

CHAPTER 36

Emission Modeling

Benjamin Kickhöfer

36.1 Basic Information

Entry point to documentation:

<http://matsim.org/extensions> → emissions

Invoking the module:

<http://matsim.org/javadoc> → emissions → `RunEmissionToolOnlineExample` class,
`RunEmissionToolOfflineExample` class

Selected publications:

Hülsmann et al. (2011); Kickhöfer et al. (2013); Kickhöfer and Nagel (2011, 2013); Hülsmann et al. (2013); Kickhöfer (2014); Kickhöfer and Kern (2015)

36.2 Introduction

This chapter presents the emission modeling tool developed and tested by Hülsmann et al. (2011) and further improved by Kickhöfer et al. (2013). The text in this chapter is a slightly updated version of the emission modeling tool description in Kickhöfer (2014). The tool calculates warm and cold-start exhaust emissions for private cars and freight vehicles by linking MATSim simulation output to the detailed “HBEFA (Handbook on Emission Factors for Road Transport)” database, available for many European countries.

The chapter is structured as follows: Section 36.3 reviews literature for other attempts to model transport-related emissions. Section 36.4 presents an overview of the “EMT (Emission Modeling Tool, see Chapter 36)” and Section 36.5 shows how the tool is embedded in MATSim’s software structure.

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36.3 Integrated Approaches for Modeling Transport and Emissions

Over the last two decades, the modeling of transport-related environmental externalities has received increasing attention in transportation science. The following paragraphs briefly present some recent work in the exhaust emission modeling area; additionally, they highlight differences to the EMT, which will then be described in subsequent sections.

Creutzig and He (2009) and Michiels et al. (2012) use very aggregated figures to estimate air pollution in Beijing and Belgium, respectively. Neither approach mentions any particular underlying transport model. It seems that transport related emissions are based on aggregated origin-destination matrices or aggregated demand functions. These two studies are on a very different level of aggregation than the EMT, and a comparison does not seem constructive.

Beckx et al. (2009) use a sophisticated activity-based model to simulate activity schedules for roughly 30% of all households in the Netherlands. Traffic assignment for passenger cars is performed by using an aggregated “all-or-nothing” assignment approach, resulting in hourly aggregated traffic flows on the network. Based on the average speed for a trip, the MIMOSA (Modélisation Isentrope du transport Méso-échelle de l’Ozone Stratosphérique par Advection) model then calculates emission and fuel consumption rates, possibly dependent on vehicle category. The idea of using an activity-based model to simulate time-dependent emissions is similar to the EMT. In contrast to the latter, the underlying transport in Beckx et al. (2009) does not account for congestion effects and different traffic states. Additionally, similar macroscopic emission models are typically unable to capture certain microscopic behavior accurately (see, e.g., Ahn and Rakha, 2008).

Hirschmann et al. (2010) link the microscopic traffic flow simulator VISSIM (Verkehr In Städten – SIMulationsModell) with the instantaneous emission model PHEM (Passenger Car and Heavy-duty Emission Model).¹ At first glance, this approach seems very promising, as it also builds the basis for the HBEFA database. In contrast to the EMT, it is not suitable for large-scale scenarios due to the computational complexity of VISSIM (Verkehr In Städten – SIMulationsModell). In Kraschl-Hirschmann et al. (2011), the same authors attempt to develop a parametrization of fuel consumption based on average speeds of vehicles. Such parametrization could be helpful—in the future—to replace time-consuming lookups in large databases (e.g., HBEFA). However, the model would need to allow for more input variables (e.g., vehicle category, traffic state, etc.) and provide more differentiated outputs, e.g., different emission types.

In a similar study, Song et al. (2012) couple VISSIM (Verkehr In Städten – SIMulationsModell) with the emission modeling tool MOVES. They find that the VISSIM (Verkehr In Städten – SIMulationsModell)-simulated, vehicle-specific power distribution for passenger cars deviates significantly from the observed distribution, meaning that the estimated emissions also contain significant errors. Here again, the proposed model cannot be used for large-scale scenarios. Additionally, it seems questionable whether such detailed modeling will prove to be superior to less detailed models as the EMT.

Wismans et al. (2013) compare passenger car emission estimates of static and dynamic traffic assignment models. They claim that little research has been done in connecting macroscopic or meso-scopic dynamic traffic assignment models with emission models. According to the authors, static assignment models predict congestion on the wrong locations and ignore spillback effects. They argue that emission hotspots are, in consequence, also predicted at the wrong locations and/or with the wrong amplitude. To counter these disadvantages, they couple a static and a dynamic traffic assignment model with the exhaust emission model ARTEMIS. Large differences in air pollutant emissions are found and hotspot locations differ.

¹ The PHEM (Passenger Car and Heavy-duty Emission Model) model uses speed trajectories as input and was tested against the output of the EMT by Hülsmann et al. (2011).

Hatzopoulou and Miller (2010) develop a methodology for calculating exhaust emissions, using MATSim as transport model. The approach is therefore similar to the EMT. In contrast to that study, the EMT does not assume fixed exhaust emissions per time unit. It uses a more detailed calculation of emissions based on the two different traffic states: “free flow” and “stop&go”. It is, thus, able to capture congestion effects that emerge, as well as the time spent in traffic jam. Furthermore, the EMT calculates exhaust emissions for passenger cars *and* for trucks. Finally, since the methodology is based on HBEFA, it can be transferred to any scenario in Europe.

36.4 Emission Calculation

Air pollution is caused by different contributions of road traffic: Warm emissions are emitted while driving and are independent of the engine’s temperature. Cold-start emissions also occur during the warm-up phase and depend on the engine’s temperature when the vehicle is started. Warm emissions differ with respect to: *driving speed*, acceleration/deceleration, *stop duration*, road gradient, and *vehicle characteristics* consisting of vehicle type, fuel type, cubic capacity, and European Emission Standard Class (André and Rapone, 2009). Cold emissions differ with respect to: *driving speed*, *distance traveled*, *parking time*, ambient temperature, and *vehicle characteristics* (Weilenmann et al., 2009).

Currently, the emissions contribution to MATSim considers all differentiations above marked in *italic*. Road gradient and ambient temperature are not considered; gradient is always assumed to be 0 %, and ambient temperatures are assumed to be HBEFA average. In addition to warm and cold-start emissions, evaporation and air conditioning emissions also result from road traffic. At the moment, these are not considered in the emission modeling tool, because they contribute little to the overall emission level.

The calculation of warm emissions is composed of two steps:

1. deriving *kinematic characteristics* from the simulation, and
2. combining this information with vehicle characteristics to extract emission factors from the HBEFA database.

In the first step, driving speed, as well as stop duration (and possibly an approximation of acceleration/deceleration patterns), is captured by a mapping of MATSim’s dynamic traffic flows to HBEFA traffic states. These traffic states, namely “free flow”, “heavy”, “saturated”, and “stop&go”, have been derived from typical driving cycles, i.e., time-velocity profiles. A parametrization of these profiles led to the definition of these traffic states, which depend on speed limit, average speed, and road type. Thus, typical emission factors for a specific traffic state on a specific road segment can be looked up in the HBEFA database. In MATSim, neither the location on a road segment, nor the exact driving behavior of an agent is known (see Section 1.3). It is quite straightforward to extract agents’ travel times on the road segment which, thanks to the queuing model, also includes interactions with other agents and spillback effects. The average speed of an agent on a certain road segment is thus used to identify corresponding HBEFA traffic states, and to assign emission factors to the vehicle. As of now, the emission modeling tool considers only two traffic states: free flow and stop&go.² Each road segment is divided into two parts representing these two traffic states. The distance l_s that a car is driving in stop&go traffic state is determined by the following equation:

$$l_s = \frac{l v_s (v_f - v)}{v(v_f - v_s)}, \quad (36.1)$$

² Simplified because the difference between traffic states—free flow, heavy, and saturated—emission factors are only marginal. In contrast, emission factors for stop&go are roughly twice as high.

where l is the link length in kilometers from the network, v_s is the stop&go speed in km/h for the HBEFA road type, v_f is the free flow speed in km/h from the network, and $v = \frac{l}{t}$ is the average speed on the link for the vehicle, t being the link travel time of the vehicle in the simulation. For the derivation of Equation (36.1), please refer to Kickhöfer (2014). The distance that the car is driving in free flow traffic state is then simply the remaining link length $l_f = l - l_s$. The interpretation of this approach: Cars drive in free flow until they have to wait in a queue. Stop&go traffic state applies only in the queue. According to the MATSim queue model presented in Section 1.3, a queue emerges if demand exceeds capacity of a road segment, which can also result in spill-back effects on upstream road segments. The length of the queue is, thus, approximated by Equation 36.1, where the average speed v on a link is the only exogenous variable.

For the second step, agent-specific vehicle attributes are needed. They are usually obtained from survey data during the initial population synthesis. The vehicle attributes typically comprise: vehicle type, age, cubic capacity and fuel type. Because MATSim keeps socio-demographic information throughout the simulation process, it can be used at any time for reference in the detailed HBEFA database. Additionally, the emission modeling tool is designed in such way that fleet averages are used, whenever no detailed vehicle information is available.

The calculation of cold-start emissions is, again, composed of two steps:

1. deriving *parking duration* and *accumulated distance* from the simulation, and
2. combining this information with vehicle characteristics in order to extract emission factors from the HBEFA database.³

Parking duration refers to the time a vehicle is not moved *before* cold-start emissions are produced. It is calculated by subtracting an activity's start time from the same activity's end time and by checking if the trip to and from the activity is performed by car. Emission factors in HBEFA are differentiated by parking duration in one hour time steps from 1 hour to 12 hours. After 12 hours, the vehicle is assumed to have fully cooled down. The accumulated distance refers to the distance a vehicle travels *after* a cold start. According to HBEFA, there are different cold-start emissions for short trips less than 1 kilometer and for longer trips equal to or greater than 1 kilometer. In reality, cold-start emissions are emitted along the route after a cold start; at this time, the emission modeling tool maps the short trip emissions to the road segment where the engine is started, and, if applicable, additional emissions to the road segment where the accumulated distance exceeds the first kilometer. Overall, cold-start emission factors increase with parking duration and accumulated distance; they also depend on vehicle attributes. The lookup for this information is identical to the one described for warm emissions.

In order to further process warm and cold-start emissions, so-called *emission events* are generated during the simulation in a separate events stream. The definition of emission events follows the MATSim framework that uses events for storing disaggregated information in XML format. The following section provides more information on the EMT's software structure.

36.5 Software Structure

The information in this section refers to code that can be found in the MATSim repository. In the following, the software structure of the EMT at revision 30 058 is described. For information on how to use the tool, please use the entry points listed at the beginning of this Chapter 36.

³ Please note that HBEFA provides cold-start emission factors only for passenger cars. Freight traffic therefore only produces cold-start emissions of passenger cars.

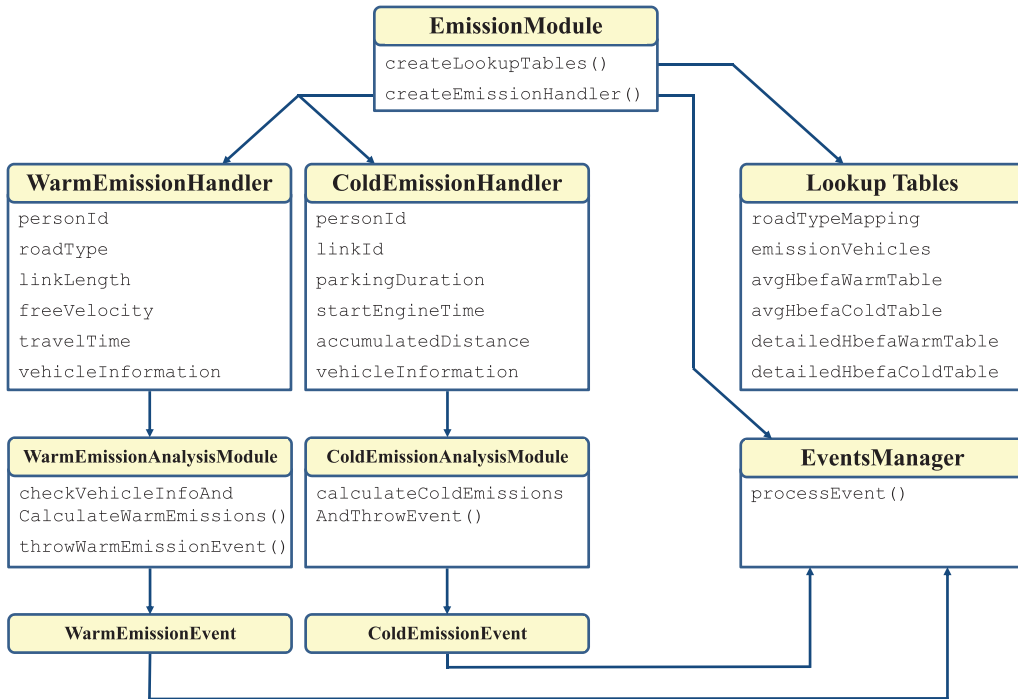


Figure 36.1: Software structure of the emission modeling tool.

Figure 36.1 shows the simplified software structure of the EMT. The core of the tool is the `EmissionModule` which needs to be created before the simulation starts. There are also two public methods that must be called: `createLookupTables()` and `createEmissionHandler()`.

The former creates lookup tables from input data that has to be exported from the HBEFA database. The path to these input files can be configured in the `EmissionsConfigGroup`. Mandatory input are files for the creation of `roadTypeMapping`, `emissionVehicles`, `avgHbfaWarmTable`, and `avgHbfaColdTable`. The first lookup table maps road types from the MATSim network to HBEFA road types. For this mapping, it is necessary to classify the network road types into HBEFA categories; this requires some transport engineering knowledge. The second lookup table defines the vehicle attributes of every owner in the population. It should therefore be generated during the population synthesis process. If no detailed information is available, the vehicle lookup table still needs to specify whether the vehicle is a car or a truck. The current implementation uses the MATSim vehicle interface `Vehicles` as container for storing the relevant data in `VehicleType`.⁴ The last two mandatory lookup tables (`avgHbfaWarmTable` and `avgHbfaColdTable`) provide warm and cold emission factors in g/km , respectively. The data is stored using a unique key. For the construction of this key, information from `roadTypeMapping` and `emissionVehicles` is needed, as well as information derived from the simulation as described in Section 36.4. The latter information is depicted in Figure 36.1 as variables of the two classes `WarmEmissionHandler` and `ColdEmissionHandler`. These two handlers implement several MATSim `EventHandler` interfaces to extract necessary information from the simulation. After gathering this information, the `WarmEmissionHandler` asks its `WarmEmissionAnalysisModule` to reconstruct the key and look up the emission factors in the

⁴ Please note that vehicle information provided to the `EmissionModule` is *only* used for storing data on individual vehicle characteristics and other information will be omitted by the simulation.

respective table. Similarly, the `ColdEmissionHandler` asks the `ColdEmissionAnalysisModule`. These analysis modules then create `Warm/ColdEmissionEvents`, which follow the `MATSim Event` interface definition. Finally, the resulting events stream is written in a joint emission events file by a separate `EventsManager`.

For the calculation of emissions dependent on agent-specific vehicle characteristics, `emissionVehicles` must contain that specific information, the corresponding flag in the `EmissionsConfigGroup` needs to be switched on, and detailed emission factor tables also need to be exported from HBEFA and provided to the `EmissionModule` with two additional input files: `detailedHbefaWarmTable` and `detailedHbefaColdTable`.