Assessing pollutant emissions on an urban area using different traffic simulation approaches: multi-agent modelling and microscopic modelling

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Abstract

Human exposure to traffic-related air pollution is widely acknowledged as a major health hazard worldwide. Computational models are estimated to be valuable tools to assess the exposure of humans to pollutant in an urban context. Promising outputs have been obtained by modelling chain of traffic models, emission models, and dispersion models. In this paper, we focus on the impact of traffic models on emissions obtained. We are coupling two traffic models, the agent-based MATSim and the microscopic simulator Symuvia, with the emission model HBEFA. Our analysis comprises three main comparison: the traffic conditions, the statistical distribution of emission and the spatial distribution of the gaps between models. Although emissions computed with the multi-agent model are higher than emissions obtained with the microscopic model, we observed some correlations between total air pollutant emissions. A correlation can be found spatially. However, we observed some significant gaps that needed to be investigated in more depth. This preliminary work is the first step in assessing human exposure to traffic-related emissions through modelling.

Introduction

Exposure to traffic-related air pollution, like the frequency of pollutant events that risk to human health, is a significant risk to humans. According to the Air Quality in Europe report (European Environment Agency, 2022), 96% of the urban population is exposed to unaccepted levels of air pollutants. Evidence supports a causal relationship between traffic exposure and exacerbation of asthma in children (Institute Health Effects, 2022), colon cancer (Roswal, 2023), and mortality (Beelen, 2008). Particulate matter (PM) inhalation induces respiratory and cardiovascular diseases (Apte, 2018). A correlation in terms of mortality has been shown between human home addresses and the proximity of congested roads (Beelen, 2008). High exposure is also a source of social inequalities and escalates urban segregation (Gurram, 2019). Emission abatement may decrease pollutant impacts on human health, but it often involves economic and social costs. Therefore, improving air quality in urban areas is a major challenge nowadays.

The contribution of traffic to individual exposure is difficult to quantify. Despite recent sensor improvements showing promise for measuring pollutant concentrations, detailed information about pollutant concentration cannot be obtained by interpolating data from sparsely distributed sensor measurements. The European Environment Agency report (2022) encourages the use of computational models to estimate air quality to support planners and policy makers. In this field, the combination of traffic, emission and dispersion models has become an extended practice to estimate human exposure. Predicting models have become an essential tool for human exposure from traffic-related assessment. Evaluating human exposure to traffic requires detailed information about the nature and distribution of pollutants' emissions and dispersion. To this end, we should look for the improvement of two aspects: (1) improving our understanding of complex interaction dynamics between traffic emission, air pollutant dispersion and human exposure, and (2) developing decision support tools to estimate exposure and reduce human nuisances via traffic mitigation strategies.

In this context, the Symexpo project (SYstemic approach for assessing the impact of urban Mobility on EXposures to environmental Pollutions) aims to investigate human exposure to traffic-related emissions in an urban context. The main expected output of the project is to formalize a framework for estimating traffic-related emissions, computing air diffusion of pollutants and estimating human exposure pollutants at different spatiotemporal scales. The developed modelling chain will also enable proposing and evaluating the benefit of mitigation strategies.To this end, this paper aims to set up preliminary bricks of the Symexpo project by investigating traffic air emission at two urban scales using two modelling chains.

Methodology

Traffic models

Estimating traffic-related air pollutant emissions is challenging. Generally speaking, a solid approach is coupling static or dynamic traffic models with emission models (Fallah, 2015). Despite their realistic macroscopic description of traffic conditions, static models do not provides a detailed spatio-temporal description of traffic conditions over the transportation network. For this reason, here we only consider dynamic traffic models.

A variety of dynamic models has been proposed. They can be resumed in three main classes: (1) in aggregated traffic models, based on the Macroscopic Fundamental Diagramm (Daganzo, 2007), traffic conditions are measured with fluid dynamics-inspired equations at the level of sub-urban areas (called reservoirs), (2) in microscopic models, the traffic condition is estimated by resenting the vehicles' individuality and calculating the main vehicle kinematic such as speed and acceleration at second, and (3) in mesoscopic models, the vehicles' kinematics are described without explicitly designing the vehicles' interactions.

An essential advantage of MFD models is the low computational cost, which allows the development of real-time network monitoring systems for traffic emissions. However, the definition of network partitioning might influence the total exhaust emissions of the network (Batista, 2022). Moreover, congestion conditions, which are supposed to be responsible for the most dangerous hot spot for human health, are aggregated at the reservoir level and do not emerge at the street level. Therefore, microscopic and mesoscopic models are more adapted for estimating human exposure. To quantitatively assess the impact of those models, we will compare emission rates obtained with the HBEFA model of the microscopic model Symuvia (Leclercq, 2007) and the mesoscopic model MATSim (Horni, 2016).

Several differences can be found between the microscopic model Symuvia and the mesoscopic model MATSim. Symuvia is a vehicle-centered model, where the route traffic choice is governed by a dynamic traffic assignment model that minimises the vehicles' travel time. A set of rules governs the vehicles' dynamics, including the laws of pursuit, lane change and intersection crossing. The main focus of this model is on understanding vehicles' interactions. Therefore, intermodality (the possibility of an individual changing his transportation mode along his trip) is not implemented. Due to the detailed modelling of vehicle interactions, the traffic situation can be measured by aggregating individual kinematics. Therefore, this approach is expensive regarding computational costs, limiting case studies on a few roads or neighbourhoods and for a few hours of a day simulation. On the other hand, MATSim is an individual-centered model where each agent of a synthetic population (representative of the real population) is associated with some daily activities. The route traffic choice is the result of the maximisation of each utility agent associated with different options, which aim to represent the profitability after each trip. Therefore, intermodality is a crucial feature of the MATSim approach. Outputs are aggregated at the level of links of the transportation network. In other words, we know the traffic condition at each link as a congestion level. The computational requirement of this approach is less than that of the Symuvia approach, allowing it to simulate the daily evolution of traffic conditions in wide urban areas.

Emission model

To estimate the real impact of the difference between those models on emissions, we coupled them with the same emission model HBEFA (Kickhöfer, 2016). This latter is a European database of emission factors for all current vehicle categories. The model is based on traffic situations: emission factors are associated with five traffic conditions (from free flow to congested) and the characteristics of the streets. Therefore, we obtained each link's traffic condition by measuring the average speed with the Symuvia and MATSim models, funding the related emission factor in the HBEFA model and computing the associated emissions for each link. We investigate the impacts of model mechanisms on emissions rates by comparing outputs from each modelling chain.

Our modelling chains have been designed as independently as possible. Concerning the origin-destination matrices as the input for the traffic models, while in Symuvia it was made from empirical observation of traffic conditions, in MATSim it was made from French census data. Furthemore, the transportation networks came from two different geographical datasets (from the French geographical dataset BDTOPO for Symuvia and from the open-access OpenStreetMap for MATSim). Due to those essential differences between modelling chains, we group our outputs by a spatial tessellation. Several kinds of tessellation can be proposed. In this paper, we start with an administrative tessellation.

Results

The study case of this paper is the L63V neighbourhood: this urban area covers the 1st, 3rd and 6th districts of Lyon and the Villeurbanne urban area (France). The area covers 10 km² of the Nord-Est Lyon metropolitan area, which covers 75 administrative subareas (IRIS). In the following, the IRIS tessellation will be used to investigate the spatial distribution of our outputs. While the MATSim simulation covers a day of simulation, the Symuvia simulation covers 4 hours (between 6:00 am and 10:00 am). Our analysis is over this last time range, and our results are aggregated for 15 min time slots.

Figure 1 depicts the traffic condition for each 15 minutes time slot. Although the total distance of vehicles at each time slot is similar (figure 1, left), the number of vehicles currently over the networks is 3 times more in MATSim simulation than in the Symuvia simulation (figure 1, middle). Intuitively, the average vehicle speed is less in MATSim (figure 1, right).

As expected, the different traffic dynamics of models impact emissions of PM10, CO2 and NOx (figure 2). The shape of the distribution of emission obtained from the MATSim and Symuvia simulations are similar (Gaussian-like shape). However, for all pollutants, MATSim overestimates pollutant emissions compared with Symuvia.

Figures 3 depicts the correlation between the total emissions obtained from MATSim and Symuvia models, while Figure 4 depicts the spatial distribution of the total gap between emissions obtained from both models. As previously mentioned, total emissions are overestimated by MATSim model compared with that of Symuvia. However, in Figure 3 we observe that low values are more correlated for the three pollutants than higher values.

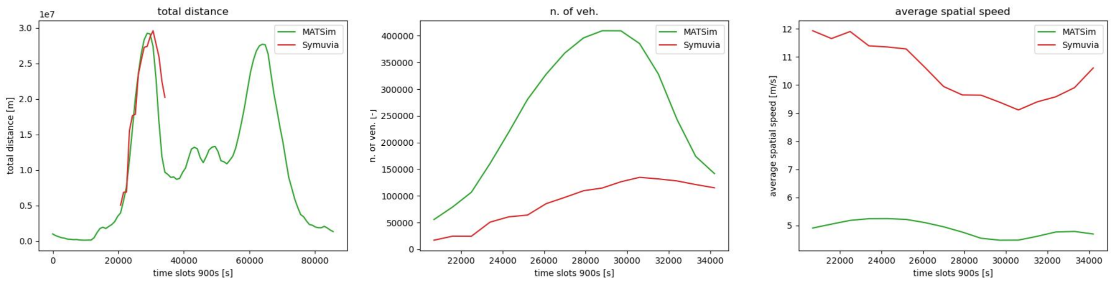

Figure 1: Traffic condition estimation: average speed (left), number of vehicles (middle) and total distance travelled by vehicles (right).

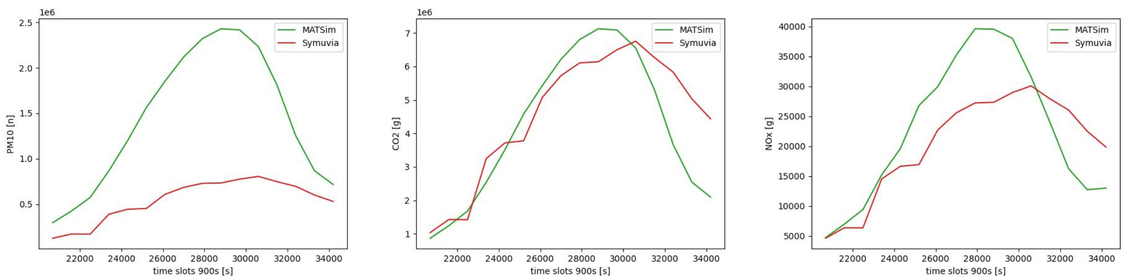

Figure 2: Total emission for 15 min slots of PM1.0 (left), NOx (middle) and CO2 (right).

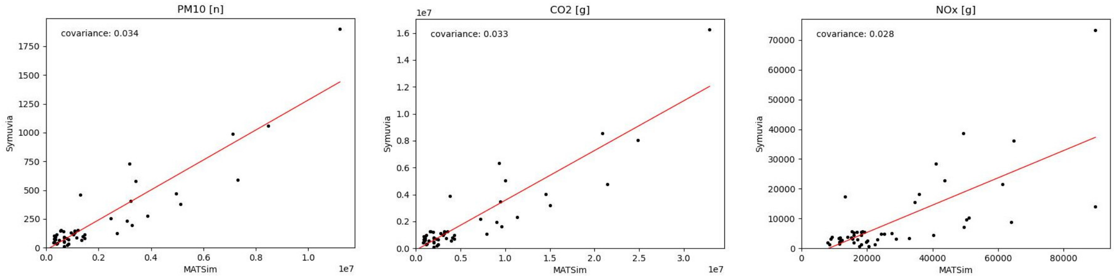

Figure 3: total emissions correlation between Symuvia and MATSim models for PM1.0 (left), NOx (middle) and CO2 (right).

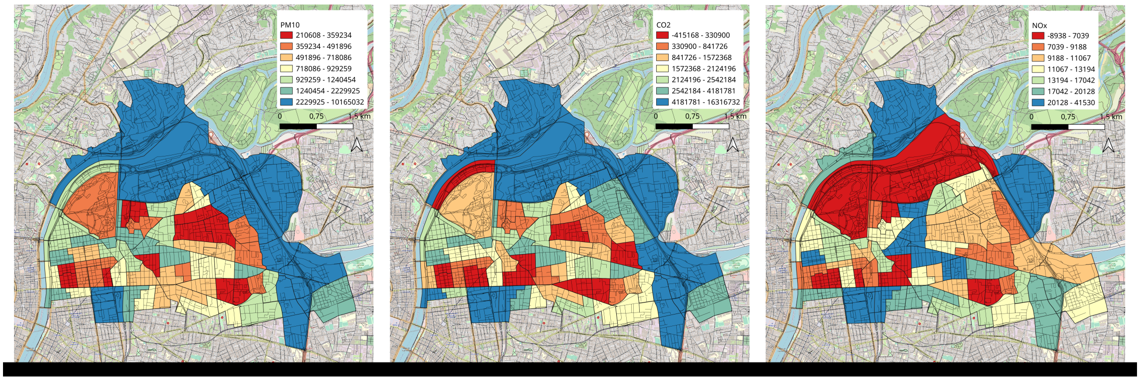

Figure 4: Spatial distribution of the gap of PM1.0 (left), NOx (middle) and CO2 (right) between the emissions computed from Symuvia and MATSim.

Discussion and conclusion

The first step to conceptualizing a modelling chain to investigate human exposure to traffic-related air pollution is coupling a traffic model with an emission model. Several kinds of models can be taken into consideration. Among the different aspects to consider, the scale of measure is a crucial feature. This paper compares traffic-related emissions computed from two completely independent models: the microscopic (Symuvia) and the mesoscopic (MATSim) traffic simulator. In order to avoid being affected by uncertainty due to emission models, we coupled both models with the emission model HBEFA, and we estimated the corresponding pollutant emissions.

First, we observe that traffic conditions are quite different between our models. The average speeds of vehicles are lower in Symuvia than in MATSim, and the number of vehicles over the network is higher in Symuvia that in MATSim. The total distance of vehicles for each 15 min time slot is similar. Those differences found reasons for the model concept of our models. In MATSim, each street is modelled as a queue in which vehicles must wait at least for the free travel time. The flow rate and storage capacity are limited to reproduce the congested phenomena. Therefore, speeds are averaged over links. Otherwise, in Symuvia, vehicles' kinematics are explicitly designed. Average speeds are computed from instantaneous kinetics.

Statistical and spatial analyses show patterns and heterogeneities of total emission over the study area. Concerning the spatial distribution of pollutant emissions, we observe that the gap between our models differs for each pollutant. For example, in the northwest of our study area, we observe a higher gap for PM10 and CO2 pollutants and a lower gap for NOx. Pollutant emissions are higher for MATSim simulation and, for lower values, strongly correlated. Moreover, higher gaps are also observed.

This work is bases on a preliminary brick assessing the impacts of traffic mitigation strategies on human exposure to traffic-related air emissions. Here our purpose is to explore the impact of two kinds of traffic models on emission rates. However, this work is open to plenty of perspectives. First, we want to improve our spatial analysis by testing different tessellations (e.g., regular grid and network-centered) to avoid spatial incoherencies. Second, in the next, we will consider time variations over the spatial tessellation to understand the gap between models on the impact of different traffic conditions on emission rates. Finally, we will validate our results by comparing the completed modelling chain with empirical measurements.

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