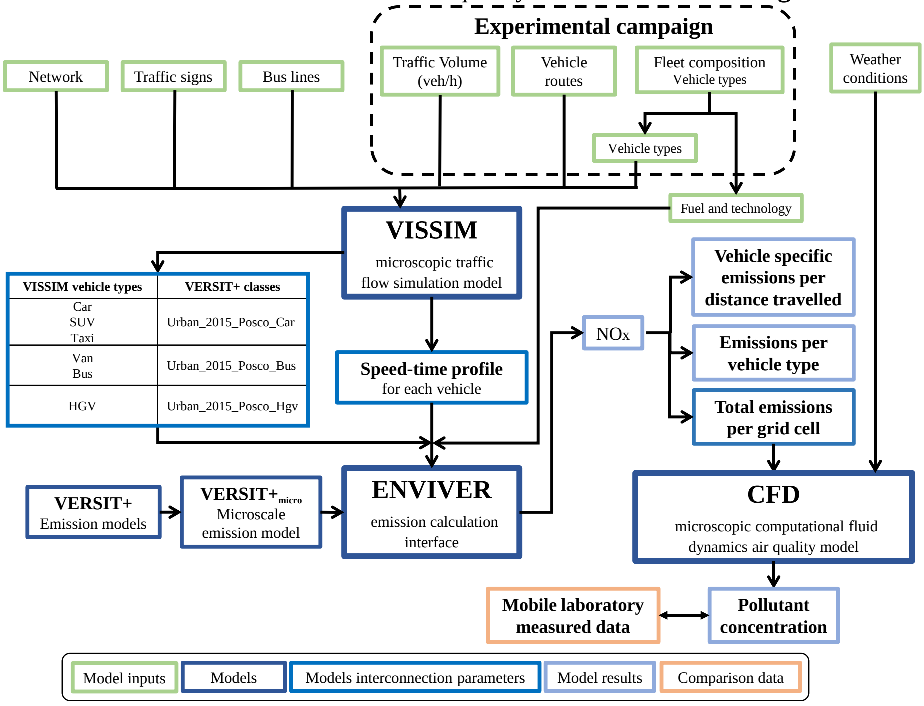

Figure 2. General flowchart of the modelling system including inputs and outputs for comparison with mobile laboratory measured data.

The three selected modelling components are: i) PTV VISSIM v. 6.22 (one of the most used traffic microsimulation models in research), which is used for microscale traffic flow modelling and includes car-following and lateral movements logics for the individual vehicle simulation. ii) TNO ENVIVER Enterprise interface (a high-resolution post-processor) that link the microscale emissions model VERSIT+$_{micro}$ (based on VERSIT+ models for emission calculations of simulated traffic streams) to VISSIM's traffic data for the calculation of traffic related emissions, and iii) CFD air quality model (Kwak et al. 2015) to solve the continuity, momentum, energy, and diffusion equations for the vehicle exhaust-gas dispersion and flow characteristics considering the emission and weather conditions.

Scenarios

Two scenarios were selected for modelling purposes. The first one is a peak hour (9:00 to 10:00 a.m.) from a typical weekday with high traffic intensity (8667 veh·h^{-1} crossing the whole domain). The other one is an off-peak hour (15:00-16:00 h) with also high traffic intensity (6591 veh·h^{-1}). The fundamental difference between both scenarios is that for the peak scenario there are substantial commuter's movements from south to west (into the city centre) and in the off-peak scenario they return from north to south. Nevertheless in both scenarios the most used route is the one from east to west.

Traffic data compilation

Traffic data were obtained from an experimental measurement campaign. The campaign was carried out from 28th July to 10th August 2015, a representative period for summer traffic conditions. In this period traffic volumes and vehicle routes were recorded with CCTV cameras. Traffic compositions for the two scenarios were obtained from a previous study carried out in 2013 (Kwak et al., 2016) (**Table 1**). Network configuration, traffic signs location and bus stops where obtained from satellite images from Google maps.

Table 1. Traffic composition for the two selected scenarios.

Vehicle type	Peak (9:00-10:00 h)	Off-peak (15:00-16:00 h)
Car	51.4%	51.1%
Taxi	21.9%	22.6%
SUV	12.0%	11.8%
HGV	5.5%	5.4%
Van	2.7%	2.2%
Bus	2.7%	2.7%
Bike	3.8%	4.3%

Traffic emission computation

Traffic information was used to generate the baseline traffic microsimulation network showed in **Figure 1** (right) along with the public transport bus lines and frequencies information. The baseline traffic network configuration consists of 20 links, 27 connectors, 4 signal heads (red lines), 9 bus stops (blue rectangles) and 24 bus lines. Traffic volume, traffic compositions and vehicle movements for each scenario were added to the baseline simulation to obtain peak and off-peak simulations. For each simulation, second-by-second information of vehicle speed and position for every individual vehicle was recorded. This information is stored in the *.fzp file which contains the necessary information of the speed-time profiles (input for the traffic emission model). Fuel distribution data were obtained from official statistics for motor vehicles registered in Seoul by fuel type in 2015 (KOSIS, 2017). This classification is subdivided as commercial and non-commercial passenger's car (Car), Van and Bus (Bus), HGV and by fuel type as petrol, diesel, LPG, CNG and electric vehicles. This classification was used in the emission model to generate the emission classes (**Figure 3**) and were assigned to the vehicle types from the traffic model.

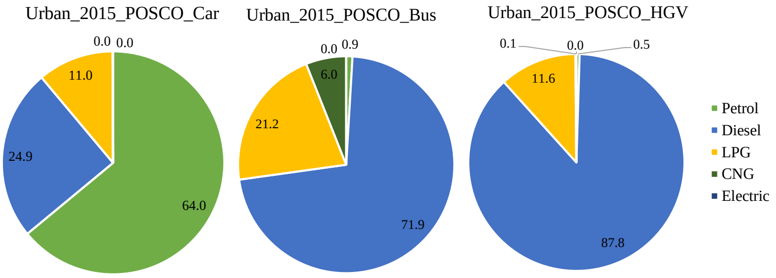

Figure 3. Fuel distribution data for the vehicle classes introduced in the emission model.

CFD modelling

Taking the simulated traffic emissions as input and the meteorological data of wind speed and direction, flow field was solved by employing the renormalization group (RNG) k-ε turbulence model, which has been extensively used to solve atmospheric flow field and pollutant dispersion in urban areas (Kwak et al., 2015). Also, a wall function was used to model the near-wall velocity profile and the number of grids were approximately 4,300,000.

Mobile laboratory measurements

On-road air pollutant concentrations (including NO_x) were measured with a Mobile Laboratory (ML) integrated in a vehicle. This allowed the collection of air pollution distribution data with high spatial and temporal resolution. The sampling inlets of the ML consisted of a Teflon tubing for gaseous pollutants. The sampling height was approximately 2m above ground level. Nitrogen oxides were measured using a NO_x analyser (CLD 700 EL, ECO PHYSICS INC., USA) and it was calibrated before and after measurements to check standard concentrations. Global position system (GPS) information was collected every second in order to locate the measured concentrations in space (Kim et al., 2014; Woo et al., 2016).

RESULTS AND DISCUSSION

Traffic emission results

The main result from the microscale traffic emission model are total emission results ($g \cdot h^{-1}$) for a 5m x 5m grid resolution. These maps clearly reflects the influence of congestion (low average speed) on exhaust emissions. Total emissions for each scenario vary from 7780.4 $g \cdot h^{-1}$ (mean emission factor of 2.34 $g \cdot km^{-1}$) at peak hour (**Figure 4a**) to 5074.6 $g \cdot h^{-1}$ (mean emission factor of 1.86 $g \cdot km^{-1}$) at off-peak hour (**Figure 4b**) which is influenced by the stop and go patterns generated by queuing after a traffic lights. More fluent traffic conditions in the off-peak hour generate less acceleration-deceleration cycles which have a clear effect on the emission factor showing a reduction of 20%. The main differences between both scenarios are the length of the vehicle queue in Samseong-ro (from South to North) and also the vehicle movements from South to West direction in the peak hour that in the off-peak hour are clearly reduced. The length of the queue generated on Teheran-ro (east) remains similar for both scenarios.

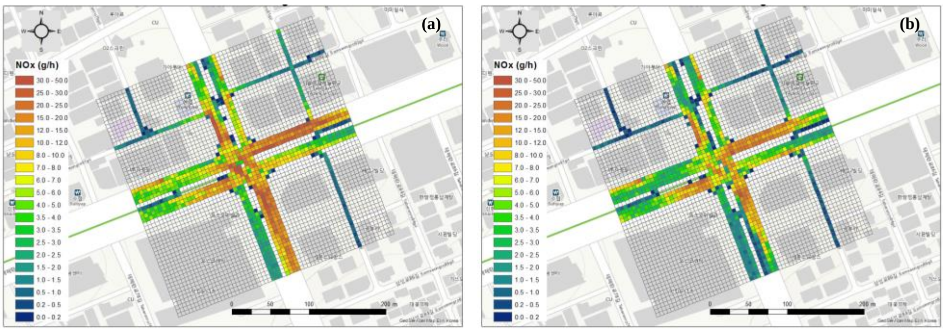

Figure 4. NO_x emission results with 5m x 5m grid resolution for (a) peak and (b) off-peak hour.

CFD simulation

NO_x concentration distribution in the domain was simulated on a 5m x 5m resolution grid (**Figure 5**). The concentration maps are based on two different wind speeds (2 and 3 $m \cdot s^{-1}$) and two wind directions (different angles both from North-West to South-East). Despite some unresolved issues with the concentrations units, spatial distribution of the concentrations will remain the same. So, in general terms the CFD model is predicting higher concentrations after traffic lights where vehicles are queuing and present the highest values near to the intersection.

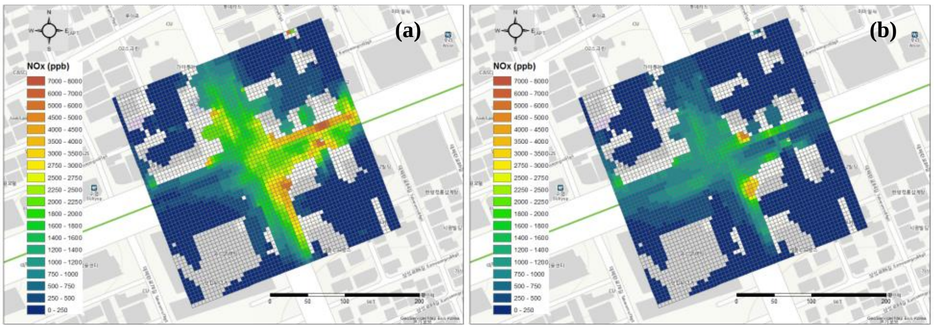

Figure 5. NO_x concentration results from CFD simulation using traffic emissions with 5m x 5m grid resolution for (a) peak and (b) off-peak scenario.

Observations

The ML information was used to generate pollution concentration maps with 10m x 10m grid resolution (due to GPS positioning deviation of 10m) for peak hour (based on 6 trips) and off-peak hour (based on 4 trips). This information was adjusted to the 5m x 5m grid mesh for comparison purposes (**Figure 6**). On this maps vehicle queues after traffic lights can be observed on Teheran-ro with maximums of up to 700 ppb near to the intersection. In general, the concentration distribution present slight similarities to the observations with higher concentrations after traffic lights and near to the intersection. Nevertheless, this comparison is limited due to the representativeness of full hour estimated emission and concentration data (for individual grid cells) to be compared to the trip measured data with second resolution. In this sense, the relationship between measured data from the ML per 5m x 5m grid cells are compared to the corresponding CFD calculated values with R^2 of 0.2. This low correlation is extremely influenced by the position of the GPS measurements with a position accuracy of up to 10m.

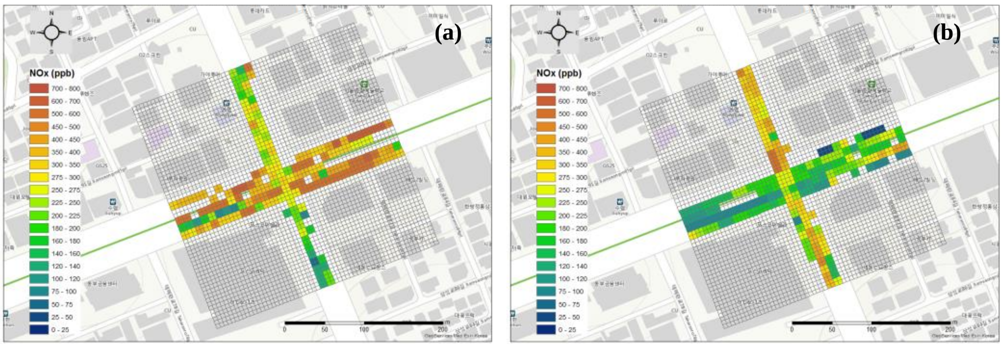

Figure 6. NO_x concentration distribution from ML measured data geolocated using GPS adjusted to the 5m x 5m grid resolution mesh for (a) peak and (b) off-peak hour.

CONCLUSIONS AND LESSONS LEARNED

This is a first approach to the validation of the high resolution emission estimation modelling system VISSIM-VERSIT+$_{micro}$/ENVIVER on a real hot-spot using ML data. This emission modelling system was coupled to the CFD based air quality model from Seoul National University to obtain concentration results with 5m x 5m resolution.

Simulated concentration results are hard to compare to measured trips data from the Mobile Laboratory. Difficulties are related to obtain individual trip data that covers the whole domain for a complete hour. Also, ML data comparison to CFD concentrations are extremely dependant of a correct location of measurements for this high spatial resolution of 5m x 5m. Nevertheless, concentration distribution maps obtained from the modelling system and from the ML measured data present, in general terms, similar concentration patterns. Both techniques present higher concentrations near to the intersection and for queuing vehicles after traffic lights in main roads.

Future work in order to resolve the high concentration levels predicted by the simulation system must be done in order to compare the results values directly to the on-road measured data. Also, to compare simulated emission data using inverse emission estimation from the on-road measured concentrations.

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