

Chapter 15

Macroscopic simulation

The final chapter of this reader discusses macroscopic simulation of traffic in general, and in particular the METANET model. METANET is a model for predicting traffic conditions on a motorway network. Besides the macroscopic traffic flow model describing what happens on the motorway links, METANET also describes route choice behaviour as well as the influence of dynamic traffic management measures.

It is emphasized that, on the contrary to microscopic models such as FOSIM and AIMSUN2, METANET is not a stochastic model but a deterministic model. As a result, it is of no use to rerun the same simulation more than one time. Instead, the robustness of the simulation results with respect to the simulation input should be considered. This particularly to the traffic demands on the network, but also on the parameters that are used to predict the traffic flows through the network,

15.1 Traffic processes in METANET

In METANET, the motorway network is represented by a directed graph that is described in the filename.nwd file. More precisely, bifurcations, junctions and on/off-ramps are represented by the nodes of the graph whereas the motorway stretches between these locations are represented by the links. The two directions of a motorway stretch are modelled as separate links with opposite directions. Inside each link we suppose homogeneous geometric characteristics. An inhomogeneous motorway stretch may be represented by two or more consecutive links separated by nodes at the locations where the change of geometry occurs. At the bounds of the network, origin or destination links are added where traffic enters or leaves, respectively, the simulated network part.

METANET considers five types of links: normal motorway links, dummy links, store-and-forward links, origin links, and destination links. In this short manual, we will only consider motorway links, origin links and destination links.

15.1.1 Normal motorway links

The simulation of traffic behaviour in the motorway links is based on a macroscopic modelling approach with the traffic variables density k (veh/km/lane), mean speed u (km/h), and traffic volume (or flow) q (veh/h). Each link is subdivided in segments with typical lengths of 300 to 800 meters. Starting with some initial values, the time evolution of every traffic variable in every segment is calculated by means of difference equations and algebraic relationships, which are calculated for every simulation time step (typically every 10s).

The following equation describes the dynamic of traffic on a motorway link. The outflow $q_{m,i}(j)$ of each segment i of link m during time period j is equal to the density multiplied by the mean speed and the number of lanes λ_m

$$q_{m,i}(j) = \lambda_m k_{m,i}(j) u_{m,i}(j) \quad (15.1)$$

The dynamics of the density on a segment (cell) is defined by the conservation of vehicle equation, given by

$$k_{m,i}(j+1) = k_{m,i}(j) + \frac{T}{L_m \lambda_m} [q_{m-1,i}(j) - q_{m,i}(j)] \quad (15.2)$$

where T is the time step. Note that the discretisation of the flow is a rather rough approximation of the actual flow between two cells, since it only depends on the transmitting segment i .

The speed dynamics are based on the Payne model. METANET uses

$$u_{m,i}(j+1) = u_{m,i}(j) + \frac{T}{\tau} [V(k_{m,i}(j)) - u_{m,i}(j)] \quad (15.3)$$

$$+ \frac{T}{L_m} u_{m,i}(k) [u_{m,i-1}(j) - u_{m,i}(j)] \quad (15.4)$$

$$- \frac{\vartheta T}{\tau L_m} \frac{k_{m,i+1}(j) - k_{m,i}(j)}{k_{m,i}(j) + \kappa} \quad (15.5)$$

where τ , ϑ and κ are model parameters and where the fundamental diagram is given by the following expression

$$V(k) = V_m^0 \cdot \exp \left[-\frac{1}{a_m} \left(\frac{k}{k_m^c} \right)^{a_m} \right] \quad (15.6)$$

where a_m is a link-specific model parameter and where V_m^0 denotes the free speed of the link; k_m^c is the link specific critical density.

For steady-state and space-homogeneous conditions, this value becomes identical with the current mean speed of the segment. The shape of the fundamental diagram is determined by the parameters V_m^0 , k_m^c and the parameter a_m . The exponent a_m has no direct physical significance and is therefore substituted by other variables in the user input.

15.1.2 Origin links and destination links

Origin links receive the corresponding user-specified demand. Their outflow may be limited by the link capacity and/or downstream congestion and/or traffic lights (in case of ramp metering). If for any of these reasons, the link demand exceeds the link outflow, a queue will be formed. Partial queues and composition rates are also present in this kind of links to represent traffic with different destinations. A simple queuing model is used to describe the traffic operations at the origin links.

The destination links represent the locations from which traffic leaves the simulated network part, in other words the exits of the network. Occasionally, traffic flow at the exits of the network may be influenced by the traffic conditions in downstream stretches (e.g. spill back of congestion). In such cases, if traffic densities at the destination links are available, they may be used to limit the outflow according to the downstream traffic conditions.

15.1.3 Discontinuities

METANET includes different models describing the effect of on ramps and lane drops. In order to account for the speed drop caused by merging (in case of on on-ramp), the following term is added to the speed-dynamic equation

$$- \frac{\delta T q_{on-ramp}(j) u_{m,1}(j)}{L_m \lambda_m (k_{m,1}(j) + \kappa)} \quad (15.7)$$

assuming that the on-ramp ‘attaches’ to the first segment of link m .

Where there is a lane drop, the speed reduction due to the lane drop is described by the following term which is added to the speed dynamic equation

$$- \frac{\phi T \Delta \lambda k_{i,N_m}(j) u_{m,N_m}^2(j)}{L_m \lambda_m k_m^c} \quad (15.8)$$

where $\Delta \lambda = \lambda_m - \lambda_{m+1}$ denotes the lane drop and where $\phi > 0$ is a model parameter.

15.1.4 Modelling of the Network Nodes

Motorway bifurcations and junctions (including on- and off-ramps), are, as already mentioned, represented by the nodes of the model. Generally speaking, traffic enters a node n through a number of input links and is distributed to a number of output links. For proper calculation of the distribution, the destinations of the inflows must be considered. The partial flow with a certain destination in an output link is calculated according to the total incoming traffic bound to this destination and according to the portion of users who choose the corresponding output link in order to travel to their destination. This portion of users is the splitting rate and describes the average route choice behaviour of the drivers at the network nodes. As already mentioned, splitting rates may be provided in several ways including the possibility to simulate the impact of variable message signs and/or route guidance measures.

Before describing the different input needed to run a METANET simulation study, let us first consider the different phases that are relevant when performing a simulation. In this short manual, we assume that METANET will be used for control scenario assessment purposes. That is, for a certain network, we aim to cross-compare different ITS scenarios. We will distinguish two main phases: preparation METANET and performing the study. The remainder provides a coarse checklist, but does not go into details.

15.2 Preparing a METANET simulation study

In chapter IV we have already outlined the different steps that are important when doing a simulation study. This section discusses some specific issues that are important when doing a METANET study, namely setting up of the simulation study and application of the model. However, another important issue is the decision to use METANET rather than some other (microscopic) simulation model. This depends on the required scale and level-of-detail: METANET can handle large network and do so with relatively low computation times. Furthermore, the data requirements are relatively low. Being a macroscopic model, the level-of-detail is only moderate. On top of this, the METANET model is macroscopic both in the representation of the traffic flow and in its description of the traffic processes. Requiring the speed-density curve as an input (and a way to describe the effects of incidents, roadworks, and Dynamic Traffic Management measures), effects of changes in (bottle-neck) geometry, traffic control, etc. need to be determined either from empirical data or using another traffic flow model.

15.2.1 Determine and acquire required input parameters and variables

METANET has no true Graphical User-Interface. Hence, to do a simulation study, different input files need to be prepared using a text editor. Furthermore, METANET has two simulation modes:

1. non-destination oriented mode (no route choice) and
2. destination oriented mode (route choice).

In destination oriented mode, METANET explicitly distinguished traffic with different destinations and their route choice. In non-destination oriented mode, no distinction is made, and hence route choice cannot be modelled.

It is beyond the scope of this reader to discuss in detail all these input files. We refer to the METANET manual for more information.

Filename	Destination	Non-destination	Description
Filename.nwd	x	x	Description of network topology (origins, destinations, motorway links, nodes)
Filename.ctr	x	x	Simulation control file, describing run-time parameters
Filename.msdl	x	x	Traffic measurement file, describing the data collected at various points in the network
Filename.odm	x	-	Dynamic Origin-Destination information
Filename.spl	x	-	Splitting fractions (not required when dynamic assignment is used)
Filename.trn	-	x	Turning rates
Filename.cpa	x	x	Control Parameters file, describing the parameter settings of the ITS measures (not required)
Filename.evt	x	x	Event and incident file, describing the time and duration of incidents and ITS operation.

Table 15.1: Input files needed for doing METANET simulation study