Abstract
This paper presents a macro emission module for macroscopic traffic models to be used for assessment of ITS and traffic management. It especially focuses on emission estimates for different intersection types. It provides emission values for CO, CO2, HC, NOx, and PM10. It is applied and validated for a macroscopic traffic model developed by the Dutch Ministry of Infrastructure and the Environment, called the ‘Regional Traffic Management Explorer’ (or Regionale BenuttingsVerkenner, RBV). In this paper, the development of the module and some validation results are presented.

1. INTRODUCTION
In order to be able to assess the emission effects of traffic management and ITS on the level of a city or a region, a general approach would be to use a mesoscopic or macroscopic dynamic traffic model and then to use the effects on the traffic flows to estimate the emission effects with an additional traffic emission model.

Generally, two types of traffic emission models exist, namely microscopic emission models that estimate emissions based on detailed individual vehicle data (speed and acceleration) and macroscopic emission models that use macro averaged emission factors and macro (aggregated) traffic data. For macroscopic traffic models, only a macroscopic emission estimation approach can be applied, since detailed individual vehicle data is not available in these models. However, in order to incorporate the effects of changes in dynamic driving behaviour, routing or traffic management strategies in a realistic and accurate way, a more detailed approach is needed. Unfortunately there are no emission factors available that can differentiate in vehicle dynamics induced by different intersection types and traffic intensity variations in a realistic and accurate way. In order to derive such emission relations, detailed information is needed about traffic behaviour for different intersection types and relations
should be found between macroscopic traffic variables and resulting emissions on a macroscopic scale. This is a challenge which has not been tackled before, but in this paper a macroscopic emission module is described that deals with this.

First potential applications are mentioned and then the macroscopic model is described. In paragraph 4 the development of the emission module is explained and validation results are given. Finally, conclusions are drawn and further research is suggested.

1.1 POTENTIAL APPLICATION OF THE MACROSCOPIC EMISSION MODULE

Local air quality is currently an important topic, especially urban air quality for which the highest values are often found near intersections. The EU has set legislated air quality standards and objectives\(^1\) which need to be met, or measures need to be taken to show how these standards can be met in the future. Also climate change and CO2 emission reduction is currently regarded as a very important topic at EU level. The European Commission launched the climate and energy package, which is a set of binding legislation which aims to ensure that the European Union meets its climate and energy targets for 2020. One of these targets is to reduce CO2 emissions with 20% by 2020.

In order to investigate which measures are most effective to reach these targets (i.e. CO2 emission reduction or local air quality improvement), models are needed to estimate the effect of different scenarios and measures. Especially when the area under investigation is large (e.g. CO2 emissions are usually considered at a large scale, a city or even a whole country), macroscopic simulation is the preferred approach, because microscopic traffic models are not suitable (yet) for very large networks. However, a macroscopic traffic model only delivers average speeds (no individual vehicle trajectories), and that implies that a detailed microscopic emission model cannot be used. Therefore, a new emission model is needed that relates the dynamic traffic effects of the measures under investigation, as calculated with a macroscopic model, with accurate emissions. The developed macroscopic emission model will fit in this approach.

In the FP7 project Amitran (Jonkers, Klunder \textit{et al}, 2013), a standard assessment methodology is being developed to determine the effects of ITS on CO2 emissions. The macroscopic emission module presented here can fit this approach for certain categories of ITS systems for which a macroscopic
approach is desired. These are measures that effect the traffic at network scale and do not change vehicle dynamics, for example routing via Dynamic Route Information panels or navigation systems, travel time information, traffic light synchronisation, or ‘Pay as you Drive’.

When a (local) authority wants to determine the effects of certain (traffic management) measures on air quality or CO2 reduction, e.g. to report the EU about the current situation or about their plans to reduce emissions, he may therefore approach a consultant or researcher to perform a simulation study using the Amitran approach and the presented macroscopic simulation model.

At this moment the macroscopic emission module is used in conjunction with the Regional Traffic Management Explorer (RBV), which contains a macroscopic traffic model. In principal, the module can be connected to any macroscopic traffic model that provides average speeds on link level. With regard to existing macroscopic emission models, the calculated emissions are potentially more accurate, especially concerning emissions near intersections (of different types).

2. APPLICATION FOR A MACROSCOPIC TRAFFIC MODEL

The Dutch Ministry of Infrastructure and the Environment has developed a tool to support the regional traffic management planning process. This process is known as sustainable traffic management (Taaie et al., 2004). The tool itself is called the ‘Regional Traffic Management Explorer’ and has proven to be an important tool in supporting regional planning and evaluation processes for traffic management (Taaie & Westerman, 2005). The core is a dynamic traffic assignment model called MARPLE (Model for Assignment and Regional Policy Evaluation).

The framework of this model is shown in figure 2. MARPLE consists of three components:

- A route set generation model;
- A dynamic route choice model;
- And a dynamic network loading model.
Given the transportation network, routes are generated by a route set generation model. These routes are typically generated without any knowledge of travel demand. Only the set of origin-destination (OD) pairs is passed to the route generation model. Once a route set is determined, route flows are computed for each OD pair and each departure time interval based on a generalized dynamic route travel costs (which normally includes route travel times and sometimes other attributes). Finally, these route flows are propagated along each route on the network by using a dynamic network-loading (DNL) model. For the DNL model, MARPLE uses travel time functions and propagates traffic through the network based on these functions, taking blocking back effects into account. The nice thing for the connection with emissions is that the model uses different functions for different intersection types. Four intersection types are distinguished: uncontrolled, signalised, roundabout and give way.

Based on travel times on the available routes between each OD pair in the network with demand, an assignment is used to distribute the demand on these routes. The available routes between an OD pair can be maximized and are determined using a Monte Carlo simulation with free flow travel times and Dijkstra’s algorithm for the shortest path. In an iterative process with the DNL sub-model and the assignment, the model converges to a true dynamic user equilibrium. The outcome of the model consists of indicators on (sub-) network level (total distance travelled, total delay, etc.), on route level (flow, travel time and delay per time period) and on link level (flow, speed and density per time period). More details of all three components are described by Taale (2008).

MARPLE can be used to determine the effects of traffic management measures such as traffic signal control, peak hour lanes, speed measures and buffers on a macroscopic scale. With the macro emission module, emissions
of CO, CO2, HC, NOx, and PM10 are added to the output of MARPLE, for each link and time interval (normally in the order of 10-15 minutes).

3. DEVELOPMENT OF THE MACROSCOPIC EMISSION MODULE

In order to find relations between macroscopic traffic variables and macroscopic emissions, many micro simulation runs were performed for different types of intersections, using the micro traffic simulation model VISSIM. Intersection types taken into account were single and double lane roundabouts, a controlled intersection, an intersection with priority and road sections (without intersection) for several speed limits. All simulations had a duration of 30 minutes, starting with an empty network and using a flat demand profile in order to avoid noise effects from a changing demand profile. Each scenario was run 5 times with different seed values to capture the stochastic effects of traffic.

Next, emissions were calculated with the TNO emission model VERSIT+ (Smit et al., 2007) with the individual vehicle data from VISSIM (speed and acceleration) as input on a second-by-second base. Finally, both the emission and traffic data have been aggregated in various ways. It appeared to be difficult to capture the causes of emission variation (dynamics, e.g. accelerations) in macroscopic variables per link in the intersection traffic network. A thorough investigation revealed that only the mean speed averaged over all vehicles in the network showed a clear relationship with CO2 and other emissions (CO, HC, NOx, and PM10). This approach led to sets of macroscopic emission rate curves (emissions in gram/second) as a function of the mean speed. That is, per intersection type and speed limit a set of intersection size\(^1\) dependent curves was derived and these macro emission rate curve sets are used in lookup tables in the so-called macro emission module. An example of such a set of emission rate curves is given in Figure 1 for a single lane roundabout.

In order to calculate the total emissions of the simulation (time interval), the appropriate emission rate value as determined from the set of curve (by lookup table interpolation) needs to be multiplied with the number of vehicles of the correct type and the number of seconds in the time interval. If there is no emission rate curve available for a certain situation, the emission rate curve of the situation with the closest match will be used.

\(^1\) In this context the size of an intersection is the size of the model links at the intersection, including the connected links to and from the intersection.
Some challenges for this approach were how to cope with differences in links leading towards or away from an intersection, emissions on the intersection space itself, different link lengths and varying aggregation intervals. The problem with different link lengths is that the extra emissions due to the intersection will be averaged over a longer length and time for longer links. This has been solved with a practical approach: emission rate curves have been derived for different link lengths. For a specific length, the emission rate will be derived by interpolating between the two closest link lengths. A comparable practical approach has been chosen for the emissions on the intersection itself; they are added to the emissions of the approaching and leaving links. Concerning the aggregation intervals, different aggregation intervals showed comparable results, though calculations based on a longer aggregation interval showed more clear relationships between mean speed and emissions because the data are averaged based on more data points and hence show less fluctuations. The best results for curve fitting were obtained with an aggregation interval of 10 minutes, therefore an aggregation interval of 10 minutes was chosen to derive all emission curves and as preferred application interval.

The lookup tables with sets of emission rate curves can and should be updated periodically to account for changes in the vehicle fleet or to include more intersection types and link lengths. Due to the approach chosen, this
can be done very easily and without any changes to the calculation part of the macro emission module.

4. VALIDATION OF THE MACROSCOPIC EMISSION MODULE

Validation of the macroscopic module is very hard, because a proper validation would need real-world measured emission data for a large set of individual vehicles over prolonged time and for many traffic situations, which were not available during this project. Therefore, validation has been done against the available traffic and emission models. Since the used models (VISSIM, VERSIT+, RBV) are widely used and considered as state-of-the-art, this is an acceptable method (the best we could do given the non-availability of real-world data).

For the validation of the emission module, three types of comparisons have been made:

1. As a first verification the total emissions calculated directly from the VISSIM/VERSIT+ micro simulations, was compared to the total estimated emission calculated from the derived macro relations applied to the VISSIM mean speeds. This comparison proved to be very acceptable with a relative difference of less than 0.1% using 10 minutes averaged data.

2. Mean speeds on a macroscopic scale derived from the VISSIM micro simulations were compared to the macroscopic speeds from MARPLE for the same intersection types and traffic settings. The average speeds of VISSIM were calculated in the same way as was used to derive the emission curves. Without extensive calibration, differences were found up to 50% between the speeds of both models. In order to get the speeds matching closer, several tuning steps were performed in MARPLE. Most important were tuning of the intersection capacity and link capacity. However, there were still considerable differences in speeds observed. The accuracy and reliability of the emission module for MARPLE very much depends on the average link speeds and the similarity of those with the VISSIM average link speeds. By tuning the simulations it is possible to achieve a larger similarity and accuracy. Therefore we recommend to perform extensive tuning of simulations in MARPLE before executing and interpreting the simulation results of the emission module.

3. Emissions based on microscopic traffic data from the VISSIM/VERSIT+ micro simulations compared to emissions based on macroscopic data from the RBV and the macro emission relations from the macro emission module. The mean difference of all estimates was very small, around 1%, but the separate emission components showed larger differences. This can
be reduced by better tuning of MARPLE. The differences are largely due to the speed differences between both models as mentioned above. Another reason is differences in flows, which depend largely on the capacity of the intersections. Especially the medium traffic flow scenarios are very sensitive to small differences in capacity, because this flow is around the turning point between free flow and congested traffic.

5. CONCLUSIONS AND FURTHER RESEARCH

Summarising, emissions are calculated based on emission rate curves derived from micro simulations, which give the macroscopic emission rates in gram/second as a function of the mean vehicle speed on the network component. For each link type (single lane roundabout, double lane roundabout, etc.), link length (in classes) and vehicle type (car or truck), there is a specific emission rate curve. In total, the emission module currently contains 260 emission rate curves, grouped in 80 link size dependent lookup tables.

From the research performed so far, the following conclusions with respect to the development and verification of the RBV Macro Emission Module can be drawn:

- Suitable macroscopic relationships were identified for the mean emission rate as a function of mean vehicle speed per vehicle type (‘average European’ car or truck) per time period and per network component type. For several identified challenges, practical solutions were sought and found. This concerns for example averaging the emission effect over the whole intersection, interpolating between different link lengths and speed limits. The identified macroscopic relationships were implemented as emission rate lookup tables. The first version is currently being evaluated by TNO and the Dutch Ministry of Infrastructure and the Environment.

- The ‘intrinsic’ verification of the total estimated emissions calculated directly from the VISSIM/VERSIT+ traffic micro simulations compared to the total estimated emissions from the macro emission module based on the same simulations of VISSIM, proved to be very acceptable. However, further verifications, using similar traffic networks simulated in MARPLE using the macroscopic emission relationships and comparing these to the VISSIM/VERSIT+ micro simulation results, showed that mainly due to calibration difficulties of the macro (MARPLE) and micro (VISSIM) traffic models, there are/remain substantial differences in the mean speeds and thus in the resulting associated emissions.
Therefore the following recommendations are formulated:

- In order to further validate the performance and reliability of the emission results for larger networks, a larger network consisting of several intersections and traffic flow regimes could be simulated both in VISSIM and MARPLE and the traffic and emission results compared.

- In order to get a higher accuracy, MARPLE should be tuned more elaborately to match the average speeds and flows better with VISSIM (or preferably with the real-world). Another possibility would be to investigate the assumptions made for the VISSIM micro simulations and their influence on the results.

- The current approach is to provide an emission rate curve for a larger number of intersection and road types, ideally covering all possible infrastructure and traffic flow regimes. However, it is practically not possible to cover all possible situations. At the moment, situations for which an emission rate is not available are covered by interpolating between curves which are as similar to the situation as possible. It should be investigated if important or frequent situations are missing and whether these should be added, for example by performing more simulations. This can be done quite efficiently, because the code for processing the simulation data and deriving the emission curves as well as that for applying the curves is already available without changes.

Traffic behaviour and vehicle technology change over time. Therefore the emission module should be updated regularly. The software and procedure to do this should be efficient such that it can be done in little time and by incorporating the new emission rate curves easily in the software. The current software has already been written in such a way that this is easily possible.

The macroscopic emission module can theoretically be used with all (macroscopic) traffic models. However, calibration/validation should be done separately for each traffic model.

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BIBLIOGRAPHY


NOTES

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