COMPARISON OF ESTIMATION OF EMISSIONS BASED ON STATIC AND DYNAMIC TRAFFIC ASSIGNMENT MODELS

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ABSTRACT

For the estimation of air quality and noise nuisance often the output of static traffic assignment models is used. However, static traffic model have several limitations related to the realism of dealing with saturated traffic conditions, which are important for the estimation of emissions. Static traffic assignment models predict congestion on the wrong locations and can not deal with traffic flow phenomena like spillback. As a result also air quality or noise bottlenecks can be predicted on wrong locations, which may lead to erroneous policy decisions concerning new infrastructural measures or implementing mitigating measures on wrong locations. Dynamic traffic assignment models can take these traffic flow phenomena into account and are therefore more suitable to estimate emissions and can in the long term replace the use of static traffic assignment models for larger networks. To provide insights in the differences between estimates based on static and dynamic traffic assignment models in realistic cases, a highway case and urban case are used applying the ARTEMIS model (air emissions) and AR-INTERIM-CM model (noise emissions). The comparison for both cases shows that large differences are found in the estimates for noise (i.e. > 3 dB(A)) and also for the local estimates of air emissions (e.g. up to 45% for NO\textsubscript{x} emissions). When an infrastructural measure is taken the comparison shows that not only the location and extent of effect, but also the direction of effect can be different (i.e. increase versus decrease and vice versa).
INTRODUCTION

Sustainability has become a key aspect in the field of traffic and transport and considering the externalities of traffic is therefore of increasing interest when policy decisions are made. Most countries have regulations regarding air quality and noise, but also in earlier planning stages these aspects are important in the appraisal of alternatives (e.g. using cost-benefit analysis). These aspects, but also energy use and CO₂ emissions, are becoming more and more important. To assess the effects of measures transport models can be used. Traffic assignment is the step in transport modeling in which trips are assigned to the network by confronting demand with supply resulting in route choice, loads and traffic conditions. Different types of assignment models can be used for the assessment of measures, and can be classified into static and dynamic models. Static traffic assignment (STA) models describe the interaction between travel demand and infrastructure supply assuming that the traffic demand and supply are time-independent, hence constant during the considered time period (stationary). The basic output of these models are link loads (amount of traffic using individual roads) and average link travel times or speeds. STA models are generally used at the strategic level in order to carry out long-term studies into effects of (mainly mobility-) measures. Dynamic traffic assignment (DTA) models are typically flow propagation models over time that calculate the resulting traffic conditions, taking changes in supply and demand over time into account.

In most cases the output of STA models is used to assess the effects on emissions [1]. The output used is related to traffic volume, traffic composition (i.e. passenger cars and trucks) and the level of service (i.e. average traffic conditions). The level of service is mostly based on the volume/capacity (V/C) ratio, direct or indirect via the used travel time functions within a STA or using a post-processing procedure (e.g. estimation of modal activity). However, the limitations of STA particular for over-saturated traffic conditions and the importance of taking traffic dynamics (i.e. realistic flow characteristics as well as temporal information) into account when assessing emissions are widely recognized. Many traffic flow phenomena cannot be taken into account which DTA typically can which are important for the estimates of emissions [2]. In general, when using STA, only the average traffic condition per road can be determined, queues appear in the bottleneck instead of upstream the bottleneck, and spillback is typically neglected. Spillback is the phenomenon that a queue on a downstream link affects the possible output volume of the upstream link or links connected to it. Different studies have shown that there is a proven relation between traffic dynamics and externalities. High speeds, significant speed differences between vehicles, and speed variation (accelerating, braking) have for instance a negative effect on air and noise emissions [3,4,5,6]. Using the outcome of DTA, show high potential to improve the emission estimates significantly. Although microscopic models can capture most traffic dynamics, there are several issues in using these models related to the realism of vehicle operations on this microscopic level and the needed computation times. Therefore, especially macroscopic or mesoscopic models may in the long term replace the use of STA models for larger networks. These models can capture many traffic flow phenomena which are important for the emission estimates and can be used on larger networks than microscopic models [7].

Although it has been acknowledged that DTA models provide more realistic flow characteristics and the estimates of emissions improves when DTA models are used, there is limited knowledge on the possible errors made in the estimation of emissions for realistic cases when STA models are used especially when the effects of measures are assessed. The contribution of this paper is therefore to provide these insights by comparing STA and DTA in estimating air or noise emissions for two realistic cases (i.e. a highway network as well as an urban network). The estimates based on these models are also compared with using measurements (i.e. volumes and speeds) as an input for the emission calculations. To be able to perform this comparison both model types are connected with a suitable emission model for air and a suitable emission model for noise which can be used in conjunction with DTA as well as STA assuring consistency in emission modeling. The second section of this paper provides background on emission
modeling and current practice. The importance of capturing traffic dynamics for the emission estimates is described in the third section. The fourth section describes the used framework in this research to compare STA and DTA for the estimation of emissions. The comparison using a highway and an urban case is described in the fifth section. This paper ends with the conclusions and discussion.

EMISSION MODELING

Air emissions
To determine air emissions of substance \( E \) on road links \( a \) the next general formula is used:

\[ E_a = aK_a, \]

where \( a \) is the emission factor and \( K \) amount of vehicle kilometers.

This method is generally used in conjunction with traffic models. The factors that are determinative are averaged or used to differentiate the emission factors and vehicle kilometers. There are many different emission models that can be connected to traffic models to estimate emissions. The types and main characteristics that can be distinguished are presented in Table 1 (adapted from [7]). Aggregated emission functions use single emission factors representing a particular vehicle type and a general driving type. Vehicle operation is therefore only taken into account at a very rudimentary level. More sophisticated aggregated emission functions are based on traffic conditions in which cycle average emission rates are correlated with various driving cycle parameters and are referenced to specific traffic situations. These traffic situations relate to certain conditions (e.g. level of service). Average speed models are based upon the principle that average emission factors vary according to the average speed during a trip. In general a continuous average-speed emission function is fitted for several vehicles over a range of driving cycles. In principle, the input is the trip-based average speed, although in practice it is also common to be used for local speed at discrete locations. Within regression models, each driving cycle used is characterized by a (large) number of descriptive parameters (e.g. average speed, relative positive acceleration and number of stops per km) and their derivatives. A regression model is fitted to the average emission values over the various driving cycles, resulting in the determination of the best predictors for emissions. In modal models, emission factors are allocated to the specific modes of vehicle operation encountered during a trip. Different types of modal models exist, and the terminology used can be confusing. A possible simple type defines vehicle operation in terms of modes like ‘idle’, ‘acceleration’, ‘deceleration’ and ‘cruise’. Instantaneous speed based models relate fuel consumption and/or emissions to vehicle speed and acceleration during a driving cycle, typically at one-second intervals. Instantaneous power based models use a description of the engine power requirement in which the most complex models represent physical and chemical phenomena that generate emissions. Methods part of these types are load based using engine maps or methods using a surrogate of engine power by using e.g. the product of speed and acceleration instead of acceleration, and relate fuel consumption and/or emissions to vehicle speed and this product.

In current practice often STA models are used to assess traffic and transport policies on emissions. Until recently many countries used an average speed based emission model (e.g. COPERT in Europe and MOBILE in the United States). The past few years the modal approach (e.g. MOVES) and traffic situation based emission models (e.g. ARTEMIS) are emerging [1,8]. The calculated V/C-ratios’ are mainly used to estimate the average traffic conditions. These ratios’ can for instance be used to determine the fractions of traffic situations or operational modes of vehicles. Other often used approaches are calculating link speeds based on the travel time functions possibly in combination with post-processing methods to improve speed estimates or to derive other congestion indicators (e.g. delay or queue length).
### Table 1. Overview model types

<table>
<thead>
<tr>
<th>Model type</th>
<th>Function type</th>
<th>Input level</th>
<th>Road characteristics</th>
<th>Vehicle characteristics</th>
<th>Driving characteristics</th>
<th>Traffic characteristics</th>
<th>Example</th>
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<td>Road type</td>
<td>Vehicle class</td>
<td>Flow</td>
<td></td>
<td>NAEI, CAR, EMFAC, VFEM</td>
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<td>function</td>
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<td>Vehicle class</td>
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<td>Trip</td>
<td>-</td>
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<td>Flow, (Adjusted)</td>
<td>Average speed</td>
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<td>UROPOL, MEASURE, MOVES</td>
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<td>Continuous</td>
<td>-</td>
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<td>Vehicle class</td>
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<td>Continuous</td>
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<td>Driving-cycle, used gear</td>
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</table>

#### Emissions of noise

To determine sound emissions, generally functional relationships are used based on statistical analysis per vehicle type and possibly in 1/3-octave frequency bands. In most source models, also called emission laws, rolling noise and aerodynamic noise are combined, but can also be separated functions. Often, the function used is fitted for reference conditions, and for other situations deviating correction factors (γ) are used. These correction factors in most models include influence of road surface, weather and driving conditions (acceleration/deceleration). The general formula for the sound power level \(L_w\) of a single vehicle is:

\[
L_w = \alpha + \beta f(v, v_{ref}) + \gamma_{corrections},
\]

where \(f\) is either a logarithmic function of the vehicle speed in case of rolling and aerodynamic noise, and a linear function of vehicle speed for propulsion noise. The parameter \(\alpha\) is the noise production of a vehicle at the reference speed at a specific distance from the road centre. If the sound power level is calculated per 1/3-octave frequency band, the parameters \(\alpha, \beta\) and \(\gamma\) are also per 1/3-octave frequency band. In general two types of emission functions can be distinguished, instantaneous or traffic situation based. The instantaneous based assumes smooth and homogeneous flow and possibly uses a correction factor for acceleration. Traffic situation based distinguishes traffic conditions for which different functions are used. In the latter the influence of accelerations is incorporated in the emission functions. The types and main characteristics that can be distinguished are presented in Table 1 (adapted from [7]).
Also for noise the current practice is to use the outcome of STA models to estimate emissions. In contrast to the air emissions most countries do no use an estimate of travel speed based on the STA, but use the posted speed limit or operating speed. The new European CNOSSOS model [9] also recommends to use the posted speed limits when estimating noise emissions using STA. Although this is a conservative assumption for highways, for urban road networks this can result in underestimating noise emissions. The correction for driving conditions is often connected with facilities (e.g. intersections, toll plaza’s), which means that for noise the predicted traffic conditions based on the STA model is rarely used.

**IMPORTANCE OF TRAFFIC DYNAMICS**

Traffic dynamics and especially saturated traffic conditions are, next to traffic volume and traffic composition, important explanatory variables for the air and noise emissions [7]. In current practice this has also resulted in taking traffic dynamics to a certain level into account when STA are used. However, STA models can only determine the average traffic conditions and STA models have several limitation in capturing traffic flow phenomena and therefore possibly predicts incorrect traffic conditions. Figure 1 presents the relation between traffic condition and externalities for different road types based on the ARTEMIS emission model [10]. Four different traffic conditions are distinguished and 10 road types. The importance of traffic dynamics is obvious, based on the differences in emission factors dependent on traffic condition. Emissions increase when traffic conditions get saturated and can be higher at high speeds. Similar relations can be found for other substances like particulate matter (PM\textsubscript{10}) and carbon dioxide (CO\textsubscript{2}). For trucks, not presented in this paper, the emissions are especially higher for stop & go traffic conditions.

![Emission factors dependent on traffic condition and road type](image)

**Figure 1.** NO\textsubscript{x} emission factors dependent on traffic condition

The relevance of capturing realistic traffic dynamics has been subject of research for many years now. In [11] for example it was found that an error of 5 km/h in the estimate of speed could result in a 42% difference in CO emission predictions. Smit et al. [12] found that considering speed distribution instead of average single mean speed can improve emission predictions since this would be closer to reality and can lead to up to 24% higher emissions of CO, HC, NO\textsubscript{x}, PM\textsubscript{10} and CO\textsubscript{2}. In [13] it is shown that the ability to take modal activity into account quadruples the estimated emission benefits of signal coordination. In the past years there is an increase in research in which the output of DTA models is used to estimate the air
emissions. Often this research is based on using microscopic simulation models \[14,15,16,17,18\]. Less research has been done in connecting macroscopic or mesoscopic DTA models with emission models. In \[19\] for example, a framework has been developed for dynamic estimation of traffic emissions using REALITY, a road activity emission calculation model, together with LADTA, an analytical dynamic traffic assignment model. A traffic situation emission model VERSIT$_{\text{macro}}$, in conjunction with the macroscopic DTA model INDY was used in \[12\]. The VERSIT$_{\text{macro}}$ emission model consists of composite emission factors for discrete traffic situations. The mesoscopic DTA model Dynasmart-P and the average speed based emission model EMFAC was used in \[20\] to analyze trip-based versus link-based traffic data for emissions estimation.

![Figure 2. Noise emission dependent on traffic condition](image)

The relation between speed and noise is presented in Figure 2 and based on the AR-INTERIM-CM model \[21\]. The figure illustrates that emissions increase in saturated conditions, because of an increase of vehicles accelerating and because at low speeds the propulsion noise becomes the dominant source for noise. For trucks a similar relation exist, however in this case propulsion noise stays dominant at higher speeds and as a result the emissions for trucks in saturated traffic conditions can be higher than in free flow conditions on highways.

In \[22\] and \[23\] it is concluded that there are several benefits in considering temporal information on dynamics of traffic in order to improve road noise emissions estimates, because of identifying local peaks and variations. The relevance of traffic dynamics for noise emission estimates has been subject of research by \[6\] and \[24\]. Both compared noise assessments using static and dynamic traffic models in conjunction with a noise emission model for a urban network (single intersection or corridor). Both concluded that STA is not refined enough to guarantee precise noise estimates and that incorporating more dynamics could improve noise estimates. The French ‘Guide du Bruit’ (also used for the AR-INTERIM-CM model) is used in \[6\] and \[24\] the FHWA noise emission database, in which the sound power level depends on vehicle speed and throttle conditions (cruising or full). Earlier \[25\] concluded that a macroscopic dynamic traffic model is sufficient for noise assessments in urban traffic conditions but can be improved by using microscopic traffic models. Research in which DTA models are used in conjunction with noise emission models are however less available. Examples are \[23,26,27\].

In general, literature agrees that traffic dynamics are important for emission estimates and that the estimates improve when DTA models are used instead of STA models. Most efforts made use
microscopic DTA models in conjunction with emission models. However, as argued by [7], [13] and [19] these type of models are less suitable for large networks because of calculation times and can also result in apparent accuracy when individual vehicle operations are used. As a result still STA is mainly used to estimate emission. However, there is less research available on the possible error of using STA especially when assessing the effects of measures taking into account the limitations of STA for realistic cases. Using STA models can result in predicting congestion on wrong locations namely downstream the bottleneck instead of upstream, STA models do not model spillback and do not take into account that bottlenecks will influence downstream traffic demand. As a result the errors in the emission estimates based on STA can be possibly large especially in oversaturated traffic conditions.

MODELING FRAMEWORK

Based on the extensive review [7] emission models are selected which are suitable to use in conjunction with DTA models, but which can also be used with STA. The ARTEMIS model for air emissions and AR-INTERIM-CM model for noise emissions were selected. Both models are traffic situation based model which can take traffic dynamics into account. For the comparison an emission module has been developed based on these models and connected with the OmniTRANS transport planning software. The Streamline DTA model [28] is part of this software, which is a second order multi-class macroscopic DTA model with physical queuing and spillback. The used STA as well as DTA uses junction modeling to take delay at intersection into account.

The estimation of air emissions is based on the ARTEMIS model which distinguishes 4 traffic conditions to calculate hot engine emissions (cold start emissions can be calculated but are not considered in this comparison, assuming these to be equal in STA and DTA). Based on Dutch figures on the distribution of vehicle types for different base and forecast years weighted emission factors are derived per vehicle class, for 10 road types and these 4 traffic conditions. Figure 1 shows the resulting weighted NO\textsubscript{x} emission factors for passenger cars (2008). The calculation of emissions based on the outcome of the DTA model is done by determining the traffic condition based on calculated speed and fundamental diagram (input of DTA model) per link for each time interval. The traffic condition determines the which emission factors should be used and based on the volumes and composition for that same time interval the emissions are calculated. The total emission of a link is the summation over all time intervals:

\[
E_a = \sum_t \sum_m \sum_d q_{am}^d(t) \delta_{ad} E_{sd}^t \left(v_{am}^d(t), v_{am}^{\text{free}}, v_{am}^{\text{c}}\right) l_a
\]

with:

\[q_{am}^d(t)\] : Volume vehicle class \(m\) for link \(a\) at time \(t\) (veh)

\[v_{am}^d(t)\] : Average speed of vehicle class \(m\) on link \(a\) at time \(t\) (km/h)

\[v_{am}^{\text{free}}\] : Free flow speed of vehicle class \(m\) on link \(a\) (km/h)

\[v_{am}^{\text{c}}\] : Speed at capacity of vehicle class \(m\) on link \(a\) (km/h)

\[E_{sd}^t\] : Emission factor of substance \(s\) for vehicle class \(m\), depending on speed (grams/(veh*km))

\[l_a\] : Length of link \(a\) (km)

\[\delta_{ad}\] : Road type indicator, equals 1 if link \(a\) is of road type \(d\), and 0 otherwise

For the calculation based on STA the average traffic condition for the period considered (e.g. morning peak hour) is based on the V/C-ratio. Note, that in this case the outflow capacity, based on junction modeling, is used to determine the V/C-ratios on urban links at intersections if the outflow capacity is lower than the link capacity. The emission factors are interpolated (see Figure 3), to avoid large (unrealistic) changes in emissions in the case of small changes in the V/C-ratio. The interpolation method is also used in the Dutch prescribed standard method to estimate emissions. The boundaries for the traffic condition bins are based on Dutch default values used in current practice. The total emission of a link is:
\[ E'_a = \sum_{m} \sum_{d} Q_{am} \delta_{md} \left( Q_a C_a C_{outflow} \right)^{l_a} \]  \hspace{1cm} (4)

with:
- \( Q_{am} \): Volume vehicle class \( m \) for link \( a \) (veh)
- \( Q_a \): Total volume all vehicle classes for link \( a \) (pcu)
- \( C_a \): Capacity for link \( a \) (pcu)
- \( C_{outflow} \): Outflow capacity for link \( a \) (pcu)
- \( E'_m (\cdot) \): Emission factor of substance \( s \) for vehicle class \( m \), depending on V/C (grams/(veh*km))
- \( l_a \): Length of link \( a \) (km)
- \( \delta_{md} \): Road type indicator, equals 1 if link \( a \) is of road type \( d \), and 0 otherwise

**Figure 3.** Interpolation emission factors when applying STA

For noise two emission functions are used and derived from the AR-INTERIM-CM model: one for saturated and one for non-saturated conditions. In Figure 2 the noise emission functions for passenger cars are shown. The AR-INTERIM-CM is based on the French ‘Guide du Bruit’ and like the ARTEMIS model developed in a project of the European Union. The emission functions are road type independent, however correction factors can be used to correct for road surfaces. There are different emission functions per vehicle class. The calculation of emissions based on the outcome of the DTA model is done by determining the traffic condition based on calculated speed and fundamental diagram (input of DTA model) per link for each time interval. The traffic condition determines which emission function should be used and based on the traffic volumes and traffic composition (energetically summed) for that same time interval the noise emissions are calculated. The average sound power level (i.e. noise emission) of a link is calculated by energetically averaging the emissions over time:

\[ L_{an}(t) = \alpha_n \left( v_{am}(t) \right) + \beta_n \left( v_{am}(t) \right) \log \left( \frac{v_{am}(t)}{v_{ref}} \right) + 10 \log (q_{am}(t)) \]

\[ L_{a} = 10 \log \left( \frac{\Delta t \sum_{m} \sum_{n} 10^{L_{an}(t)/10}}{T} \right) \]  \hspace{1cm} (5)
with:

- \( q_{am}(t) \) : Volume vehicle class \( m \) for link \( a \) at time \( t \) (veh/hour)  
- \( v_{am}(t) \) : Average speed of vehicle class \( m \) on link \( a \) at time \( t \) (km/h)  
- \( L_{am}(t) \) : Sound power level of vehicle class \( m \) on link \( a \) at time \( t \) (dB(A))  
- \( L_a \) : Average sound power level for link \( a \) (dB(A))  
- \( v_{ren} \) : Parameters dependent on vehicle category and traffic condition for noise calculations  
- \( L_\text{ren} \) : Reference speed dependent on vehicle category (km/h)  
- \( \Delta t \) : Time interval output data DTA model (h)  
- \( T \) : Total time period (h)

For the calculation based on STA there are two options. The first option uses the posted speed limit (in our case equal to the free flow speed) which is often used in current practice. The second option uses the calculated speed based on the travel time functions. In the latter case interpolation is used by energetically weighing the two emission functions (default between VC-ratios of 0.8 and 1.0). The average sound power level (i.e. noise emission) of a link is calculated by:

Based on posted speed

\[
L_{am} = \alpha_m \left( v_{am}^{\text{free}} \right) + \beta_m \left( v_{am} \right) \log \left( \frac{v_{am}^{\text{free}}}{v_{am}} \right) + 10 \log \left( \frac{Q_{am}}{T} \right)
\]

\[
L_a = 10 \log \left( \sum_m 10^{\frac{L_{am}}{10}} \right)
\]  

Based on calculated speed

\[
L_{am}^{(i)} = \alpha_m \left( v_{am} \right) + \beta_m \left( v_{am} \right) \log \left( \frac{v_{am}}{v_{ren}} \right) + 10 \log \left( \frac{Q_{am}}{T} \right)
\]

\[
L_a^{(i)} = 10 \log \left( \sum_m 10^{\frac{L_{am}^{(i)}}{10}} \right)
\]

\[
L_a = \begin{cases} 
  L_a^{\text{freeflow}}, & \text{if } Q_a/C_a < a, \\
  10 \log \left( \frac{b-Q_a/C_a}{b-a} \right) + \left( \frac{b-Q_a/C_a}{b-a} \right) \frac{Q_a^{\text{exceeding}}}{10} & \text{if } a < Q_a/C_a < b, \\
  L_a^{\text{saturated}}, & \text{if } Q_a/C_a > b.
\end{cases}
\]

with:

- \( Q_{am} \) : Volume vehicle class \( m \) for link \( a \) (veh)  
- \( Q_a \) : Total volume all vehicle classes for link \( a \) (pcu)  
- \( C_a \) : Capacity for link \( a \) (pcu)  
- \( v_{am} \) : Average speed of vehicle class \( m \) on link \( a \) based on travel time function (km/h)  
- \( L_{am} \) : Sound power level of vehicle class \( m \) on link \( a \) (dB(A))  
- \( L_a \) : Average sound power level for link \( a \) (dB(A))  
- \( v_{ren} \) : Reference speed dependent on vehicle category (km/h)  
- \( a, b \) : Boundaries used for interpolation
To determine the consequences of using STA versus DTA to estimate emissions the presented methods are applied on a highway corridor, namely the highly congested A12 highway between Gouda and The Hague and a moderate congested urban corridor the Nassaukade in Amsterdam (see Figure 4) with 5 traffic controlled intersections. Network and demand were derived from existing calibrated models of the regions (i.e. morning peak of Spitsmijden model respectively evening peak of tactical model Amsterdam). For the sake of clarity corridors are selected to present the results of the comparison to assure the same route choice behavior in both models. This means that in the cases we focus on the difference as a result of the differences between static and dynamic loading and therefore the differences in capturing the traffic flow phenomena described earlier. Total demand in STA and DTA are set to be equal, however the DTA model uses a distribution over time. For the urban case of Amsterdam the demand is slightly changed, which means that the outcomes are hypothetical. The green splits of the signal plans of the 5 intersections are fixed and the same for both models, which means that the capacity given to each direction is exactly the same in the STA as well as the DTA model. Because the differences between STA, measurements and DTA in emissions comprises the difference in loads and traffic dynamics, the total air emissions were also corrected for the differences in total loads per link. This means that for the corrected effects the weighted average emission factors are calculated.
Results highway network

For the highway network also measured flow and speeds (using detector data) are available for all highway links of the morning peak. Note that these measurements were not used to calibrate the model. These measurements were also used to estimate emissions using the ARTEMIS and AR-INTERIM-CM model. In the remainder of this paper we will refer to these results as measured emissions. Figure 5 shows the results of the total emissions of all highway links (corrected and not corrected) as well as the differences per link (only corrected, direction of travel from right, link 15 near Gouda, to the left, link 1 near The Hague). In both figures the measured emissions are the reference case (index=100), which means that if the value is closer to 100 the estimated emission based on the model is closer to the measurements.

The results show that the average speed and link load as well the emission estimates based on the DTA model are closer to the measurements than those based on the STA model. The total emission of NO\textsubscript{X} estimated by the STA is for example 23\% higher than the measured emissions (corrected 11\% higher) and for PM\textsubscript{10} 13\% higher (corrected 2\%). The estimates based on the DTA model are 8\% (corrected 4\%) higher for NO\textsubscript{X} and for PM\textsubscript{10} 5\% (corrected 1\%). For noise a comparison is made in which the noise emissions are calculated based on the posted speed limit as well as the calculated (and measured) speed. The average noise emissions based on the posted speed limit is 5\% (in dB(A)) higher compared to measured emissions. Note that, noise is measured on a logarithmic scale. This means that the average noise emission is 4 dB(A) lower in absolute values, which equals a reduction of traffic volume of more than 50\%. When the calculated speed is used, the DTA model performs slightly better than the STA model (0.3\% versus 0.5\%).
For the individual links the differences are larger and it is even possible that the STA estimates are lower than measured emissions while the DTA estimates are higher and vice versa. At almost every link the DTA model performs better. There is one link where the DTA model performs significantly worse because there DTA model predicts a totally different traffic condition than the measurements indicate. The differences between the DTA and measurements is mainly caused by the differences in demand and resulting traffic conditions. If the DTA model would have been calibrated using the measurements the differences would be much smaller. The comparison between the estimates based on DTA and STA therefore provide an indication of the possible error which is being made when using a STA. This comparison shows that the emissions of NO\textsubscript{x} are between 30% lower and 42% higher (corrected 38% lower and 28% higher) when a STA is used. For PM\textsubscript{10} the differences are smaller but still 15% lower or 15% higher (corrected 10% lower and 7% higher). For CO\textsubscript{2} the differences are locally even larger than for NO\textsubscript{x}, however for CO\textsubscript{2} the local emissions are not relevant. For noise the sound emissions can be 8% lower based on the DTA model compared to STA using the posted speed limit. Note that higher is not possible on highways. If the calculated speeds based on the travel time functions are used for the STA it is possible that the noise emissions can be 5% higher or 6% lower compared to the DTA model (in absolute values these are enormous differences of over 4 db(A)). These differences found in the estimates of
emissions for peak hours are large and can have a significant influence even when translated to 24 hour values for policy decisions (e.g. within cost-benefit analysis or comparison with limit values).

The differences between DTA and STA are also of interest when the effects of a measure is assessed. We assume that an additional lane is realized between Zoetermeer and Nootdorp and demand stays fixed. In this case the STA estimates a decrease of emissions and also only for those links where the capacity is increased. Within the DTA model also other links are affected by this measure, because the interaction between links is considered. The DTA shows that for some links emissions increase (especially downstream) and for some links the emissions decrease (especially upstream). On the total network the DTA model estimates an increase of PM$_{10}$ emissions while the STA model estimates a decrease of PM$_{10}$ emissions. This indicates that not only the location at which the STA predicts an effect is unreliable, but also the extent and even the direction of effect.

**Results urban network**

For the urban case only the comparison between STA and DTA are presented. Figure 7 shows the total emissions and average emission factors. The comparison shows that for the urban case the emission estimates using the STA model are lower than the DTA model. One of the reasons is that in the urban case the junctions are determinative for the traffic conditions. The possible congestion problems as a result of these junctions are taken into account by translating them to the first upstream link. However, the STA model can not model spillback, which means that in saturated conditions and relative short link length the STA model can underestimate the congestion problems. On the other hand, STA models do not take into account that traffic is metered by upstream bottlenecks, which means that traffic demand can be overestimated in STA models at specific locations. Because in our urban case the total traffic demand in this corridor network is chosen to be the same for STA and DTA and the congestion problems are moderate (i.e. only two links with V/C ratio’s above 1, namely 1.07 and 1.03) the emission estimates of the STA model are lower. As a result the differences between STA and DTA in total emissions and

![Effect measure](chart.png)
average emission factors are similar. As depicted in Figure 7 the NO\textsubscript{x} emissions are 9% lower based on the STA and the PM\textsubscript{10} emissions 1% lower. The weighted average sound emissions are in this case equal when based on the calculated speed instead of the posted speed limit.

The local differences can be larger. The total NO\textsubscript{x} emissions can be 10% higher or 23% lower for STA compared with DTA (corrected for load differences 5% higher or 24% lower. For PM\textsubscript{10} the total emissions can be 11% higher or 5% lower (corrected 3% higher or 6% lower). For sound the emissions based on the calculated speed versus the posted speed limit (both for STA) can be 2% higher (approximately 1 dB(A) higher) or 3% lower (approximately 2 dB(A) lower). The difference between STA based on the posted speed limit and DTA can be 2% higher or 4% lower. This shows that in the urban case the emissions based on the calculated speed can be higher than based on the posted speed limit.

![Static versus dynamic Total network, total peak period](image)

**Figure 7.** Results assignments urban case Amsterdam

When introducing a measure, namely realizing an additional lane for the direction with the highest V/C-ratio (i.e. traveling from north to south, first intersection (V/C-ratio 1.07)), similar results are found as in the highway case. This means that the STA model only predicts a lower V/C-ratio for the link with an additional lane, while for the DTA model this measure influences the traffic conditions on many links. In the STA case the emissions slightly decrease on network level (less than half percent for all substances), while in the DTA model the emissions slightly increase (approximately half percent dependent on substance) because of worsened traffic conditions downstream. These changes are also small because, the green split of all intersections remains the same and congestion problems are moderate. For the DTA model traffic conditions can only change downstream of the second intersection due to changes in composition of traffic (i.e. distribution of directions). Although, the effects on network level are small, in this case the STA model predicts a reduction for all substances, while the DTA predicts an increase.

Again the difference in the estimated effect by STA or DTA on a local level can be large. In Figure 8 the estimated effect for links on corridor from north to south which are numbered from 1 to 11. As shown, the STA model only predicts an effect on a single link (i.e. link 5). The STA model predicts a reduction in total emissions on this link, while the DTA model predicts an increase in total emissions which is mainly due to an increase of volume. This is also the main reason of the increase in emissions of link 2, 3 and 4, while for link 6, 7, 8 and 9 (i.e. downstream) the increase is also due to deteriorating traffic conditions. This means that also the urban case shows that location, extent and direction of effect
estimated by STA can be unreliable, given the realism of estimating traffic conditions using both types of assignment models.

![Effect measure on total NO\(_x\) emissions individual links](image)

**Figure 8.** Effect measures on total emissions based on STA and DTA

**DISCUSSION AND CONCLUSIONS**

In current practice mainly STA models are used for the estimation of emissions. In many countries there are regulations or protocols on specific models to use and also often the prescribed use of these STA models. However the unreliability of this model type at link level can be large especially in saturated traffic conditions. Eventually this can result in erroneous policy decisions or implementing mitigating measures on wrong locations or not implementing them on locations where they should. DTA models can take the traffic flow phenomena into account which are important explanatory variables for emissions. The current generation of DTA models and the increasing computation power (e.g. using parallel computing) has improved the scalability of this model type significantly and are therefore capable in assessing large networks. However, computation times may remain an issue. Developments in quasi-dynamic assignments like STAQ [2] are therefore of interest because they further improve the scalability of DTA while improving the realism of STA. Comparison of emission estimates with these type of models is therefore of interest.

For noise emissions often the operational (free) speed or posted speed limits are used. For highways this means that the estimates are often to conservative (i.e. can be more than 4 dB(A) lower in reality). However for urban roads this can result in an underestimate of emissions, depending of the source model used and way of application. The urban case showed that noise emissions can be 1 dB(A) higher. For emissions the estimated traffic conditions based on STA can result in large over- and underestimates compared to DTA (e.g. for NO\(_x\) up to 42% higher and 30% lower for the highway case and 10% higher and 23% lower for the urban case). In general, the differences will be larger when the congestion problems are larger, because the limitations of STA in capturing realistic traffic flow phenomena is mainly associated with these traffic conditions. The possible errors made may be even larger than found in the presented cases, because the STA model does not take into account that upstream bottlenecks not part of the cases presented in this research influence local demand. In addition, the
behavioral responses, not considered in this comparison, in both model types can be different as well because of differences in the estimated effects of the measures taken on travel costs. As a result the errors in the emission estimates based on STA can be even larger. In addition, intersections which are more difficult to take into account in emission estimates based on STA models, are determinative for traffic handling on urban networks. When a measure is taken to alleviate congestion problems it is shown in both cases that not only the location at which the STA predicts an effect is unreliable, but also the extent and even the direction of effect.

The peak hours are only a part of the day and for noise the night is for example more important for the nuisance than the peak hours. However, given the found differences between STA and DTA, these can still be significant even for the consequences on a daily average. Improvements in the incorporation of traffic dynamics in the current practice of emission estimates are therefore important to assess the livability and health effects of traffic measures.

REFERENCES


