Reduction of errors when estimating emissions based on static traffic model outputs

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Abstract

The rapid growth of traffic congestion has led to an increased level of emissions and energy consumption in urban areas. Well designed infrastructure and traffic controllers along with more efficient vehicles and policy measures are required to mitigate congestion and thus reduce transport emissions. In order to evaluate how changes in the traffic system affect energy use and emissions, traffic analysis tools are used together with emission models. In large urban areas emission models mainly rely on aggregated outputs from traffic models, such as the average link speed and flow. Static traffic models are commonly used to generate inputs for emission models, since they can efficiently be applied to larger areas with relatively low computational cost. However, in some cases their underlying assumptions can lead to inaccurate predictions of the traffic conditions and hence to unreliable emission estimates. The aim of this paper is to investigate and quantify the errors that static modeling introduces in emission estimation and subsequently considering the source of those errors, to suggest and evaluate possible solutions. The long analysis periods that are commonly used in static models, as well as the static models’ inability to describe dynamic traffic flow phenomena can lead up to 40 % underestimation of the estimated emissions. In order to better estimate the total emissions, we propose the development of a post processing technique based on a quasi-dynamic approach, attempting to capture more of the excess emissions created by the temporal and spatial variations of traffic conditions.

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1. Introduction

The growing need of travelling, which is one of the main characteristics of our modern societies, has led to highly congested urban areas with high pollutant levels. Efficient usage of our transport systems, by good traffic planning, control and development of traffic policy measures, is nowadays even more essential than earlier. In order to evaluate how changes in the traffic system affect energy use and emissions, traffic analysis tools are used together with emission models. Depending on their level of detail, emission models can be distinguished in instantaneous and aggregated...
models. Instantaneous emission models calculate emissions second by second, based on vehicle trajectories derived from floating car measurements or microscopic traffic models. However, such trajectory data is not available from traffic models commonly applied to larger urban areas. Alternatively, aggregated emission models that are based on traffic activity aggregated in time and space, can be applied at regional and national levels. While instantaneous models rely on microscopic traffic flow models outputs, aggregated emission models rely on aggregated macroscopic traffic data that can be attained from macroscopic traffic assignment models. Specifically, in large urban areas, static traffic assignment models are mainly used for this purpose, since they can efficiently be applied to larger areas with relatively low computational cost.

Static assignment models are used at a strategic level in order to assess long-term effects of changes in the transportation infrastructure. However, their underlying assumptions can lead to inaccurate predictions of the traffic conditions. By using static models, many important dynamic traffic flow phenomena, such as the formation and the propagation of queues, cannot be taken into account. Each link’s travel time is associated with a volume delay function (VDF) that depends only on the flow traversing that specific link, and the link is modeled independently of the other links’ traffic conditions. In this way, queue spill-back is not explicitly considered, and hence congestion appears at the wrong location, specifically at the bottleneck instead of upstream the bottleneck. However, during an air quality analysis, the accurate determination of the congested traffic state and its location is essential, since air quality effects are location specific. Therefore, the spatial average travel times and consequently the average link speeds, computed by static models, may be insufficiently accurate for use in emission modeling, especially in congested networks.

Additionally, another inability of static models that can also lead to incorrect emission estimations, is related to the temporal resolution of the analysis period. Static assignment models consider a stable demand during a fixed time period, commonly covering a period of several hours, (in Sweden a three hour period is used when modeling the morning peak in Stockholm) and the results are expressed in temporal mean values. Thus, if the speed fluctuation is high, which is not uncommon during a three hour morning peak period, average speed and flow cannot capture the speed variations and consequently emissions based on the average traffic conditions may be inaccurate. The difficulty of using mean speeds and flows as input to emission models have been discussed in several papers (Nesamani et al., 2007; Muller-Perriand, 2014; Ryu et al., 2015).

While static models describe a mean traffic state over a longer time horizon, dynamic modeling approaches allow the traffic conditions to be described for shorter time periods. Also, blocking back of the queues, as traffic demand exceeds capacity, and dispersion of the queues when demand is below the capacity, can be modeled. Therefore, dynamic modeling approaches are better suited to model changes in traffic conditions, and are well equipped to model both the spatial and temporal distribution of congestion. Trying to take advantage of the dynamic modeling benefits that potentially can improve emission estimation, Smit et al. (2008), Aguilera and Lebacque (2010) and Borge et al. (2012) applied dynamic traffic models in order to generate inputs for emission models. Furthermore, Wismans et al. (2013) performed a comparison between the emission prediction based on static and dynamic models. From an emission modeling perspective, it was clearly shown that there is large absolute difference between modeled emissions depending on whether static or dynamic models are used.

Nevertheless, while dynamic approaches provide mechanisms for high resolution modeling of both the spatial and temporal congestion’s distribution, it is important to recognize that they heavily rely on the availability of high resolution data, both in terms of demand and calibration data. Additionally, in general a unique equilibrium solution does not exist for dynamic traffic assignments, which may create difficulties during the comparison of different policy measurements. Finally, complexity issues make dynamic modeling computationally expensive and time consuming to calibrate, and hence static assignment models are still the main tool for traffic analysis in larger urban areas. Therefore, it is of interest to consider how the output from a static model can better be explored in the emission modeling process, in order to improve the quality of the emission estimations.

The aim of this paper is to investigate and quantify the errors that the average speed and flow outputs of static modeling introduce in the emission estimation process. Subsequently, considering the type and the nature of those errors, our aim is also to suggest and evaluate improvements in the modeling process. The paper is structured in the following way: Section 2 gives a short description of aggregated emission models and how they can be applied to outputs from static traffic models. The paper continues with an overview of methods for post-processing of static modeling results in Section 3. In Section 4 the different sources of errors (temporal and spatial) of emission estimations from static models are presented, together with computational examples for a motorway stretch in Stockholm. In
Section 5 a quasi-dynamic network loading technique is applied and evaluated as a post-processing method of static modeling outputs. The paper ends with conclusions and discussion on future research in Section 6.

2. Aggregated emissions models and their application on static traffic model outputs

In aggregated emission models, emissions are calculated by multiplying the traffic activity with the corresponding emission factor. The basic aim of the emission models is to provide the user with the appropriate emission factor for each vehicle and road category. Emission factors are functional relationships, computing the quantity of a pollutant that a vehicle emits per a specified distance driven. The emission factors can be obtained from dynamometer test or other experimental data corresponding to a specific driving cycle. A detailed review of the experimental approaches that have been used in practice for the development of the emission factors can be found in Franco et al. (2013).

Today, COPERT and HBEFA are the two leading aggregated emission models in Europe. COPERT (Computer programme to calculate emissions from road transport, Gkatzoflias et al., 2007) is used by several European countries in order to officially report their national inventories of emissions from road transport. The emission factors depend on vehicle and road class, and are defined as continuous functions of average speed. Average speeds can be derived from the outputs of traffic models, by dividing the predicted average travel time with the length of each link. HBEFA (Handbook on emissions factors for road transport, Keller, 2010) is an emission factor database which is developed on behalf of several European countries (Germany, Austria, Switzerland, Norway and Sweden). The HBEFA database includes emission factors as a discrete function of vehicle legislative class, road category and traffic situation. The vehicle classes are defined by the exhaust emission limits according to the European emissions standards, while the traffic situations are defined by indicative flow and speed levels. HBEFA emission factors rely on four traffic situations: Free flow, Heavy, Congested, and Stop and go. The road categories are divided by road environment (rural and urban), speed limit and road type (Motorway, Trunk road/Primary, Distributor/Secondary, Local/Collector, Access/Residential). A detailed description of the two models, as well as an overview of the research issues that the European Research Group on Mobile Emissions Sources (ERMES) is facing regarding the two models can be found in Franco et al. (2012).

In this study we used the HBEFA emission factors adapted for Swedish roads and traffic conditions. Using information of the Swedish vehicle fleet composition, we calculated the weighted average of the emission factors corresponding to different vehicle classes, fleet mix and mileage. Finally, our estimations were based on emission factors for five pollutants ($HC$, $CO$, $NO_x$, $CO_2$ and $PM_{10}$) and fuel consumption ($FC$), for four traffic situations (Free flow; Heavy; Congested; Stop and go) and for two different road types (Urban motorway (URB) with a speed limit of 90 and 70 km/h). An example of the $CO_2$ and $NO_x$ HBEFA emission factors that reflect the Swedish conditions is illustrated in Figure 1.

For the traffic situation distinction we used the volume capacity ratio ($V/C$) thresholds (Table 1), suggested by the Swedish Traffic Agency Handbook for road traffic and air pollution Trafikverket (2012). In this way, the assigned flow together with the capacity is used to determine the traffic situation for each link in the network.

![Figure 1. HBEFA emission factors; (a) $CO_2$ (b) $NO_x$.](image-url)
3. Methods for post-processing of static modeling results

Static models’ inability to describe dynamic phenomena of traffic flow can possibly lead to considerable errors concerning the emissions. Conversely, dynamic models include representation of the traffic dynamics and might therefore be better suited as a basis for computing reliable emissions. However, they require additional computational time and calibration. An alternative approach with relatively low computing cost, is to post-process the static models outputs in order to provide more accurate estimates of the traffic conditions and thus more accurate emissions.

During the past years, several papers have addressed the problem of average speeds from static models by proposing such post-processing techniques. Many researchers have moved towards the development of congestion correction techniques, capable to reflect the speed variability (Negrenti, 1999; Nesamani et al., 2007; Smit et al., 2008; Ryu et al., 2015). The main hypothesis of these approaches is that the application of correction techniques over the static modeling results will lead to more accurate emission estimations. Bai et al. (2007) considered direct speed post-processing techniques for improving the emission estimates derived from the static traffic assignment models, based on intersection delays and queueing analysis approaches. However, by applying such post-processing methods, queues are represented as vertical points and propagating phenomena like spill-back are not taken into account.

The developed post-processing techniques mainly focus on post-processing of link speeds. However, they do not take the network topology and interactions between links into consideration. An alternative approach would be to apply a simulation based network loading technique. Such techniques are commonly applied in dynamic traffic assignment approaches, and can be distinguished in micro, meso or macroscopic simulation approaches. All such approaches rely on dynamic route and demand information, and the quality of their results is largely depending on the calibration of the model. For micro and meso approaches, this requires more detailed input about the road infrastructure in comparison to what is needed for static traffic models. Macroscopic approaches, however, are more similar to static models, in their level of aggregation and simplification of the road infrastructure. Such network loading approaches have been incorporated in static models, in order to take into account interactions between the links (Bundschuh et al., 2006; Bliemer et al., 2012). However, this type of models has so far only been used for improved estimation of travel times on routes, but not for emissions estimation since their outputs cannot straightforward be applied to an emission model.

4. Emission estimation errors when using static model outputs

In order to illustrate the emission estimation errors that static models can cause, a 6.6 km long section of the E4 motorway, north of the Stockholm city centre has been used as a test case. The motorway section includes three on-ramps and three off-ramps and hence it was divided into 7 links, see illustration in Figure 2. Additionally, this section is equipped with radar sensors, measuring average speed and flow per lane during one minute intervals. Between the sixth and the seventh link the capacity changes drastically and thus during the morning peak-hour the latter becomes an activated bottleneck, resulting in queues spreading over several of the upstream links. Therefore, we focused on the morning peak between 6:30 and 9:30, which is a sufficiently long time interval for the complete formation and also the dissolution of the queues. Data from three months (February, March and May of 2012) was used.

The $V/C$ thresholds, as were described in Section 2 cannot directly be applied to the measurements since they are developed to be used with outputs from static models. Static assignment models allow the volume to be higher than the capacity of the road since the underlying VDF represents travel times as a function of demand rather than the actual flow. However, in reality it is not possible for the flow to be higher than the capacity and accordingly, by applying the $V/C$ thresholds (or flow thresholds derived from the $V/C$ thresholds multiplied by the capacity) on
measurements the Stop and go situation cannot occur (Figure 3 (a)). However, as it is depicted in Figure 1, the Stop and go situation corresponds to the higher emission factor, and hence the accurate prediction of this situation becomes essential. Therefore, in order to more efficiently capture the Stop and go situation we used the fundamental diagram that more realistically captures the relationship between flow, density and speed. In contrast to the VDF, the relationship between flow and speed is not monotonic. Low flows can correspond either to low speeds, in the case of saturated conditions, or to high speeds, in the case of non-saturated conditions. Thus, since flow cannot by itself determine the traffic situation, we converted the V/C ratio thresholds into speed thresholds. Using the fundamental diagram, proposed by Smulders (1988), the flow thresholds were projected to the speed axis in order to determine the speed thresholds, as illustrated in Figure 3 (b). Figure 3 (c) illustrates the way that the measurements are distributed to each traffic situation, according to the speed thresholds. Additionally, as mentioned in Section 2 the HBEFA emission factors is a discrete function of the traffic activity. However, in order to avoid large changes between the emissions factors for small changes in the traffic activity, we suggest a continuous version of HBEFA derived by linear interpolation between the emission factors corresponding to the adjacent traffic situation, similar to the interpolation done in (Wismans et al., 2013).

4.1. Temporal errors of emission estimations

In order to obtain a more clear view of the problem, the errors that static modeling can introduce to the emission estimation are distinguished in two categories. Errors that concern the temporal resolution and errors related to the spatial variation of mean speed. Firstly, concerning the errors related to the temporal resolution of mean speed, and trying to quantify the influence of using longer aggregation periods, we calculated the emissions using the radar sensors outputs aggregated over three different periods, 15 minutes, 1 hour, and 3 hours. The 15 minutes period was considered as the most representative aggregation level, which can catch the temporal speed variations due to fluctuations in demand. Therefore, emission estimates for this aggregation period, were used as a baseline and compared with the emission estimates using longer aggregation periods.

By taking average speed aggregated over longer periods, we were not able to capture the temporal variations of the traffic situations, and consequently the proportion of the different traffic situations is significantly affected, as illustrated in Figure 4. As can be seen in Figure 5 (a) this can lead to underestimations up to 6% and 24% compared to the
baseline of 15 minutes aggregation level, for the case of 1 hour aggregation level and 3 hours aggregation level respectively. Nevertheless, in Sweden a 3 hours aggregation period is used when the morning peak is modeled. Therefore, even if we assume that a static model would accurately predict the same speeds and flows with the measurements, there are still substantial errors because of the low temporal resolution. However, by applying the continuous version of HBEFA as presented in Section 4, the errors caused by the temporal resolution can be significantly reduced. Figure 5 (b) illustrates that using the interpolated version, the emissions calculations becomes less sensitive to the aggregation period.

Figure 6 shows how the temporal errors are spatially allocated among the links of the network, when the 3 hours aggregation level is compared with the baseline 15 minutes. We can notice smaller differences among the different aggregation levels at the bottlenecks (link 7) since the traffic conditions are more stable there. Conversely, the highest differences are observed at the links upstream the bottleneck. At these links, the speed variations are higher due to the backwards propagating queues formed by the bottleneck. Comparing the results between the discrete HBEFA version (Figure 6 (a)) and the continuous version (Figure 6 (b)), it becomes clear that the continuous version of HBEFA can effectively reduce the estimation errors.

**4.2. Spatial errors of emission estimations**

In order to quantify the errors that static models introduce in the spatial dimension, we compared emissions estimations based on radar sensors measurements with emissions estimation derived from static assignment outputs. Assignment is an iterative procedure, where demand with the help of costs, calculated from VDFs, is assigned to each path of the network and links are loaded with flow. However, at our corridor network there is only one possible path between each origin-destination (OD) pair, and therefore there is no route choice. Therefore we are only interested in the loading phase of static models. Considering the fact that there is no queue formed before the start of the first hour, and all the queues have been discharged after the end of the third hour of the analysis period, we assumed that the
three hour demand equal to the total three hours network inflow of an average weekday. Next, the network was loaded with the assigned demand at each path, and at every link a V/C ratio was defined. As it was mentioned in Section 2 when the results of static models are used as emission estimation inputs, the distinction of the traffic situations is based on the V/C ratio (Figure 1 (b)). It should be noticed here that the continuous version of HBEFA was used.

Figure 7 illustrates the combination of the spatial and temporal errors when emissions based on static modelling outputs are compared with the baseline (measurements aggregated over 15 minutes), and also how these errors are distributed in the network. From Figure 7 it is clear that the emissions are underestimated on the links upstream of the bottleneck link. The static model is not able to capture the propagation of the queues as well as the three hours analysis period cannot reflect the temporal variations of traffic activity. However, concerning the bottleneck (link 7), where the demand is higher than the capacity, the static model loads the whole demand into the link without any capacity constraint, resulting high V/C ratio, and finally overestimation of emissions.

![Figure 7. Combination of temporal and spatial errors. Relative difference in % between emissions calculated from measurements (15 minutes aggregation) and emissions calculated from the outputs of static modelling.](image)

5. Quasi dynamic loading as a post-processing technique

Based on the state-of-the-art and the results from the error estimation it becomes clear that some kind of post-processing of static modeling results are needed before their use as input to emission models. As seen in Section 3, several post-processing methods have been suggested and tested. However, none of these methods take into account spill-back of the queues. Nevertheless, as it was demonstrated in Section 4, insufficient modelling of the queue propagation can have crucial effects on emission estimations.

However, the quasi-dynamic loading techniques suggested by Bundschuh et al. (2006) and Bliemer et al. (2012) consider spill-back phenomena and queues are propagated in a more realistic way. Bundschuh et al. (2006) proposed a pseudo-dynamic model that is capable of reflecting spill-back but with less computer resources required than dynamic loading techniques. However, this method is not based on a realistic fundamental diagram and it is not clear how the queueing capacity can be determined. Alternately, by applying the loading model proposed by Bliemer et al. (2012) queues are propagating based on the kinematic wave theory (KWT) and more realistic results can be obtained. Nevertheless, the outputs of those quasi-dynamic loading models have not until now been used as inputs to the emission models. Our hypothesis is that the application of a quasi-dynamic model could lead to more realistic emission estimations than a static model but with less computer effort than a dynamic.

5.1. Static assignment with queueing

Static assignment with queueing (STAQ, Bliemer et al., 2012) is a quasi-dynamic flow propagation model derived from the dynamic link transmission model (LTM, Yperman, 2007). LTM is a dynamic network loading model that propagates traffic through the network based on the KWT. According to the KWT, traffic flow is considered as a partially compressible mono-dimensional fluid, propagating into the network through kinematic waves. Lighthill and Whitham (1955) and Richards (1956) first proposed and analyzed kinematic waves on homogeneous links. The corresponding model is known as the LWR model and is described by a first-order, nonlinear partial differential equation, known as conservation law. Daganzo (1995) proposed the Cell Transmission Model (CTM) which constitutes a discrete in time and space numerical solution scheme for the LWR. In contrast to the CTM, LTM does not require the spatial discretization of links into cells and is mainly based on the simplified wave theory of Newell (1993).

The quasi-dynamic model STAQ is derived from the event based LTM, by considering two static assumptions. The demand is stationary over a given period and traffic propagates instantaneously. STAQ consists of two phases, the
squeezing and the queuing phase. During the squeezing phase, in which there is no time variable, the network is loaded with flow through an incremental assignment that ensures that no link flow exceeds capacity, and queues are built vertically. Next, during the queuing phase the effect of blocking back is considered and queues spill-back to the upstream links. The propagation of the queues is determined by the shockwaves speeds calculated according to the KWT. Whenever a shockwave reaches the beginning or the end of a link, or meets another shockwave, a so called event occurs. The queuing phase ends when all traffic demand has reached its destination.

5.2. Determining emission factors based on queuing information

The main output of the STAQ model as it is described in Bliemer et al. (2012) is average link travel times, calculated by the cumulative number of vehicles. However, by applying static loading with queuing it is also possible to keep track of the spatial position of the shock wave when an event occurs. In our study, trying to make the model’s outputs suitable for emission estimation, we split each link into queuing and running space-time areas using the queue spill-back information. Each area corresponds to different regime of the fundamental diagram and hence the crucial for the emission estimation average link speed acquires spatial and temporal variability.

Consider a network including a set of consecutively numbered links \( A \). Then, during a simulation period \( t \), we assume that \( n \) consecutive transitions between a set of numbered traffic conditions (running or queuing condition) \( I \) can be occurred. Figure 8 illustrates the outputs of the applied event based queueing model for two transitions between the traffic conditions \( 1, 2, 3 \in I \), first from 1 to 2, and then from 2 to 3, and for two typical links \( \alpha, \beta \in A \). The wave speeds \( \omega \) between the traffic situations have been calculated according to the KWT. The time when a backward wave reaches the upstream end of a link \( a \) is denoted with \( \text{event}^a_\alpha \), while the time when a forward wave reaches the downstream end with \( \text{event}^a_\beta \). For each link \( a \in A \) and each traffic condition \( i \in I \) a two-dimensional section with known area is formed, associated with a density \( k_i^a \), a flow \( q_i^a \) and an average speed \( u(q)^i_a \) derived from the speed-flow fundamental diagram. Assume that the area of each section is \( A^i_{a, \alpha} \). While the average speed \( u(q)^i_a \) of each part is known, the HBEFA emission factor \( E^i_{f_a} \) can be found. Finally the total emissions of the network are estimated by:

\[
\text{Total emissions} = \sum_{a \in A} \sum_{\alpha \in I} A_{a, \alpha}^i \cdot E^i_{f_a} \cdot q^i_a
\]

5.3. Application and experimental results for the Stockholm motorway stretch

As we have aforementioned, our hypothesis is that the application of a quasi-dynamic model as a post-processing technique could potentially reduce the emissions estimation errors introduced by static models. Therefore, in order to quantify this reduction, we applied the STAQ for the same Stockholm’s test site network and we compared the resulted emission errors to the errors presented in Figure 7.

The main inputs required by the STAQ model are the demand between each O-D, as well as a fundamental diagram in order to calculate the shockwave speeds. We assumed the same three hours demand as the demand that was used in Section 4.2. However, as it was demonstrated in Section 4.1, a three hours aggregation period can lead to significant
emissions underestimations. Therefore, we divided the analysis period into three smaller, one hour long sub-periods, and we ran the model three times separately for each period. The division of the analysis period was performed based on the flow variation indices suggested by Björketun and Carlsson (2005). Specifically, to the first hour (6.30-7.30), 27% of the total demand was assigned, while to the second (7.30-8.30) and to the third (8.30-9.30), the 37.5% and the 35.5% respectively.

Regarding the fundamental diagram we selected to use the diagram proposed by Smulders (1988) instead of the triangular. According to the Smulders fundamental diagram, the speed decreases linearly while the flow increases at the flowing regime, in contrast to the triangular, where at the same regime the speed is constant and equal to the free flow speed.

Figure 9 presents the post-processing results, illustrating the variations of speed (Figure 9 (a)), fuel consumption (Figure 9 (b)) and of a representative emitted pollutant (Figure 9 (c)), while the queue, formed by the bottleneck, is propagating into the network. It can be seen that the link speed in not constant any more, but varies spatially and temporally influencing significantly the emission estimates.

Figure 9. Space-time domain during the second hour of our analysis period: (a) Speed; (b) Fuel consumption; (c) NOx.

Figure 10 (a) illustrates the spatial allocation of the errors, when the emissions computed by the STAQ outputs are compared with emissions computed by measurements. Although the errors on the first upstream the bottleneck link have been reduced compared to the simple static case (see Figure 7), considerable underestimations can still be observed at the more upstream links. Nevertheless, Figure 10 (b) demonstrates that the total networks’ errors between the emissions calculated from measurements and the emissions calculated from the quasi-dynamic model, have been reduced compared to static case. The magnitude of this reduction varies among the pollutants. By applying the post-processing technique, the estimates were improved 20% for FC, 19% for HC, 45% for CO, 32% for NOx, 20% for CO2 and 38% for PM compared to the simple static case.

Figure 10. (a) Relative difference (%) between emissions calculated from measurements (15 minutes aggregation level) and the quasi-dynamic model (Static with queuing) outputs; (b) Total emission estimation errors(relative difference (%)), when the static model is used and after the post-processing.

6. Conclusions and future research

In large urban areas, static models are commonly used in order to generate inputs for emission models. However, the results presented in this paper show that their simplified way of representing traffic can lead to significant emission estimation errors. Longer analysis periods that are considered by the static models, tend to underestimate the estimated emissions when the discrete emission model HBEFA is used. Nevertheless, using a continuous version of the model, the temporal resolution problem can be satisfactorily moderated. Additionally, the inability of static models to describe
dynamic traffic flow phenomena can cause considerable emissions estimation errors. Considering the sources of the errors we suggested to divide the analysis period into shorter sub-periods as well as to apply post-processing of static models outputs by using a quasi-dynamic loading model capable to describe queues’ spill-back. Finally, by applying the modified model, we estimated more accurate emission compared to the simple static case.

It should be noticed here, that for our experiments a simple corridor network was used, and thus no route choice was considered. However, by modeling statically a larger, more complicated network, route choice and network topology, possibly would generate even higher emission estimation errors. Therefore, the quantification of the emission errors and the investigation of the post-processing influence when a more complicated network is modelled, would be an interesting future research topic. Additionally, according to the Figure 10 (a), emissions are considerably underestimated even after the division of the analysis period and the application of a quasi-dynamic model. This may be caused by the fact that each sub-period is modelled independently. Queues are dissolved after the end of each sub-period and the next one starts with zero queue length. The emission estimation, in the case that the post-processing algorithm considers not only the queues’ spatial propagation among the network’s links, but also the temporal transmission of the queues between the sub-periods, would be also an interesting topic under investigation for the future.

References


