METANET: a macroscopic simulation program for motorway networks

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2 authors:

Albert Messmer
Independent Researcher

Markos Papageorgiou

METANET

A SIMULATION PROGRAM FOR

MOTORWAY NETWORKS

Documentation

Technical University of Crete, Dynamic Systems and Simulation Laboratory,

and

Dr.-Ing. A. Messmer

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CONTENTS

1 INTRODUCTION

Modelling of traffic flow on motorway networks is a useful tool for several traffic engineering tasks such as:

i) Development and evaluation of traffic control strategies.

ii) Short-term prediction and surveillance of traffic state in complex networks.

iii) Evaluation of the impact of new constructions, comparison of alternatives, etc.

iv) Evaluation of the impact of capacity reducing events (e.g. road works) or increased demand, etc.

According to the specific task, the use of the model may be either off-line or in real time.

METANET is a program for motorway network simulation based on a purely macroscopic modelling approach. This leads to relatively low computational effort, which is independent of the load (number of vehicles) in the simulated network and allows also for a real-time use of the model. The overall modelling approach allows for simulation of all kinds of traffic conditions (free, dense, and congested) and of capacity-reducing events (incidents) with prescribed characteristics (location, intensity, and duration).

METANET may be applied to existing or hypothetical, multi-origin, multi-destination, multi-route motorway networks with arbitrary topology and geometric characteristics including bifurcations, junctions, on-ramps and off-ramps. By use of a special modelling option (store-and-forward links), METANET provides also the possibility to consider non-motorway links in a simplified way.

METANET considers the application of traffic control measures, such as collective and/or individual route guidance as well as ramp metering and motorway-to-motorway control, at arbitrary network locations. Several options are offered for describing or prescribing the average route choice behaviour of drivers groups with particular destinations. Route guidance and dynamic traffic assignment considerations in METANET are based on the notion of splitting rates at bifurcation nodes rather than on path assignment. Among other advantages, this approach enables consideration of route guidance or traffic assignment for a part of the network (rather than the whole network) if so desired by the user.

Simulation results are provided in terms of macroscopic traffic variables such as traffic density, traffic volume, and mean speed at all network locations as well as in terms of travel times on selected routes. This is done on a configurable output time interval that is chosen usually significantly longer (typically several minutes) than the simulation time step (typically 5 to 20 s). Visualisation of results is provided both by time trajectories of selected variables and by graphical representation of the whole network. Global evaluation indexes such as total travel time, total travelled distance, total fuel consumption, total waiting time at network origins, total disbenefit of routed drivers, etc. are also calculated.

For displaying traffic data generated or used by METANET in a transparent form, a specific graphical output program called METAGRAF is available. This tool is described in Appendix B.

This documentation describes in its main parts the off-line METANET version.

2 SIMULATION MODEL

In this chapter a brief outline of the modelling approach used in METANET is given. This is done for the purpose of enabling the reader to understand the information given in Chapter 3 about program realisation and usage. A complete documentation of all modelling equations can be found in Appendix A.

2.1 Network Representation

The motorway network is represented by a directed graph. 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 such as number of lanes, upgrades, curvature, etc. 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.

2.2 Required Traffic Data

Essentially the simulation is fed with demands at its boundaries (inflows) plus origin-destination information (if necessary). These data together with other values which act at the network bounds (speeds at main inflows and traffic densities at main outflows) are called *boundary data* (or input traffic data) in the following. The origin of the data may be from measurements (if real traffic situations are reconstructed), or the data may be hypothetical (if certain types of traffic situations are studied). The files in which boundary data are provided may contain also data from inside the network which are not considered by METANET but which can be used by METAGRAF for comparison purposes. A detailed description of these files is given in Section 3.4.

Each origin-destination couple may be connected by one or more routes. Based on the network topology, METANET finds automatically all possible loop-free routes.

The route choice behaviour inside the network is described by use of *splitting rates* which express the portion of drivers deciding at a bifurcation node to use a certain alternative output link towards their destination. Splitting rates can be looked upon as turning rates (the ratio of the traffic volumes in each output link of a node) *by destination*. There are three alternative ways for the user to provide the simulation with splitting rates:

– In an input file
– By an extra program module (see Section 3.6) containing a control strategy. This option is used, if information and/or route recommendation via variable message signs or route guidance measures are to be studied. Compliance of the drivers to the displayed messages influences the resulting splitting rates.
– As a further possibility the user may choose a simple reactive procedure for automatic traffic diversion in the sense of dynamic traffic assignment, in which case the splitting rates are generated by the program without any user intervention (see Appendix A.4 and Section 3.4.3.2).

For simulation of control measures via variable direction indication and also for traffic assignment studies, the destination-oriented way of modelling, as outlined above, is necessary. However, for some applications the user may not be interested in the composition of traffic in terms of destinations. In this case no origin-destination information is necessary, and moreover no splitting rates, but simply turning rates, are needed at the network nodes.

2.3 Modelling of the Network Links

2.3.1 Link Types

METANET considers five types of links:

– normal motorway links,
– dummy links,

– store-and-forward links,
– origin links, and
– destination links.

Each one is used for different reasons and thus treated in a distinct way.

2.3.2 Normal Motorway Links

The simulation of traffic behaviour in the motorway links is based on a macroscopic modelling approach with the traffic variables *density* ρ (veh/km/lane), *mean speed* v (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 (see Appendix A.1.2) which are calculated for every simulation time step (typically every 10s).

The link-specific traffic behaviour is mainly influenced by the fundamental diagram that is expressed by the following equation

$$V(\rho_{\mathrm{m,i}}(\mathrm{k})) = \mathrm{v}_{\mathrm{f,m}} \cdot \exp\left[-\frac{1}{a_m}\left(\frac{\rho_{\mathrm{m,i}}(\mathrm{k})}{\rho_{\mathrm{cr,m}}}\right)^{a_m}\right]$$

where the function V provides a speed value used in the above mentioned difference equations for the segment i of the link m, and is a function of the segment's density $\rho_{m,i}(k)$ at discrete time k. 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 $v_{f,m}$ (free flow speed), $\rho_{cr,m}$ (critical density) and the parameter a_m. In contrast to $v_{f,m}$ and $\rho_{cr,m}$, the exponent a_m has no direct physical significance and is therefore substituted by other variables in the user input (see Section 3.4.4 and Appendix A.1.2).

Some further traffic variables, namely the *partial densities* and the *composition rates*, are required for each segment in the destination-oriented utilisation of METANET.

Partial densities are traffic densities per destination reachable through the corresponding link. Composition rates are portions of the traffic volume for each destination reachable through the corresponding link. Appropriate difference equations are used to describe the time and space propagation of these variables (see Appendix A.1.8).

2.3.3 Dummy Links

Two real nodes may be very close to each other; i.e. the link connecting them is very short. In these cases, if the interactions taking place inside this short link are of little interest, the link may be represented as a dummy link. Note that if a very short link would be represented as a normal link, then the simulation time step for the whole network should be chosen accordingly short (for numerical stability reasons, see Appendix A.1.1) which would increase the overall computational effort accordingly.

Dummy links are considered to have zero length and are only used to forward traffic flow to the corresponding next downstream node, and/or to transfer the impact of downstream links (e.g. congestion spill back) to upstream links without any own dynamics.

2.3.4 Store-and-Forward Links

In many cases, the simulated motorway network includes internal ramps connecting different motorway parts as shown in Figure 1. Obviously, these motorway-to-motorway links are, at the same time, on- and off-ramps of different motorway stretches. Usually, motorway-to-motorway links have a relatively short length, however, the interactions (e.g. queue spill back) taking place inside them may in some cases be of importance thus preventing their modelling as dummy links. On the other hand, modelling them as normal links might result in a significant increase of the computational effort as they may require (for numerical stability reasons, see Appendix A.1.1) accordingly short simulation time steps.

Furthermore, for simulation of control measures (e.g. motorway to motorway control) at internal network locations, the normal link model may be less suitable, as in such cases the interesting variables are waiting queues, ordered and metered on-ramp volumes, etc. Hence, even if the links are not short, application of motorway-to-motorway control may require a distinct treatment. For these reasons, motorway-to-motorway links are treated within METANET as store-and-forward links.

Store-and-forward links may also be used for a completely different purpose, namely for simplified consideration of alternative non-motorway routes with limited capacity. For example, modelling of traffic flow on a long motorway axis with possibility of diversion towards a parallel arterial may be performed by use of store-and-forward links that represent corresponding portions of the parallel arterial. But also when modelling a genuine motorway network, there is often a need to take into account various possibilities of partial diversion via non-motorway routes (arterials, urban roads, dual carriageways, etc.). All these non-motorway routes may be conveniently represented by store-and-forward links.

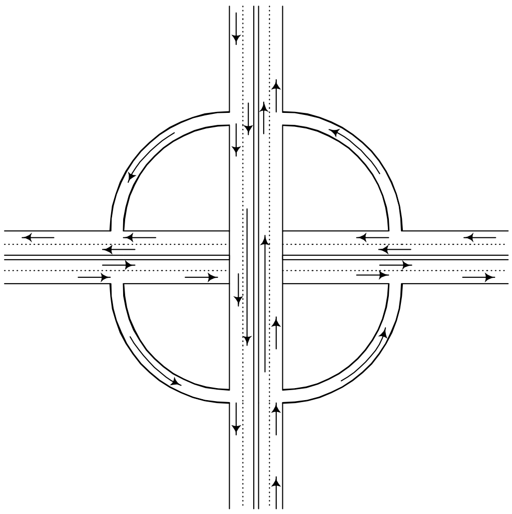

Figure 1: Example of Motorway-to-Motorway Links.

Finally, store-and-forward links may also be used in order to model the impact of possible traffic lights just upstream of an on-ramp or downstream of an off-ramp. If the traffic lights are operated in a fixed way, the corresponding store-and-forward link is given an according outflow capacity. If the traffic lights are operated in a traffic-responsive way, the outflow capacity may be changed at each time step in dependence of the current link’s queue. The dependence must then be programmed by the user as described in Section 3.6.

The simulation of traffic behaviour in a store-and-forward link is based on a constant travel time plus a waiting queue model, whereby the link outflow may be limited by the link capacity and/or downstream congestion and/or traffic lights (e.g. in case of motorway-to-motorway control). Queue spill back is modelled to have an impact on the traffic flow of upstream links. Partial queues and composition rates are also included in order to describe the portions of the traffic with different destinations reachable through these links. Appropriate difference equations are used to describe the time propagation of all these variables (see Appendix A.1.8).

2.3.5 Origin 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.

2.3.6 Destination Links

These 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.

2.4 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.

2.5 Incidents and Control Measures Modelling

METANET provides two ways of specifying incidents:

- an old style way via appropriate entry(ies) in the Simulation Control file (see 3.4.3) which is kept for compatibility reasons, and
- via a Control Measures and Incidents file (see 3.4.7).

The latter way allows also for the specification of a number of different control measures. A Control Measures Parameter file is expected here in addition (also described in 3.4.7).

2.5.1 Incidents

In the frame of control strategy testing it may be important to assess the appropriate and efficient reaction to exceptional situations caused by incidents. For that reason the user is able to specify the occurrence of incidents in the Simulation Control file or the Control Events and Incidents file by giving the:

– occurrence time and duration,
– location (link and kilometre on the link), and
– severity in terms of relative capacity (old style way) or remaining absolute capacity or closed lanes.

Incidents can only be modelled on normal motorway links. The modelling method is described in Appendix A.

2.5.2 Control Measures

METANET (off-line) offers the option to model incidents and a number of different types of control measures. The available control measures are:

- Variable Direction Indication (VDS),
- Queue Information via Variable Message Signs (VMS),
- Lane Closures,
- Shoulder Lane Opening,
- Variable Speed Limitations,
- Ramp Metering,
- Traffic Lights at on- and off-ramps.

Related static parameters have to be given in the Control Measures Parameter file. This comprises compliance rates, feedback parameters (for VMS response modelling and traffic responsive ramp metering), fundamental diagram parameter sets (for speed limitation, lane closures and shoulder lane opening) and resulting capacities (for traffic lights modelling).

The adopted modelling methods are described in Appendix A.

2.5.3 Concurrency of Control Measures and Incidents

Control and incident events can be specified in arbitrary order in the Control Events and Incidents file. Concurrent (in terms of time <u>and</u> location) control measures of the same kind make, however, no sense. In that case the program terminates with an error message.

Control measures or incidents which are not of the same kind, may overlap in terms of time and location. It can be distinguished between three groups of measures/events:

- route choice influencing measures, i.e. direction indication and queue information

- stretch (links) parameter influencing measure/events, i.e. shoulder lane opening, lane closure, speed limitation, incident,
- ramp metering, traffic lights.

Measures/events of different groups need no specific care in case of overlapping.

Coincidence of direction indication and queue information:

The direction information formula (see Appendix A) is always calculated first and on top of that the queue information formula is applied. The resulting splitting rate $\beta_{n,j}$ of the first formula is used as β_N value for the second formula.

Lane closures parallel to speed limitations:

The parameters of the links' speed-density relation (free speed, critical density, capacity ..) as given for an active speed limitation overwrite the parameter modifications as done for lane closures.

Shoulder lane opening parallel to lane closures or speed limitations:

The parameters of the links' speed-density relation as given for an active shoulder lane opening overwrite the parameter modifications as done for speed limitation or lane closure.

In any case (any combination of lane closure, speed limitation and shoulder opening) the number of remaining lanes is calculated as the combination of lanes closures on the main carriage way and the opened shoulder lane.

An additional incident is treated as follows:

If the remaining capacity for the incident is given, maximum flow at the incident location is taken as the smaller one of the remaining capacity and the capacity of anyhow usable lanes. The current capacity may be already modified due to lane closures/openings or speed limitations and the number of usable lanes may be already reduced/increased due to lane closures/openings. A warning message is issued in the log file if the remaining capacity of an incident exceeds the capacity of the anyhow usable lanes, i.e. if the incident has no effect.

If the set of closed lanes is given for the incident (instead of the remaining capacity), the number of lanes closed in total is calculated as the combination of the set of lanes closed/opened by the lane closure / shoulder lane opening measure and the set of lanes closed by the incident. There is one lane more which could be closed by an incident in case of an opened shoulder lane.

<u>Ramp Metering parallel to Traffic Lights:</u>

An active ramp metering measure (not deactivated by the density constraint or the queue constraint) overwrites a traffic light placed at the same on-ramp.

2.6 Calculation of global Performance Criteria

In order to assess and compare the efficiency of various control measures and/or control strategies, some global *performance criteria* are calculated as integral over the simulated time horizon:

– total travel time,
– total waiting time (in the queues of the origin links and of the store-and-forward links),
– total distance travelled
– total amount of fuel consumed, and
– total disbenefit of routed drivers.

3 PROGRAM REALISATION AND USAGE

This chapter describes the technical realisation of the simulation program METANET. The main part of the chapter is dedicated to the usage of the program (input requirements) and can be regarded as a user's manual.

The program is written in C. With slight modifications, it can be compiled on any machine equipped with an ANSI-C compiler. Compilation is tested and according make-files are available for UNIX (system V) and for MS-Windows using the Visual C++ compiler. For PC (under Windows) an already compiled exe-file (running in a console window) is delivered with METANET.

METANET uses dynamic memory allocation for the bigger data structures, i.e. at run time, after reading the network configuration, the structures containing network information and traffic data are allocated according to the actually required size. This helps for better utilisation of available memory, thus enabling the simulation of very complex networks. Indications about required memory, computation time, etc. can be found in Chapter 4 for the example shown there.

3.1 Installation

For the installation of METANET it is sufficient to copy the METANET.EXE file which is about 400 kByte in size to any appropriate directory. If the directory containing METANET.EXE is not identical with the work directory used when invoking METANET, an appropriate path has to be declared (on PC this is done in the AUTOEXEC.BAT file).

For output on the screen, METANET uses ANSI cursor control sequences. A Windows console window is by default not able to interpret these sequences. For proper screen output the following line has to be inserted in CONFIG.SYS:
"DEVICE=<path>\ANSI.SYS" .
Where <path> is normally "\WINDOWS\COMMAND".

3.2 Simulation Program Structure

Figure 2 depicts the global program structure of METANET. A simulation run starts with reading the file for simulation control (*ctrname*.ctr) and the file which describes the network to be simulated (*nwdname*.nwd). In order to give the user the opportunity to check the input, all data together with additional information generated by the program are written to a check file (*smdname*.chk). Numerous input data checks are performed already by the program. If inconsistent input data are found or if information is missing, an error message is displayed and the program terminates.

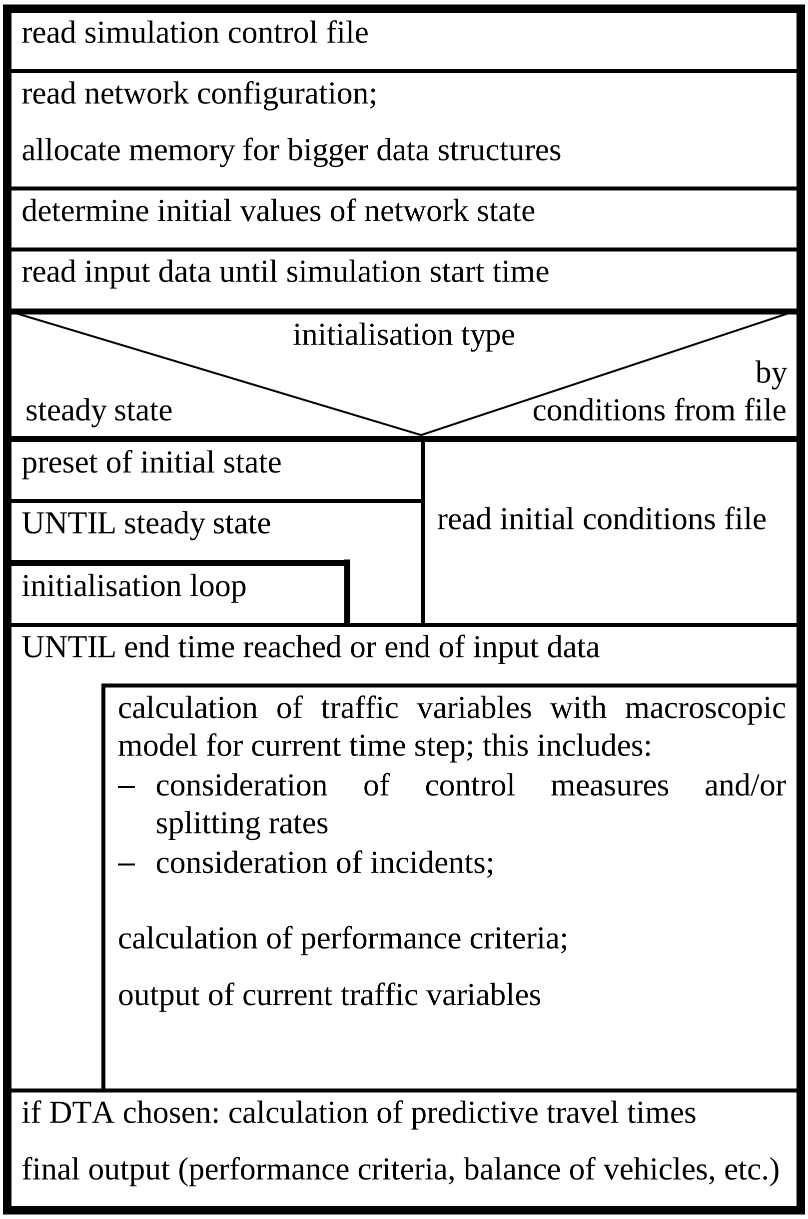

Figure 2: Global structure of METANET.

The determination of the network's initial state follows. There are two user options which are described in the next section.

After initialisation, the main simulation loop starts. For each time step the simulation is fed with new boundary traffic data and splitting rates which are interpolated from data provided in the corresponding traffic data files (*trdname*.*). Interpolation is necessary if the time raster of provided boundary data is coarser than the simulation time step of e.g. 10s. In a user-specified time raster, the currently calculated traffic variables are then written to output (*smdname*.smd). The user may specify a subset of all available traffic variables which should be written to the output.

The simulation loop is terminated after a predefined number of steps or if an end of file is encountered in one of the traffic data input files. At the end of the simulation run and if the DTA option (see 3.4.3.2) is activated, the shortest predictive travel times along the different directions of the selected bifurcation nodes over the simulation horizon are calculated. Some final information (e.g. performance criteria) is written to output and a balance (by destination) over all vehicles that entered and left the network is made (considering the vehicles still being in the network). An error message is issued if balances deviate significantly from zero.

Figure 3 gives an overview of the involved in/output files and their usage by the program. A description of each file is given later.

3.3 Determination of Initial Network State

The user may choose between two options:

- Initialisation with steady-state conditions according to boundary conditions (mainly network inflows) valid at begin time of simulation. No particular input file containing initial conditions is necessary. To speed up, however, the process of finding the steady states, an initial conditions file *nwdname*.ini may be given.

- Initialisation with user-specified values. An initial conditions file *nwdname*.ico is necessary.

The format of the mentioned initial condition files is described in the next section. The selection of the possible options is done via the *init_type* entry in the simulation control file (see also next section).

Steady-state conditions (first option) are determined via an apriori simulation loop which obtains as input the boundary values and the splitting rates valid for the start time of simulation. This loop is executed with the same constant input data until a steady state is reached throughout the whole network.

3.4 User Input Specifications

3.4.1 Overview

Figure 3 gives an overview of the input and output files.

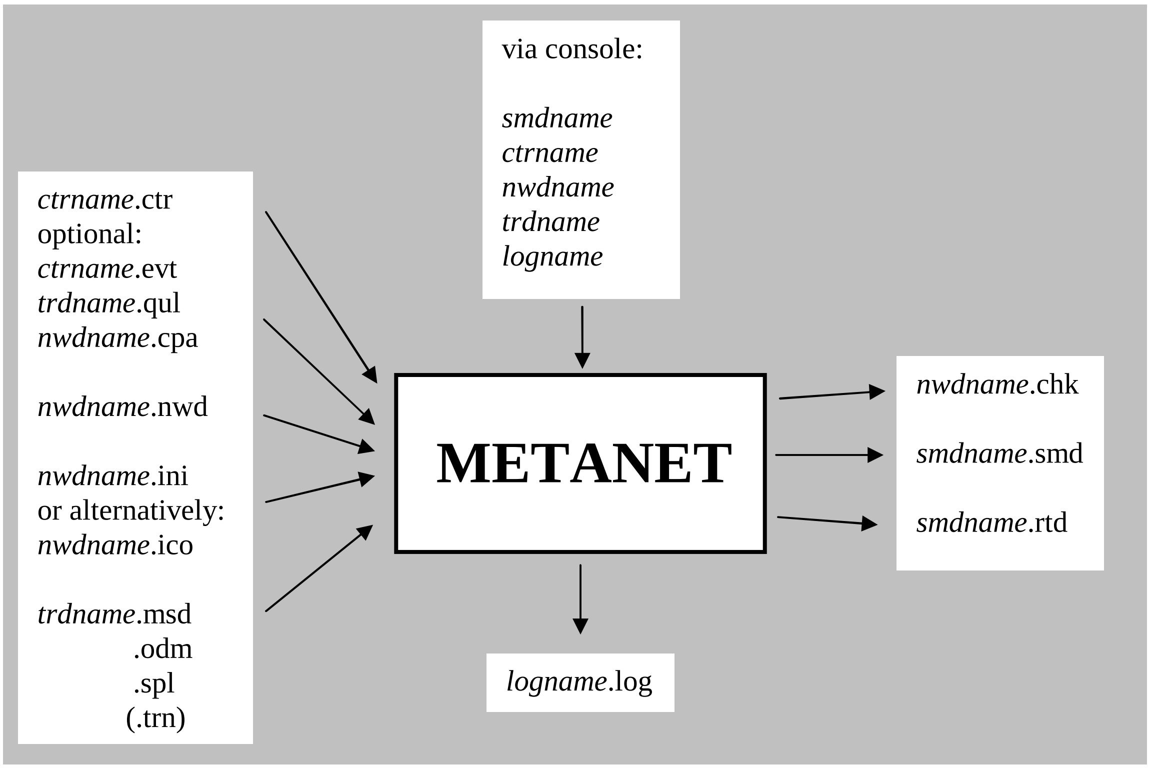

Figure 3: **Overview of METANET input/output**

In order to run METANET, the following input files must be prepared:

- A simulation control file *ctrname*.ctr in which the user can specify the simulation time step T, simulation horizon, simulation mode, usage of input traffic data, incident modelling, amount of output, and optionally dynamic traffic assignment parameters.
- A network description file *nwdname*.nwd containing global network parameters, lists of origins, links, destinations and their characteristics (lengths, numbers of lanes, free speeds, critical densities, capacities, etc.) and a list of the nodes with their interconnection to the links.
- An initial traffic condition file *nwdname*.ini (optional) or *nwdname*.ico
- The following traffic data files:
  - *trdname*.msd (measured or hypothetical boundary traffic data; contains optionally also internal traffic data for comparison purposes),

  additionally:

  in the case of destination oriented simulation:
  - *trdname*.odm (origin-destination information) and
  - *trdname*.spl (splitting rates at specific network nodes) if not calculated by control strategy or traffic assignment module

  or alternatively in case of non-destination oriented simulation:
  - *trdname*.trn (turning rates at all bifurcation nodes in the network)

  for the period to be simulated.
- optionally there is:
  - A Control Measures and Incidents file *ctrname*.evt and
  - a related Control Measures Parameter file *nwdname*.cpa.
  - For feeding the queue indication control algorithm with recurrent queue lengthes, a file *trdname*.qul is used.

The following output files are produced:

- a check file *nwdname*.chk,
- a simulation data file *smdname*.smd,
- a route data file *smdname*.rtd, and

- a log file *logname*.log.

The log file contains all error messages and warnings as they were also written onto the screen. The purpose of the file is to have a record of all the warning messages which may have been issued during the simulation run. Since the program keeps on running after the issuing of a warning, the according message may be overwritten on the screen by new ones. The log file is also helpful in cases where the program stopped due to an error and the according error message cannot be read on the screen since the window where METANET was running has been already closed.

The names *ctrname*, *nwdname*, *trdname* have to be provided at the beginning of the program. This is done interactively via console input. In the PC console version these names can also be specified in the command line which starts METANET (i.e. "metanet [*ctrname* [*nwdname* [*trdname*]]][1] "). "metanet" is used as default for *ctrname*, *nwdname* and *trdname*.

The elements of the network (origins, destinations, nodes, and links) are referred by their names in every input file. Input data are checked by the program with respect to consistency and completeness.

3.4.2 General Properties of Input Files

All in/output files are of type text (ASCII). Generally in all files every line is marked by a character in the first column which specifies the line type. The following characters are used:

'C' for a comment line. These lines are skipped by METANET and can be used to improve readability.

'H' for a headline. It has to appear as first non-comment line in every input file. The content of a headline is treated as text and is used in METANET output to document which input was used.

'|' for any line containing data (configuration data as well as traffic data).

'M' for configuration data of store-and-forward links.

'E' for an end of list (e.g. list of links, list of measurement locations, etc.); no data are expected on this line. Also in case of a particular list being empty this delimiter is expected.

and especially for traffic data files:

'F' for a traffic data format description line.

'T' for a time step specification line (if necessary).

'N' for a line which gives the names of the locations (network elements) to which following traffic data are corresponding.

'O' for a line in which a mean vehicle length is given.

The last four line types are needed in traffic data files in order to specify how the data which are following should be interpreted (see also 3.4.6).

If nothing appears in the first column (i.e. a white space character is placed), this line is regarded as the continuation of the line before. This enables the user to break up data input lines which are too long for normal editors and/or to arrange input in easily readable form.

The entries which follow the line type specifier are interpreted as one of the following data types (depending on the file and the position):

Type	**Description**
textline	Entry is treated as text. It may contain any ASCII character. METANET reads a maximum of 80 characters. Additional characters till end-of-line are skipped.
real	Entry is interpreted as real number according to C conventions.
integer	Entry is interpreted as integer number.
typespec	Entry has to be one character from a set of allowed characters and is used to choose between several options.
time	Entry is interpreted as time (time of day or time interval). Format: hours[:minutes[:seconds]].
name	Entry is treated as name (e.g. for network nodes). Names should not be

[1] Any entry between square brackets can be omitted by the user (i.e. it is optional).

longer than 16 characters. No blanks, tabs and '@'s are allowed.

Consecutive entries in one line have to be separated by at least one blank or tab.

In the following the detailed structure of each input file is given. An example for every file can be found in Appendix C for the test example presented in Chapter 4.

Some comment lines are used to clarify the structure of the files. The user is free to write any other comment line which can appear at any location in the file, however not before a continuation line. The order of the entries has to be obeyed strictly. On the other hand, inside a list (e.g. list of links) the order of entries is arbitrary. The lengths of the lists (number of entries) are not explicitly limited. Only the amount of available memory at run time may be the limiting factor.

3.4.3 Simulation Control File

3.4.3.1 Mandatory Part of Simulation Control File

The simulation control file *ctrname*.ctr is structured:

---------------------- *ctrname*.ctr -----------------------------

H *headline_1*

H *headline_2*

H *headline_3*

| *sim_start sim_end sim_step*

| *sim_mode contr_type* [*init_type*][2]

C List of boundary locations (origins and destinations) for model input:

| *loc_name link_name link_km*

| •

| •

| •

E

C List of internal measurement locations for comparison purposes:

| *loc_name* *link_name* *link_km*

| •

| (List may be empty if no comparison values available)

| •

E

C List of incidents:

| *inci_start* *inci_end* *link_name* *link_km* *inci_sev*

| •

| •

| •

E

| *out_type* *out_start* *out_end* *out_step*

C List of locations for output

| *link_name* *link_km*

| •

| •

| •

E

(end of file) --

The lengths of the lists (number of entries) are not explicitly limited. Only the amount of available memory at run time is the limiting factor.

Description of Entries:

Name	**Type**	**Description**
headline_i	textline	Optional headlines; headline_1 and 2 are shown on screen during simulation run and appear also in output files.
sim_start	time	Begin of the time period to be simulated; the user is free to interpret it as time-of-the-day or just as time value. In the latter case 00:00 may given.
sim_end	time	End of simulated period (or simulation horizon if 00:00 is

		given for *sim_start*).
sim_step	real	Time step T of simulation in seconds; for numerical stability reasons, T has to be smaller than the shortest time to travel through a segment in the simulated network. For more precise description see Appendix A.1.1.
sim_mode	integer	Mode of simulation; 0 = destination oriented, 1 = non-destination oriented.
contr_type	integer	Type of traffic control; 0 = no control (splitting or turning rates at nodes, as they are read from input file, are not touched), ≥ 1 = control measures are involved i.e. the routines INIT_CONTROL, CONTROL, END_CONTROL of the module mn_contr are called by the main program, ≥ 19 is reserved for special purposes.
init_type	integer	Type of determination of initial condition; 0 = according to steady state, 1 = according to initial conditions file *nwdname*.ico.
loc_name	name	Name of an input traffic data location as expected in traffic data input file *trdname*.msd.
link_name	name	Name of a link as specified in the network description file *nwdname*.nwd.
link_km	real	Link kilometre specifying a certain location on the link; for origin, destination, and store-and-forward links *link_km* can be omitted. This value is converted internally into the no. of the according segment. In the list of locations for output: If a negative value is specified for this variable, data for all segments are written to output.
inci_start	time	time of occurrence of incident
inci_end	time	time of clearance of incident
inci_sev	real	severity of incident; ranges from 0 to 1, 1 corresponding to a total blockage.
out_type	typespec	specifies amount and averaging of output; possible options:

		a, A: traffic variables of specified segments (in following list)
		b, B: as A but taking the mean over the output interval
		c, C: traffic variables of all segments of all links
		d, D: as C but taking the mean over the output interval
		upper case letters: reader friendly format
		lower case letters: compact format
out_start	time	begin of output window (in terms of simulated time)
out_end	time	end of output window
out_step	time	output interval

3.4.3.2 Optional Part of Simulation Control File for DTA Parameters

METANET includes a device for Dynamic Traffic Assignment (DTA), which calculates internally the splitting rates at user-chosen bifurcations of decision in the case of destination oriented simulation mode. The applied DTA methods and a test example may be found in Appendix A.4 and Section 4.2, respectively.

In order to use the DTA function of METANET, the user can optionally specify in the simulation control file a number of parameters. More precisely, if the activation of the DTA function is desired, the following part should be appended to the simulation control file:

-------------------- Optional part appended to *ctrname*.ctr ---------------------------

C OPTIONAL PART OF SIMULATION CONTROL FILE FOR DTA

C Parameters for DTA type choice

| *dta_type* *threshold-l-r*

C Parameters for DTA method choice

| *dta_method* *BETA_N* *K_p* *K_i* *beta_min* *beta_max* [*dta-interval*]

C List of bifurcation node-destination couples subject to DTA

| *node_name* *dest_name* *beta_n*

| •

| •

E

(end of file) --

dta_type	integer	type of DTA 0 means no DTA (splitting rates at bifurcations are read from SPL file), which is equivalent to omitting this optional part completely. 1 means DTA for **all** bifurcation-destination couples for which a route choice exists and the corresponding length ratio is less than *threshold_l_r* (see also below). 2 means DTA only for the bifurcation-destination couples specified below in the list of the optional part.
threshold_l_r	float	Threshold of length ratio is used only in the case of *dta_type* equal to 1 to suppress the treatment of bifurcation-destination couples with a too high ratio between the shortest and the travel times on other routes (see Appendix A.4.1). The travel times used here are calculated by assuming free speed conditions. The ratio is always taken by dividing the higher by the lower value. By specifying a very high threshold value (e.g. 1000), this feature is effectively switched off.
dta-interval	real	Time interval for adopting DTA feedback control laws in seconds, should be a multiple of *sim_step*
dta_method	integer	adopted DTA method (see Appendix A.4.3): 0 means bang-bang strategy 1 means P strategy 2 means PI strategy 3 means no strategy, but output of Route Data file
BETA_N	float	global nominal splitting rate (mandatory)

K_p	float	proportional parameter for P or PI controller, globally used if *dta_method* is unequal to 0
K_ i	float	integral parameter for PI controller, globally used if *dta_method* is equal to 2
beta_min	float	lower bound of splitting rate (see Appendix A.4), globally adopted; this value should be within [0,1] and *beta_min* ≤ *beta_max*.
beta_max	float	upper bound of splitting (details as for *beta_min*)
node_name	name	name of bifurcation node
dest_name	name	name of destination
beta_n	float	individual nominal splitting rate for the particular bifurcation-destination couple (optional)

If *dta_type* is 1:

- The splitting rates of all bifurcation-destination couples for which route choices exist are calculated by the DTA function of METANET.
- *BETA_N* is used as the nominal splitting rate for the P strategy (if selected) at each bifurcation-destination couple.

If *dta_type* is 2:

- For the bifurcation-destination couples specified in the list, the splitting rates are calculated by the DTA function. If an individual *beta_n* is given and the P strategy is selected, this individual *beta_n* is used as the nominal splitting rate.
- For the bifurcation-destination couples specified in the list without individual splitting rates, *BETA_N* is used as the nominal splitting rate if the P strategy is selected.
- For bifurcation-destination couples not specified in the list, the corresponding splitting rates:
  - are taken from the splitting rates input file, if it exists, and if the data are provided there (it is allowed that the splitting rates file does not provide the values for some or all bifurcation-destination couples)

- or are set to *BETA_N* otherwise.

All *BETA_N* and *beta_n* values, as given in the simulation control file, are interpreted in the sense that they specify the portion of traffic which leaves the bifurcation via the direction, i.e. the out-link (see Appendix A.4.1) with the shortest free-speed travel time. Therefore, the given *BETA_N* and *beta_n* values should typically lie closer to 1.0 than to 0.0 in order to account for the fact that the route which is shortest in free-speed travel time is typically preferred by the drivers. The nominal rates for the other out-links (i.e. the values $\beta_{n,\mathrm{j}}^{\mathrm{N,m}}$ as used in (A34), see Appendix A) are determined by distributing the left portion of traffic (i.e. 1 – beta_n) equally to the rest of the out-links.

3.4.4 Network Description File

The network description file *nwdname*.nwd is structured:

--------------------- *nwdname*.nwd ----------------------------

H *headline*

C Global network parameters:

| *tau kappa nue vmin romax delta phi*

C List of origin links:

| *orig_name lanes qinmax vfree [angle]*

| •

| •

| •

E

C List of network links:

C for normal and dummy links:

| *link_name lanes capacity vfree rocrit cap60 length nrof_segs*

C or for store-and-forward links:

M *link-name lanes capacity vfree travtime saf_length*

| •

| •

| •
E
C List of destination links:
| *dest_name lanes qbound vfree [angle]*
| •
| •
| •
E
C List of network nodes and their connection to links:
C one line for the node plus two lines for listing the in- and out-links
| *node_name [x_coord] [y_coord]*
| *in_link_1 [in_link_2 … in_link_i]*
| *out_link_1 [out_link_2 … out_link_m]*
| •
| •
| •
E
(end of file) ---

Entries in square brackets are only needed for graphical display routines. If the file is used only for simulation input, they can be omitted.

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline

global parameters used for the whole network (see Appendix A.1 for usage in link modelling equations):

tau	real	parameter τ in seconds
kappa	real	parameter κ in vehicles/km

nue	real	parameter ν (in km^2/h)
vmin	real	minimum speed v_{min} in km/h (see A.1.7)
romax	real	maximum density ρ_{max} in vehicles/km/lane used for density limitation
delta	real	parameter δ for consideration of merging effects
phi	real	parameter φ for consideration of weaving due to lane drops

Appropriate values for these global parameters can be found in Chapter 4 (test example).

link specific parameters:

lanes	integer	number of lanes
qinmax	real	maximum possible inflow per lane (veh/h) for origin links
qbound	real	Specifies the maximum outflow per lane for destination links. If a negative value is specified, no limitation of the outflow takes place. *qbound* is ignored if boundary input data for traffic density at the same destination are provided (see Appendix A.2.2).
capacity	real	capacity (maximum flow according to fundamental diagram) per lane in network link
vfree	real	free speed of link
rocrit	real	critical density in network link. Not to be specified for store-and-forward links.
cap60	real	flow value according to fundamental diagram at a density value of 60 vehicles/km/lane in network link. Not to be specified for store-and-forward links.
travtime	integer	constant travel time (in sec) for store-and forward links only; must be at least equal to the simulation time step T (*sim_step*).
saf_length	real	nominal length of the SaF link in km; is used for calculating the virtual density of a SaF link acting towards upstream.

For the normal and dummy network links, the parameters *capacity*, *vfree*, *rocrit* and *cap60* specify the shape of the fundamental diagram and the parameters of the according equation used for link modelling. The meaning of these parameters in the fundamental diagram is explained in Appendix A.1.2. Since three of the four above mentioned parameters are sufficient to specify the fundamental diagram, one of the parameters *vfree*, *rocrit* or *cap60* has to be left unspecified. For capacity always a valid value has to be given. A parameter is looked upon as not specified if it is negative, i.e. if it is marked by a minus sign. In order to get a valid fundamental diagram, the value for *vfree* has to be greater than *capacity*/*rocrit*.

length	real	total length of the link in km; for dummy links only, *length* = 0.
nrof_segs	integer	number of segments; METANET divides the link automatically into this number of segments each having equal length (*length/nrof_segs*). For the admissible range of segment lengths see Appendix A.1.1. For dummy links *nrof_segs* has to be set to zero.
orig_name	name	name of origin link
link_name	name	name of network link
dest_name	name	name of destination link
node_name	name	name of network node
in_link_i	name	name of link no. i which enters node (must be one of the origin or network links as specified in the above lists)
out_link_m	name	name of link no. m which leaves node (must be one of the destinations or network links as specified in the above lists)

The number of links entering a node (in-links) is limited to 8. The same holds for the maximum number of leaving links (out-links). The first link specified in the line (*in_link_1* or *out_link_1*) is looked upon as the main axis entering or leaving the node i.e. *out_link_1* is the straight continuation of *in_link_1*. This has significance for the modelling of merging phenomena and lane drop effects as described in Appendix A.1.3, A.1.4. The links building the main axis are denoted as *primary* and the links that are joining or branching as *secondary* in the following.

angle	real	Is used only for graphical output and specifies the direction of the arrow symbol used in network plots for origins and destinations.

		The angle is given in degrees and is defined as direction to the node for origins, and direction from the node for destinations.
x_coord	real	X co-ordinate of the node in network plot
y_coord	real	Y co-ordinate of the node in network plot

Since the size of the network plot is automatically adapted to available drawing area, the units used for *x_coord* and *y_coord* are arbitrary.

3.4.5 Initial Condition Files

There are two possible initial condition files:

nwdname.ini

The initial condition file *nwdname*.ini provides the values which are used to pre-set the traffic variables density, speed, and composition rates before the initial steady state for simulation is calculated. It is used if init_*type* is set to 0 or is omitted in *ctrname*.ctr. As already mentioned, the values specified in this file have no influence on the calculated initial state, but appropriate values will shorten the computation time required for initialisation. In order to avoid numerical errors, no zero values should be specified as initial densities. The file *nwdname*.ini is allowed to be empty and may even be omitted completely.

The initial condition file *nwdname*.ini is structured:

---------------------- *nwdname*.ini -----------------------------

H *headline*

C List of initial densities for all network and destination links:

| *link_name ro_begin ro_end*

| •

| •

| •

E

C Initial composition rates for each network link:

C One line for the specification of the used order of destinations plus two
C lines for the composition values at begin and end of link:
| *link_name dest_name_1 dest_name_2 dest_name_3* . . .
| *comp_1_beg comp_2_beg comp_3_beg* . . .
| *comp_1_end comp_2_end comp_3_end* . . .
| •
| •
| •
E
(end of file) --

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
link_name	name	name of a link as specified in the network description file (*nwdname*.nwd)
ro_begin	real	density at the beginning of link
ro_end	real	density at the end of link; can be omitted for destination links
dest_name_i	name	destination no. i reachable through the link
comp_i_beg	real	portion of traffic (composition rate) with destination no. i at the beginning of the link
comp_i_end	real	portion of traffic (composition rate) with destination no. i at the end of the link

Specification of *comp_i_beg* and *comp_i_end* is not required in case of non destination-oriented simulation.

The values specified for the beginning and the end of a link are assigned to its first and last segment respectively. For the other segments these values are interpolated.

nwdname.ico

This type of initial condition file is mandatory if *init_type* is set to 1 in *ctrname.ctr*. It allows for specification of density and optionally mean speed or flow for each segment of each link individually. The simulation starts directly with the state-variable values as read from that file (no preparing model loop for reaching steady state).

In the initial conditions file *nwdname*.ico, two lists are expected. In the first list all initial queue lengths at origins are expected. In the second list the initial conditions for all internal network links are expected.

The initial condition file *nwdname*.ico is structured:

--------------------- *nwdname*.ico ----------------------------

H *headline*

C List of initial queue lengths at origins:

| *orig_name queue_len*

| •

| •

| •

E

C List of initial conditions for all segments of all links, one line per link and

C per line as may value triples (density, speed, flow) as segments in link:

C for a normal motorway link:

| *link_name density mean_speed flow density mean_speed flow . . .*[2]

| •

| •

C for a Store-and-Forward link:

| *link_name flow queue_len*

[2] It is allowed that a new line begins after each triplet of values if the date line would become too long otherwise. As long as there is no "|" sign in the first column of a new line, it is regarded as continuation of the current data line.

| •
| •
| •
E
C optional for destinations in case of outflow limitation by q_bound :
| *link_name* *density*
E
(end of file) ---

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
orig_name	name	Name of an origin as specified in the network description file (*nwdname*.nwd)
link_name	name	Name of a link as specified in the network description file
queue_len	real	Queue length at origins or Store-and-Forward links in vehicles
density	real	Density in according segment in vehicles/km/lane (must be valid in any case), in case of destinations it is the boundary destination as used initially when limiting the outflow via *qbound* (see equ. A28).
mean_speed	real	Mean speed in according segment in km/h (may be marked as not defined)
flow	real	For motorway links: Flow in according segment in veh/h (may be marked as not defined) For Store-and-Forward links: Flow in veh/h to be assigned to the time-lag stretch of the link.

A value is regarded as not defined (invalid) if it is negative (e.g. -1). If both, *mean_speed* and *flow*, are invalid, *mean_speed* is calculated from *density* according to the fundamental diagram (and *flow* = *mean_speed* / (*density* • *lanes*)). If *mean_speed* is valid, it is directly used. If only flow is valid, *mean_speed* is calculated via: *mean_speed* = *flow* / (*density* • *lanes*).

A third list specifying boundary densities at destinations which would complete the initial conditions, as they exist in METANET, is not yet implemented. If there are destinations in the network for which a valid *qbound* parameter is specified, METANET would terminate during initialisation with an according error message.

3.4.6 Traffic Data Files

The traffic data files provide all input which is necessary to feed the simulation during a run. As already mentioned, traffic data consist of:

- *boundary data* (measured or hypothetical) which are split up in two input files:
  - The file *trdname*.msd containing the demands (inflows into the network) and, if available, other boundary conditions like speeds at origins and densities at destinations; this file may contain also data from internal sites of the network which are, however, not used by METANET but e.g. by METAGRAF for comparison purposes.
  - The file *trdname*.odm containing the *origin-destination information* (composition rates of demands, i.e. destination specific fractions of the demand normalized by the total demand).
- The file *trdname*.spl containing *splitting rates*, or, in the case of non destination oriented simulation, the file *trdname*.trn containing *turning rates.*

Linear interpolation is performed between the values at the given time instants by the program if the input time step is greater than the simulation time step (which is the typical case).

In every traffic data file a specification of the data following and the used time format has to be given (see 3.4.6.1).

The data themselves given for a number of (arbitrary) time instances are put in the form of consecutive entries in one or more lines. The beginning of each new time instance is marked by a '|' in the first column. All traffic data entries are interpreted as real numbers and have to be separated, as other data, by at least one blank or tab if they are on the same line. The format line consists of a string of indicating letters given in the same order as traffic data which they describe.

Any given data set provided in any ASCII format can be easily adapted to be readable for METANET by adding a data and time format description at the beginning of the file, and each data line must be marked by a '|' in the first column.

3.4.6.1 Traffic Data Format Description Lines

The format header of any traffic data file consists of the following elements:

- A format line (marked by an 'F' in the first column) to give optionally the time format and to explain the physical meaning and the scope of data provided from each *station* (measuring locations or boundary points),
- a conditionally necessary time format line (marked by a 'T' in the first column),
- a conditionally necessary line (marked by a 'O' in the first column) specifying the mean vehicle length as needed for converting occupancy values into traffic density values and
- name line(s) (marked by an 'N' in the first column of the first line) giving the correspondence between the order of *stations* in the traffic data file and the network locations (element names and sometimes km-values).

<u>The Format Line has the following structure:</u>

F *[[***T***]|[***T:***]]* *[***,** *[***n***]***(***[***i***]***L***[***, ...***])***[***, ...** *]]*[3]

[3] Square brackets in italics embrace different options. The vertical bar | stands for mutually exclusive.

where **n** and **i** are optional preceding integers (multipliers) and **L** stands for the following possible letters as used to explain the physical meaning and the order of the given data values (coming later in the file):

'Q' for flow value in vehicles/h
'D' for density in vehicles per km and lane
'V' for mean speed in km/h
'O' for occupancy in percent
'G' for composition rate (γ, $0 \leq \gamma \leq 1$)
'B' for splitting rate (β, $0 \leq \beta \leq 1$)
'U' for turning rate
'X' for entry which is to be skipped during reading

The brackets have to be used to indicate that a set of data values (typically of different type) belongs to the same location. The multiplier (**n**) can be placed immediately before the opening bracket in order to shorten the format in case of multiple measurement locations with the same type of data. For example the string "5(Q,V)" in the format line describes that data will follow (one line for every time instant) for five locations (*stations*) consisting of a flow and a speed value for each location. The type indicating letters 'G', 'B', 'U' and 'X' can be multiplied in the same way (by the multiplier **i**).

The comma is used as separator between type indicating letters as well as between stations and time format and first station.

The specification of the physical meaning of the data for each *station*, i.e. the second part of the format line, is only for Input Traffic Data files (see 3.4.6.2) mandatory. In case of the other traffic data files only one specific type of data is allowed (i.e. composition rate, splitting rate or turning rate) and the order of the data can be unambiguously deduced from the name line.

For the time format (first part of the line) there are three alternative options by specifying:

a) '**T**' ,
b) '**T:**' or

c) nothing.

Case a) means that the time instances to which the following data lines belong, are identified by a time step number (integer) right after each '|' (begin of new data line). In case of option b) a time stamp (type: time) specifying an absolute time value is expected right after each '|'. In case c) the data are expected to begin after each '|' without any step number or stamp. METANET counts in that case the data lines internally beginning with 0. In cases a) and c) a time format line (marked by a 'T' in the first column) is expected to follow the format line which contains start time and time step of the data.

Examples for the format line can be found in Appendix C for the test example presented in Chapter 4.

The structure of the name line(s) is explained in the following subchapters for each traffic data input file in particular.

3.4.6.2 Input Traffic Data

As already mentioned, this file may contain input data for simulation input as well as for comparison purposes. The description contained in the format header of the file allows METANET to pick the data which are required (demands) or optionally usable (inflow speeds and destination densities) for its input.

Traffic demands (inflow values) at the network origins are mandatory data. If inflow data for one of the origins are missing, an error message is issued and the program is terminated. As additional data, which are used by METANET for improvement of simulation accuracy, if found, the file may contain speed values at origins and density values at destinations. All other data contained in the input traffic data file are not considered by METANET.

The traffic data file *trdname*.msd is structured:

--------------------- *trdname*.msd ----------------------------

H *headline*

F *data_fmt*

C If the data contain occupancy values:

O *veh_len*

C If no complete time stamp (no T: format) is given with each data line:

T *start_time time_step*

C

N *loc_name_1 loc_name_2 loc_name_3* . . .

C Traffic data as specified above:

| •

| •

(end of file) ---

The order of the O- and the T-line can be exchanged.

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
data_fmt	(max. 256 characters)	specification of traffic data following; no data of type G, B or U are allowed.
veh_len	real	mean vehicle length (in meters); is needed to calculate densities from given occupancy values; can be omitted if no occupancies are contained in the provided data
start_time	time	time instant of the first provided data
time_step	time	time step of the provided data; if a time step no. is given ("T" in format line) with data, this value is multiplied with the current step no. to calculate the time instant for which the data are valid.

start_time and *time_step* can be omitted if a complete time stamp is given for every new time instant with the data.

loc_name_i	name	name of the location no. i to which the following belong; since in *trd_fmt* the number of provided values from each location is specified, it can be recognised by METANET which data belong to which location.

3.4.6.3 Origin-Destination Information

The file *trdname*.odm provides the composition of the traffic at the network origins with respect to the possible destinations. This input file is needed only if the destination-oriented simulation mode is chosen.

The origin-destination file is structured:

--------------------- *trdname*.odm ----------------------------

H *headline*

F *data_fmt*

C If no complete time stamp (no T: format) is given with each data line:

T *start_time time_step*

C

C Structure of O-D information:

N *orig_name_1* *dest_1_1 dest_1_2* . . .

orig_name_2 *dest_2_1* • . . .

• • • . . .

• • • . . .

• • • . . .

C Composition rates as specified above:

| •

| •

| •

(end of file) ---

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
data_fmt	(max. 256 characters)	specification of following origin-destination information; only data of type G are allowed. An origin with all composition rates to its reachable destinations is looked upon as one location (*station*).
start_time	time	as in *trdname*.msd file
time_step	time	as in *trdname*.msd file
orig_name_i	name	name of origin link no. i for which composition rates are given; all origins from which at least two destinations are reachable have to be listed. Origin names which are not known from *nwdname*.nwd are ignored by METANET (values are skipped).
dest_i_j	name	name of destination link no. j which is reachable from origin no. i; the sum of the composition rates from one origin to all possible destinations must always be equal to 100% (one). Non reachable destinations are skipped when reading values.

The 'N'-line(s) must be written in matrix form, i.e. for each origin a new line has to be begun (see example in Chapter 4 and Appendix C). The number of origins showing up in the name line(s) must be equal to the number of *stations* as specified by *data_fmt* or, if the second part of *data_fmt* is omitted, must be equal to the number of actual origins in the network.

3.4.6.4 Splitting Rates

The file *trdname*.spl contains all splitting rates which are needed as input to describe route choice behaviour of the drivers at the nodes of choice. A node of choice is characterised by the possibility to leave the node on more than one out-link for the same destination. Consequently a node of choice has at least two out-links.

The Splitting Rates file is needed if destination-oriented simulation is chosen (*sim_mode* = 0) and no control strategy or dynamic traffic assignment device (DTA) is used to calculate the splitting rates during simulation (*contr_type* = 0 and *dta_type* = 0 or 2).

The splitting rate file is structured:

---------------------- *trdname*.spl -----------------------------
H *headline*
F *data_fmt*
C If no complete time stamp (no T: format) is given with each data line:
T *start_time time_step*
C Structure of provided splitting rate data:
N *node_name_1* *link_1_1 link_1_2 [… link_1_m]*
dest_1_1 dest_1_2 dest_1_3 . . .
node_name_2 *link_2_1 link_2_2 [… link_2_m]*
dest_2_1 dest_2_2 dest_2_3 . . .
• • •
• • •
• • •
C Provided splitting rate values in the order as specified before:
| •
| •
| •
(end of file) ---

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
data_fmt	(max. 256 characters)	Specification of number of splitting rate values following; only data of type B are allowed. A node with all its splitting rates is looked upon as one location.
start_time	time	as for *trdname*.msd file
time_step	time	as for *trdname*.msd file
node_name_n	name	name of node n for which splitting rates are given; all nodes of choice have to be listed. Also *unpractical* but in principle possible routes have to be considered (but no loops). Nodes which are not known from *nwdname*.nwd are ignored by METANET. If some nodes or some reachable destination have been forgotten, METANET will terminate with an indication of the additional data required.
link_n_m	name	name of leaving link (out-link) m of node n. All out-links must be comprised, i.e. also the ones through which none of the destinations of choice are reachable. The specified order is arbitrary but determines the order of the data which are following (see below).
dest_n_j	name	name of destination j which is reachable from node n; all destinations which are reachable via at least two leaving links (i.e. a route choice exists) have to be listed.

The following order of the given splitting rates $\beta_{n\,j}^{\,m}$ for each node n is expected according to the N-line:

$$\beta_{n1}^{1} \ldots\ \beta_{n1}^{m} \ldots \beta_{n1}^{M} \quad \beta_{n2}^{1} \ldots\ \beta_{n2}^{m} \ldots \beta_{n2}^{M} \quad \ldots$$

where *M* denotes the total number of out-links at node *n*. The splitting rate $\beta_{n\,j}^{\,m}$, $0 \le \beta_{n\,j}^{\,m} \le 1$, is the portion of the traffic leaving node n with destination j which goes via out-link m. For out-links trough which j is not reachable, a splitting rate value of zero is expected. The sum of all splitting rates in one node for the same destination must be equal to one (i.e. $\beta_{n\,j}^{1} + \ldots\ \beta_{n\,j}^{m} + \ldots \beta_{n\,j}^{M} = 1$). This concept allows for error checking (100% checksum) in each data line. The values *beta_min* and *beta_max* introduced in Section 3.4.3.2 are only considered for user-specified (n,j)-couples when the DTA device is activated. Moreover, in this case, the splitting rates $\beta_{n\,j}^{\,m}$ from the splitting rate file are only used for non-specified (n,j)-couples. In any case, $\beta_{n\,j}^{\,m}$ provided by the user via the splitting rate file is not restricted by *beta_min* and *beta_max*.

The 'N'-line(s) must be written in the form:

- one line for the node name and for the names of all out-links plus
- a further line for the destinations subject to route choice at that node (see example in Chapter 4 and Appendix C).

The number of nodes of decision showing up in the name line(s) must be equal to the number of *stations* as specified by *data_fmt* or, if the second part of *data_fmt* is omitted, must be equal to the number of actual nodes of decision in the network.

3.4.6.5 Turning Rates

The file *trdname*.trn contains all turning rates which are needed as input. In contrast to splitting rates, turning rates represent the percentage of vehicles using one of the leaving links of a node without distinction of their final destination. Turning rates are used only in the case of non destination-oriented simulation.

The turning rate file is structured:

---------------------- *trdname*.trn -----------------------------

H *headline*

F *data_fmt*

T *start_time time_step*

C Structure of provided turning rate data:

N *node_name_1* *link_1_1 link_1_2 [… link_1_m]*

node_name_2 *link_2_1 link_2_2 [… link_2_m]*

• • •

• • •

• • •

C Provided turning rate values in the order as specified before:

| •

| •

| •

(end of file) ---

Description of Entries:

Name	**Type**	**Description**
headline	textline	Optional headline
data_fmt	(max. 256 characters)	Specification of number of turning rate values following; only data of type U are allowed. A node with its two turning rate values is looked upon as one location.

start_time	time	Time instant of the first given turning rates
time_step	time	Time step of the given turning rates; if a time step no. is given with data, this value is multiplied with step no. to calculate the time instant for which data are given.

start_time and *time_step* can be omitted if a time stamp is given for every new time instant with the data.

node_name_n	name	name of node no. n for which turning rates are given; all nodes with two out-links have to be listed. Nodes which are not known from *nwdname*.nwd are ignored.
link_n_m	name	name of leaving link (out-link) m of node n; All out-links have to be listed. Their order is arbitrary but determines the order of the data which are following (see below).

The following order of the given turning rates β_n^m [4] for each node n is expected according to the N-line:

$$\beta_{\mathrm{n}}^{1} \dots \ \beta_{\mathrm{n}}^{m} \dots \beta_{\mathrm{n}}^{M}$$

where M denotes the total number of out-links at node n. The turning rate β_{n}^{m}, $0 \le \beta_{\mathrm{n}}^{m} \le 1$, is the portion of the traffic leaving node n via out-link m. The sum of the turning rates for all out-links at one node must be always equal one.

The 'N'-line(s) must be written in the form:

- one line for each bifurcation node specifying the node name and the names of all out-links (see example in Chapter 4 and Appendix C).

[4] For the sake of simplicity the same letter β as for the splitting rate is used.

The number of bifurcation nodes showing up in the name line(s) must be equal to the number of *stations* as specified by *data_fmt* or, if the second part of *data_fmt* is omitted, must be equal to the number of actual bifurcation nodes in the network.

3.4.7 Control Measures and Incidents Input

If *contr_type* is set to 19 in the Simulation Control file, the files described in the following three subsections are expected.

3.4.7.1 Control Measures and Incidents File

All control measures or incidents to be modelled during the simulation horizon have to be given in that file. Arbitrary combinations are allowed. Input has to be given in terms of events (control measures or incident events). For each event there is one data line. An event has a time instant where it begins and a time instant where it ends plus further details depending on the type. All time instant specifications are interpreted in the same way as the *sim_start* and *sim_end* parameters in the Simulation Control file (typically as time of the day).

In the general case the given time instances may lie (partially) outside the current simulation time window, i.e. the event:

- may have begun before the start time of the simulation and/or
- may end after the end time of the simulation or
- may be completely outside the simulation window.

Only in the latter case the event is not considered at all, otherwise the part of the event time which is inside the simulation window is considered.

The control measures and incidents file is named ”ctrname.evt” (events) and is structured:

---------------------- ctrname.evt -----------------------------

C List of events (control measures and incidents)

C Line format for a Variable Direction Indication control measure:

| DI *start_time end_time decision_node infd_destination beta_vms_1 … beta_vms_m message*

| .

C Line format for a Queue Information control measure:

| QI *start_time end_time dec_node* [*w_indicated_1 … w_indicated_m message*]

| .

C Line format for a Lane Closure control measure:

| LC *start_time end_time begin_link end_link closed_lane1 closed_lane2 ...*

| .

C Line format for a Shoulder Lane Opening control measure:

| SO *start_time end_time begin_link end_link speed_value*

| .

C Line format for a Speed Limitation control measure:

| SL *start_time end_time begin_link end_link speed_value purpose*

| .

C Line format for a Ramp Metering control measure:

| RM *start_time end_time origin*

| .

C Line format for the operation of a Traffic Light

| TL *start_time end_time trf_link*

| .

C Line format for an Incident:

| IN *start_time end_time ev_link ev_km rem_cap closed_lane1 closed_lane2 ...*

| .

E end of events list

(end of file) ---

Control and incident events can be specified in arbitrary order. Concurrent (in terms of time <u>and</u> location) control measures of the same kind are, however, not allowed and will cause an according error message.

The above used parameters have the following meaning:

Name	**Type**	**Description**
start_time	time	start time of the control measure/incident event
end_time	time	end time of the event
decision_node	name	name of the node for which branching is influenced, corresponds to the notation *n* as used in the formulae given in Appendix A
infd_destination	name	name of the destination to which the variable direction indication is related, corresponds to the notation *j* as used in the formulae given in Appendix A
beta_vms_m	real	Corresponds to the variable $\beta_{n,j}^{VMS,m}$ as used in the formula (A13) given in Appendix A. The order and number of values must be the same as the order and number of out-links at node n.
message	text	message which is displayed in the labels illustrating the according control measures on the screen
w_indicated_m	real	Indicated queue length in km. Determines, if given, the variables $\Delta w_{indicated,n,j}^{m}$ as used in (A14) in Appendix A. The order and number of values must be the same as the order and number of out-links at node n. There is no distinction with respect to the destination *j*, it is assumed that the indicated queue lengths are valid for all relevant destinations *j* in the same magnitude (corresponds to reality if subsequent routes branching is downstream the queue generating location). If *w_indicated_1* … *w_indicated_m* is omitted in the input, the according values are calculated internally by the model. In the non-destination oriented simulation mode, the specification of these values is, however, mandatory (no calculation by model).
begin_link	name	name of link where the control measure begins
end_link	name	name of link where the control measure ends, if there are splitting nodes between *begin_link* and *end_link*, it is assumed that control is only active on the geometrically shortest path between the two links
*closed_lane*x	integer	no. of lane closed (counting from the middle of the road, from left to right: 1,2, ...)
speed_value	real	value of speed limitation indication
purpose	typespec	‘H’ for harmonising, ‘W’ for queue warning or ‘O’ for shoulder opening
origin	name	name of origin where ramp metering takes place
trf_link	name	name of link where a traffic light is located

event_link	name	name of link where incident occured
event_km	real	location of incident relative to begin of *event_link* in km
rem_cap	real	remaining estimated capacity at event location (in veh/h), not necessary if *rem_lanes* is given. A –1.0 marks the entry as undefined

3.4.7.2 Recurrent Queue Lengths File

In preparation of the METANET input files, the nominal splitting rates have to be determined under the assumption of normal recurrent conditions. As a by-product of the according calculation procedure also recurrent queue lengths can be obtained and made available for METANET. The tool METANET-DTA generates besides a Splitting Rates file a file containing Recurrent Queue Lengths.

The Recurrent Queue Lengths is only usable in the destination oriented mode and is similar to the Splitting Rates file in format:

---------------------- trdname.qul ----------------------------

H *headline*

F *data_fmt*

C If no complete time stamp (no T: format) is given with each data line:

T *start_time time_step*

C Structure of provided queue length data:

N *node_name_1* *link_1_1 link_1_2* … *link_1_m*

dest_1_1 dest_1_2 dest_1_3 . . .

node_name_2 *link_2_1 link_2_2* … *link_2_m*

dest_2_1 dest_2_2 dest_2_3 . . .

• • •

• • •

• • •

C Provided queue length values in the order as specified before:

| •

| •

| •

(end of file) --

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
data_fmt	(max. 256 characters)	specification of the information following in the file, only a type ‘L’ data identifier is allowed.
start_time	time	time instant of the first provided data
time_step	time	time step of the provided data; if a time step no. is given ("T" in format line) with data, this value is multiplied with the current step no. to calculate the time instant for which the data are valid.
node_name_n	name	name of node no. n for which queue lengths are given; all nodes of choice have to be listed. Also *unpractical* but in principle possible routes have to be considered (but no loops). Nodes which are not known from *nwdname*.nwd are ignored by METANET.
link_n_m	name	name of leaving link (out-link) m of node n. All out-links must be comprised, i.e. also the ones through which none of the destinations of choice are reachable. The specified order is arbitrary but determines the order of the data which are following (see below).
dest_n_j	name	name of destination no. j which is reachable from node no. n; all destinations which are reachable via at least two leaving links (i.e. a route choice exists) have to be listed.

The following order of the given recurrent queue length values l_{nj}^{m} is expected according to the N-line:

$$l_{n1}^{1} \ldots l_{n1}^{m} \ldots l_{n1}^{M} \quad l_{n2}^{1} \ldots l_{n2}^{m} \ldots l_{n2}^{M} \quad \ldots$$

where M denotes the total number of out-links at node n. The variable l_{nj}^{m} is the recurrent queue length on the route which leaves the node via link m.

By use of continuation lines, information may be arranged in matrix form for better legibility.

The legible file format allows for convenient re-editing or a completely manual creation of the input files. The format is well suited for the specification of trajectories of polygonal shape with a minimum of writing work. The user specifies values at arbitrary (non equidistant) time instances and a linear interpolation is performed between these points.

3.4.7.3 Control Measures Parameter File

The above used parameters, i.e. compliance rates, feedback parameters (for queue information modelling), fundamental diagram parameter sets (speed limitation, lane closures) etc. have to be given here.

METANET checks if all parameters for all possible control measures are given.

The control measures parameter file is named ”nwdname.cpa” and is structured:

--------------------- nwdname.cpa ----------------------------

C List of compliance rates for Direction Indication (compliances for all influenced have to be given, content ignored in case of non-destination oriented simulation):

| *dec_node dest epsilon*

| .

| .

E (end of compliance rates list)

C List of parameters for Queue Information modelling (parameters for all influenced nodes and destinations have to be given):

| *dec_node K_VMS_n epsilon_VMS_n v_jam*

| .

| .

E (end of feedback parameters list)

C parameter sets for speed limitations (list determines the known set):

| *speed_value purpose capacity vfree rocrit cap60*

| .

| .

E (end of speed limitations parameters list)

C List of symbolic speed gantries (not used by METANET)

| < content arbitrary , but this line and the following “E”-line must exist>

E (end of list of symbolic speed gantries)

C parameter sets for remaining lanes if lane closures are active (for each possible

C number of remaining lanes):

| *rem_lanes capacity vfree rocrit cap60*

| .

| .

E (end of remaining lanes parameters list)

C List of symbolic lane closure gantries (not used by METANET)

| < content arbitrary , but this line and the following “E”-line must exist>

E (end of list of symbolic lane closure gantries)

C specification of routes (not used by METANET)

| < content arbitrary , but this line and the following “E”-line must exist>

E (end of routes list)

C ramp metering parameters list:

| *origin K_AL ro_ref T_A w_max r_min r_max ro_min x_offs y_offs hor_align vert_align text_height*

| .

E (end of ramp metering parameters list)

C traffic light parameters list:

| *trf_link C_std Cap_trf_on Cap_sp_low V_low x_offs y_offs hor_align vert_align symbol_height meas_1 meas_2 ...* ~

| .

E (end of traffic light parameters list)

(end of file) ---

Description of Entries:

Name	**Type**	**Description**
dec_node	name	name of the node for which branching is influenced, corresponds to the notation *n* as used in the formulae of Appendix A

specifically for modelling impact of direction indication signs (see formula (A13)):

dest	name	name of the destination to which the variable direction indication is related, corresponds to the notation *j* as used in Appendix A

epsilon	real	the parameter $\varepsilon_{n,j}$

specifically for modelling impact of queue information signs (see formula (A14)):

K_VMS_n	real	the parameter $K_{VMS,n}$
epsilon_VMS_n	real	the parameter $\varepsilon_{VMS,n}$
v_jam	real	the parameter v_{jam}

specifically for other control measures:

speed_value	real	nominal value of speed limitation
purpose	typespec	'H' for harmonising, 'W' for queue warning or 'O' for shoulder opening (as described in section for *Control Measures and Incidents File*)
rem_lanes	integer	number of remaining lanes during lane closures
capacity vfree rocrit cap60	real	parameters of the fundamental diagram if the influenced stretch. The usage is as in the file nwdname.nwd. If –1.0 values are specified, the original parameters, as given in nwdname.nwd are used.

for ramp metering (control law specified in Appendix A.1.5):

origin	name	name of the origin link (i.e. the on-ramp) for which metering is applied
K_AL	real	the parameter K_{AL} for ramp metering
ro_ref	real	the set point value $\hat{\rho}$ in veh/km/lane for ramp metering
T_A	integer	the control interval of metering in seconds
w_max	real	the queue length threshold w_{max} in vehicles
r_min	real	the minimum metering rate in vehicles/h
r_max	real	the maximum metering rate in vehicles/h
ro_min	real	the density threshold ρ_{min} (in veh/km/lane) below which the metering is suspended

for traffic light modelling (see description in Appendix A.1.5):

trf_link	name	name of the link where the traffic light is located, it is checked against being an origin or a Store-and-Forward link
C_std	real	the capacity (in veh/h) at which the traffic light is operated if the corresponding traffic lights are not at service (switched off)
Cap_trf_on	real	the capacity (in veh/h) at which the traffic light is operated if the corresponding traffic lights are at service and none of the measurement locations has a speed below V_low
Cap_sp_low	real	the capacity (in veh/h) at which the traffic light is operated if one of the specified measurement locations detect a speed below *V_low* and the corresponding traffic lights are at service
V_low	real	the speed threshold as mentioned above

meas_*n*	name	name of a link where a measurement is located, the maximally admissible number of measurement locations is 10, only regular motorway links (no origins, no destinations, no dummy links and no SaF-links) are allowed, the measurement is assumed to be in the first segment
~	-	delimiter for termination of the sequence of measurement locations

for labelling (ignored by METANET but dummy values have to be given):

label_link/ label_node	name	link or node relative to which the according label or symbol is placed on the screen
x_offs y_offs	real	offset of label/symbol in cm relative to *label_link/node* in x- and in y-direction
hor_align vert_align	typespec	a character specifying the alignment of the label/symbol, the following characters are allowed: for *hor_align*: ‘l’ for left aligned ‘c’ for centred ‘r’ for right aligned for *vert_align*: ‘b’ for bottom aligned ‘c’ for centred ‘t’ for top aligned
text_height symbol_height	real	height of text in the label or height of symbol (with no text)

3.5 Program Output

3.5.1 Check File

While reading the network data (*nwdname*.nwd) and the initial densities and compositions (*nwdname*.ini), a check file *nwdname*.chk is created. Besides the listing of the directly read network data and interpolated initial values, the file contains also the data which are derived automatically by the initialisation routines from the primary input data. These are:

– *constqb* which is an adaptation parameter used internally for limiting the outflow of destinations to *qbound* (see Appendix A.2.2 for details) for all links:

- the number of lanes of the link(s) following (*L.NXT* [5]); this information is used by the program in connection with a lane-drop term (see also Appendix A.1.4).
- the value of the exponent in the fundamental equation (*AEXP*) which is calculated from the link parameters *capacity*, *vfree*, *rocrit*, *cap60* (see also Appendix A.1.2)

if links are joining at a node:

- name of on-ramps which join at the node where the considered primary link leaves (*ONRAMPLINK*) and the number of lanes dedicated to the on-ramp links (i.e. secondary in-links) (*DEDIC.LANES*; see Appendix A.1.3 how this is determined); this information is used by the program in connection with the merging phenomena (see also Appendix A.1.3).
- the reachable destinations of a link (*DESTINATIONS*)

This gives the user the opportunity to check the proper interpretation of the input data by the program.

3.5.2 Simulation Data

The simulation results, i.e. the traffic variables (flow, density, mean speed, composition rates, plus in case of activated DTA option: instantaneous and experienced travel times) from inside the network, are written to the output files (*smdname*.smd and *smdname*.rtd). Data from selected locations or from all segments of the network are written according to the user specifications from the Simulation Control file (see 3.4.3). The file has the same principal structure as a Traffic Data input file (see 3.4.6). There is also a format line (F) specifying the type and format of data following and a list of the locations to which these data are related (N-line). In order to obtain different identifiers for the different segments of a link, the link name is combined with a kilometre specification which is delimited from the name by a "@" character (*link_name@km*).

[5] Expressions in parenthesis reflect the titles as they appear in the check file.

According to the chosen user option, the file is written in a reader-friendly or compact format (just for processing by other programs like METAGRAF). The selection is done via an according output type specification (see 3.4.3). The reader-friendly format comprises a time stamp, the link name, and the link kilometre in the first columns of each line. The compact format omits the explicit writing of these data since link name and link kilometre are already given in the header information of the file and can be uniquely assigned by tracking the order of the data. A time stamp has to be given just once a new output time step begins.

The essential information is the traffic data which follow in the columns of the output lines. In particular, the following variables are written:

normal motorway link, 0th segment	0	upstream speed	flow
normal motorway link, segm. 1...n	density	speed	flow
normal motorway link, segm. n+1	downst. density	0	0
dummy link	downst. density	upstream speed	flow
store-and-forward link begin	queue length	upstream speed	inflow
store-and-forward link end	downst. density	0	outflow
origin link begin	queue length	boundary speed	demand
origin link end	downst. density	0	outflow
destination link	boundary dens.	upstream speed	outflow

In the reader-friendly output format also the composition rates are written in the subsequent columns.

Moreover the output data file contains additional information identifying the input data set used, the output time interval, the final values of the above mentioned performance criteria (travel time, waiting time, distance travelled, total disbenefit, and amount of fuel consumed), and vehicle balances for each destination.

3.5.3 Route Data Output File

In case of activated dynamic traffic assignment (DTA), selected via *dta_type* as described in 3.4.3.2, a Route Data file is generated. The description of its contents and format is given here for the sake of completeness. In practice the user does not have to care about details of contents and format of this file (e.g. syntax of the file's header information etc.) since it can be regarded as a data file which is normally visualised just by use of METAGRAF.

3.5.3.1 Content

A number of route related variables are interesting for the user. There may be the wish to have a look on:

- travel time differences between routes,
- absolute values of travel times on particular routes,
- splitting rates at the bifurcation nodes,
- absolute and relative disbenefit values on particular routes or route pairs,
- partial (distinguished by destinations) inflows to the bifurcation nodes,
- flows on the out-links of bifurcation nodes.

In order to avoid the recording of redundant information, just those data are written into the Route Data file which allow for derivation (by simple mathematics) of all above mentioned variables. In particular, for each (n,j)-couple the following data are recorded for both out-links of the bifurcation node *n*:

a) the partial outflow (substream destined to *j*) (in veh/h),
b) reactive travel time on the leaving routes from *n* to *j* (in minutes),
c) predictive travel time on the leaving routes from *n* to *j* (in minutes).

For visualisation, the finally interesting variables (see further above) are derived from this primary information within METAGRAF. The variables to be displayed may be selected by the user according to the specifications of Appendix B.

Note that the recording takes place only for those (n,j)-couples which have been selected by the user to be subject to DTA.

3.5.3.2 Structure

The Route Data output file has a structure and contains a flexible header information similar to the Splitting Rates file. It is suited for being read and visualised by METAGRAF. Its structure is:

```
---------------------- name.rtd ----------------------------
H    headline
F    data_fmt
C If no complete time stamp (no T: format) is given with each data line:
T    start_time time_step
C This entry specifies the order of the data following:
N    node_name_1          link_1_1 link_1_2 [ …    link_1_m]
                       dest_1_1 dest_1_2 dest_1_3   .  .  .
     node_name_2          link_2_1 link_2_2  [ …    link_2_m]
                       dest_2_1 dest_2_2 dest_2_3    .  .  .
            •                 •          •
            •                 •          •
            •                 •          •
C Provided values in number and order as specified before:
|   •
|   •
|   •
(end of file) -------------------------------------------------
```

Description of Entries:

Name	**Type**	**Description**
headline	textline	optional headline
data_fmt	(max. 256 characters)	specification of number of different values following; data of the following types are

		covered: 'F' for partial flows in the out-links 'R' for reactive travel time 'P' for predictive travel time.
start_time	time	time instant of the first written data
time_step	time	time step of written data; if a time step no. is given ("T" in format line) with data, this value is multiplied with the current step no. to calculate the time instant for which the data are valid.
node_name_n	name	name of node n for which data are written..
link_n_m	name	name of leaving link m of node n; all leaving links have to be listed in the same order as also the data are written.
dest_n_j	name	name of destination j which is reachable from node n and for which data are written.

3.6 Application of User-Programmed Traffic Control

A special program module called MN_CONTR.C is reserved for user-programmed traffic responsive control strategies which are invoked if a value greater than zero, but unequal 19 (see Incidents and Control Measures Modelling), is specified for *contr_type* in the simulation control file. At each simulation time step this module may use any available traffic variable in order to calculate the control actions "in real time". Since traffic variables are global, the control strategy can use any simulated traffic variable as "real-time measurement". In the case of traffic control via route recommendation (e.g. by variable message signs), the splitting rates are the control variables which are calculated by the control strategy. Figure 4 shows the basic scheme.

3.6.1 Globally Defined Routines for Control Purposes

The module MN_CONTR (source code file “mn_contr.c”) contains some user-specific routines. There are four global PROCEDURES in MN_CONTR which are subject to modifications and extensions by the user (existing routines can be used as template):

INIT_CONTROL

All dynamic memory and, as far as necessary, all variables for control should be allocated and initialised here. This may include the reading of controller parameters from specific configuration files. If control uses input files which provide e.g. time trajectories of variables which influence control and which are read by control during the simulation run, these files should be opened here.

INIT_CONTROL is called by the main program also during the initialisation phase.

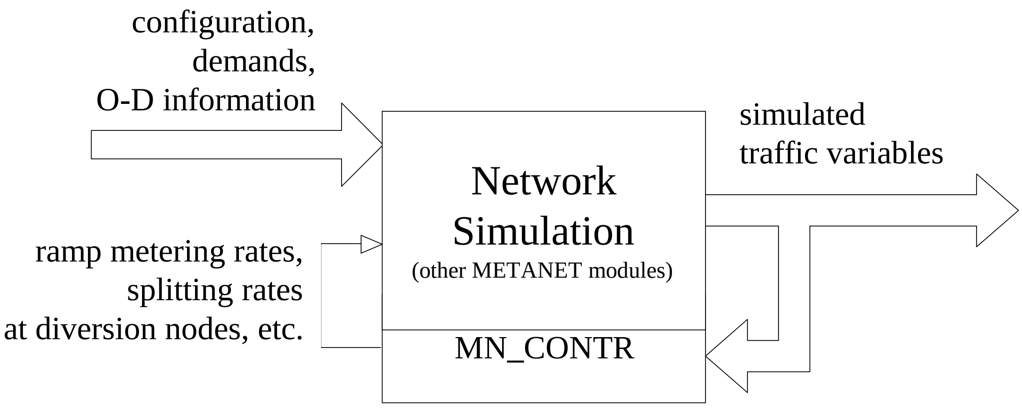

Figure 4: **Linkage of user-programmed Control.**

CONTROL

This routine contains the control strategy implementation itself.

CONTROL is called by the main program every simulation time step of the simulation loop and also every time step of the initialisation loop (calculation of initial steady state).

END_CONTROL

Criteria taken over the whole simulation horizon may be finally calculated. Last write operations e.g. for writing total criteria may be performed and files may be closed.

This routine is called at the end of simulation.

It is important to note that by the above-mentioned routines and their user-defined contents, the user has any power over the global program variables (see below). There is no encapsulation or specific protection. It is in the responsibility of the user to be careful with his statements that may overwrite global METANET variables. In order to guarantee a smooth simulation run with valid results, the restrictions as listed at the end of Section 3.6.3 should be obeyed.

3.6.2 General Principles of Access to the Variables

This and the following three sections provide the user with information about the access to the most important variables used in METANET.

All program modules may be subject to future modifications, extensions and refinements by the developers. However, the meaning and the use of the global variables, as described in the following, will be left unchanged as far as possible.

In order to obtain an optimal usage of the available memory, dynamic allocation is used for the larger data structures of the program. The usage of these data structures in the frame of the program does, however, not differ from the access to static structures.

The program works with globally defined variables for all data that are of general interest. The complete specification of the global variables can be found in the source code file *metanet.h*.

The variable names, statements and expressions as found or to be used in the program code are written in typewriter style (Courier font) in order to distinguish them form normal text.

3.6.2.1 The Most Important Global Variables

The most important global variables are:

- Time step index of simulation `k_sim`, maximum number of time steps `kmax`.
- The number of network nodes `nrofnodes`, number of links `nroflinks`, number of origins `nroforigs`, number of destinations `nrofdests`, number of Store-and-Forward links `nrofsaflinks`, and number of modelled queues in the network (at origins or Store-and-Forward links) `nrofqueues` (note that `nroflinks` comprises also the origins, Store-and-Forward links, and destinations).
- The global model parameters *t* (time step T), `tau` (τ), `kappa` (κ), `nue` (ν), `vmin` (v_{min}), `romax` (ρ_{max}), `delta` (δ), `fi` (φ) (see model equations in Appendix A).
- The vectors holding the network description (see *metanet.h* for the information stored in the vector elements):
  - vector of the information structure for node elements `node[`*nx*`]`,
  - for link elements `link[`*lx*`]`,
  - for additional information specific to origin links `origin[`*ox*`]`,
  - specific destination information `dest[`*dx*`]`.
- The arrays containing the dynamic current traffic variables for all links:
  - traffic densities `ro[`*lx*`][`*s*`]`,
  - mean speeds `v[`*lx*`][`*s*`]`,
  - volumes `q[`*lx*`][`*s*`]`,
  - partial densities `ro_partial[`*lx*`][`*s*`][`*dl_ix*`]` (used only in destination oriented simulation mode).
- The arrays containing dynamic queue related variables:
  - the current length of the modelled queues `qu[`*qu_ix*`]`,
  - the inflow into the queues `demand[`*qu_ix*`]`.
- The arrays containing the variables influencing the traffic flow (see Section 3.6.3):
  - splitting rates `beta[`*nx*`][`*dx*`][`*m*`]` (used in destination oriented simulation mode),
  - turning rates `turn[`*nx*`][`*m*`]` (used in non-destination oriented simulation mode),
  - the controlled outflow rate of the modelled queues `rate[`*qu_ix*`]` or `rate_q[`*qu_ix*`]`.

A number of different indices are used:

nx	for referencing a certain node (see 3.6.2.2),
lx	for referencing a certain link (see 3.6.2.2),
ox	for referencing a certain origin (see 3.6.2.2),
dx	for referencing a certain destination (global index, see 3.6.2.2 and 3.6.2.4),
m	for referencing a certain out-link *m* (running from 0 to M-1)
dl_ix	for referencing a certain destination in the link-specific set of reachable destinations (link-specific index, see 3.6.2.4),
s	for referencing a certain segment of a link (see 3.6.2.3),
qu_ix	for referencing a certain queue (see 3.6.2.5)

3.6.2.2 The Network Element Indices

The above listed multidimensional arrays (as `node[`*nx*`]`, `link[`*lx*`]`, `origin[`*ox*`]`, `destination[`*dx*`]`, `ro[`*lx*`][`*s*`]`, `ro_partial[`*lx*`][`*s*`][`*dl_ix*`]` etc.) have as first dimension the index of the particular network element. The indexing inside the mentioned arrays is a program-internal issue. Although the order of the elements is normally as coming from the network input file, this is not always guaranteed. Therefore user access has to be performed via index-calculating routines by use of the element names which represent the unique key for access. The following utility routines for determining the indices are available:

- `NODE_INDEX(`*node_name*`)`; returns the node index as to be used to access the elements in `node`, `beta`, and `turn`.
- `LINK_INDEX(`*link_name*`)`; returns the link index as to be used to access the elements in link, `ro`, `v`, `q`, and `ro_partial`; this includes also origins and destinations for their general link properties.
- `DEST_INDEX(`*destination_name*`)`; returns the destination index as to be used to access the elements in the destination-specific array `dest` and for use in further traffic variable arrays (see below).
- `ORIGIN_INDEX(`*origin_name*`)`; returns the origin index as to be used to access the elements in the origin-specific array `origin`.

The input argument of these routines is a string (in form of a variable as shown above or as constant character string) containing the name of the element. The statement <`LINK_INDEX(“L2”)`> returns e.g. the index for link L2 (name as used in the network description file). For example the number of lanes of that particular link can be accessed by: <`link[LINK_INDEX(“L2”)].l_lamda`>. If the specified network element is not known, the index routines return –1.

3.6.2.3 The Link Segment Index

The segment index s is just the segment’s number. The regular segments of a normal motorway link range from *1 ... n*. The traffic variable arrays `ro`, `v`, `q`, and `ro_partial` store, however, also some variables in the virtual segments *0* and *n+1*. The following tables give an overview. Note that except for a normal motorway link, the value of *n* is zero

Meaning of segment index in the array of densities `ro[`*lx*`][`*s*`]:`

value of s:	0	1 ... n (n ≠ 0)	n+1
normal motorway link	*undefined*	density of segment *s*	density acting from downstream
dummy link	*undefined*	*not existing*[6]	density acting from downstream
store-and-forward link	*undefined*	*not existing*	*undefined*
origin link	*undefined*	*not existing*	*undefined*
destination link	*undefined*	*not existing*	boundary density

Meaning of segment index in the array of densities `ro_partial[`*lx*`][`*s*`][`*dl_ix*`]` (only in destination oriented mode):

value of s:	0	1 ... n (n ≠ 0)	n+1
normal motorway link	*undefined*	density (in veh/km) of traffic portion bound to *dl_ix* in	*not existing*

[6] Means the according array element is not existing (allocated).

		segment *s*	
dummy link	*undefined*	*not existing*	*not existing*
store-and-forward link	partial queue length (in veh) of traffic portion bound to *dl_ix* in queue of link *lx*	*not existing*	*not existing*
origin link	*undefined*	*not existing*	*not existing*
destination link	*undefined*	*not existing*	*not existing*

Meaning of segment index in the array of mean speeds `v[`*lx*`][`*s*`]`:

value of s:	0	1 ... n (n ≠ 0)	n+1
normal motorway link	speed convected from upstream	mean speed of segment *s*	*not existing*
dummy link	speed convected from upstream	*not existing*	*not existing*
store-and-forward link	speed convected from upstream	*not existing*	*not existing*
origin link	boundary speed	*not existing*	*not existing*
destination link	speed convected from upstream	*not existing*	*not existing*

Meaning of segment index in the array of flows `q[`*lx*`][`*s*`]`:

value of s:	0	1 ... n (n ≠ 0)	n+1
normal motorway link	flow coming from upstream	flow in segment *s*	*undefined*
dummy link	flow coming from upstream	*not existing*	*undefined*
store-and-forward link	flow coming from upstream	*not existing*	outflow from link, i.e. from queue
origin link	demand	*not existing*	outflow from link, i.e. from queue
destination link	flow coming from upstream	*not existing*	*undefined*

3.6.2.4 The Global and the Link Specific Destination Index

The array `ro_partial[`*lx*`][`*s*`][`*dl_ix*`]` has a link-specific destination index. Since for the partial densities of a specific link only the destinations reachable by the link have to be considered, the values are stored in packed form that needs a specific indexing.

The number of reachable destinations via the link are given by <`link[`*lx*`].l_nr_dests`>, and the global indices of these destinations are given by:

<*dx* = `link[`*lx*`].l_dests [`*i*`]`>,
where *i* `= 0,`… `link[`*lx*`].l_nr_dests-1`.

The partial density w.r.t a destination “D1” in segment *s* of link *lx* is for example addressed by a sequence like the following:

```
/* search the local index of D1 */
ix = 0;
while (link[lx].l_dests[ix] != DEST_INDEX(“D1”)) ix++;
/* address ro_partial array */
.. = ro_partial[lx][s][ix];
```

This simple sequence presumes that D1 is certainly reachable through link *lx*.

3.6.2.5 The Queue Index

The vectors `qu`, `demand` and also `rate/rate_q` contain dynamic variables of the modelled queues. Only in specific kinds of links, namely origin and Store-and-Forward links, which are typically in small number in the network, queues are modelled. The mentioned vectors store therefore the queue-related variable not by link index (too sparse vector) but in packed form. The element `link[`*lx*`].l_qu_ix` in the link information structure points to the appropriate location in these queue-related vectors. In order to access e.g. the current length of the queue in link L2 (assuming this is an origin or a Store-and-Forward link) the user must write:
<`qu[link[LINK_INDEX(“L2”)].l_qu_ix]`>.

3.6.3 Control Input to the Process

The programmer of the routines in MN_CONTR is able to influence the simulated process of traffic flow by the following specific control variables:

`beta` splitting rates at bifurcation nodes with respect to destinations (only used in destination-oriented simulation mode).

Access example: `beta[`*nx*`][`*dx*`][`*m*`]` addresses the splitting rate in the node with index *nx* with respect to the destination with index *dx* (global index) valid for out-link m. for . The value for *nx* may be obtained by use of the routine `NODE_INDEX( )` and *dx* may be obtained by use of `DEST_INDEX( )`. *m* is an order number for the out-links (primary out-link means m = 0). If there is no route choice with respect to *dx*, the according `beta[`*nx*`][`*dx*`][`*m*`]` values are not defined and should not be used (value nowhere used).

`rate`, `rate_q` metering rate at origins and Store-and-Forward links (rate: old definition, rate_q: new defintion).

Access example: `rate[link[`*lx*`].l_qu_ix]` addresses the metering rate of the link with index *lx*. *lx* is obtained for origins by:

lx `= origin[`*ox*`].o_lx`, whereby ox may be obtained by use of ORIGIN_INDEX( ).

For Store-and-Forward links *lx* may be obtained directly by use of the routine LINK_INDEX( ).

`rate` is set to 1.0 and `rate_q` to max. capcacity for all origins at the initialisation phase of the simulation. As long as nothing is done on that array of variables by a user-specific algorithm in MN_CONTR, all elements of rate or rate_q remain neutral throughout the simulation (i.e. no ramp metering).

The listed control variables should be the only ones which are overwritten by control routines. Moreover:

- the user has to take care that the indices `nx`, `dx`, and `lx` are valid ones, more precisely:
  - `nx` has to be in the range of `0...nrofnodes-1`,
  - `dx` in the range of `0...nrofdests-1`, and
  - lx in the range of `0... nroflinks-1.`
  - If the mentioned indexing routines `NODE_INDEX( )`, `DEST_INDEX( )` etc. are used, it must be guaranteed that the specified network elements are existing

or the return of an index value of `-1` (element not existing) must be treated by an according error procedure.

- the written `beta` and `rate` values should be in the range of [0,1].

3.6.4. Available Control Software

Within the MN_CONTR module of the current METANET version, the user can find pre-programmed the ramp metering control strategy ALINEA. The routines implementing ALINEA may be used as they stand, or modified, or simply as a template. Appendix E provides all the relevant details.

4 TEST EXAMPLES

4.1 Basic Test Example

In order to demonstrate the use of METANET, a test example is presented. The complete input files for this example are given in Appendix C and some results are shown in this chapter. All graphical results of this chapter are produced by METAGRAF. The given input files can also be used as a template for writing the own input files. Moreover typical values of the modelling parameters (especially global network parameters) can be found. If no experience exists concerning these parameters, the values specified in the example are recommended as a first approach.

The simulated network is located in the south of Paris. It consists of two parallel motorway axes with several on- and off-ramps and two possibilities of interchange between the motorways. Only the northbound direction (towards Paris) is considered.

Figure 5 shows a sketch of this network consisting of 21 links (subdivided in 45 segments in total) and 19 nodes with a total length of about 20 km. There are five origins (U1 ... U5), U1 and U2 being the points where the two parallel motorways coming from the south enter the network. Traffic leaves the network through five destinations (Z1 ... Z5), Z1 and Z2 being the two main axes ends towards the Boulevard Périphérique of Paris. The network is described in the file A6ab.NWD (Appendix C).

This network is equipped with eight detector stations measuring flow and occupancy. The stations are located at all important origins and destinations but also inside the modelled part. The test example uses data collected during the morning hours of Tuesday the 10th of January 1989 (file: TUE10.msd). The traffic data from the network boundaries (M1, M2, M7 and M8) which are among these data are used by METANET as input. Composition rates at the origins (file: TUE10.ODM) and splitting rates at the bifurcation nodes 2 and 9 (file: TUE10.SPL) are necessary as additional input for simulation. These input values were obtained by application of appropriate estimation algorithms.

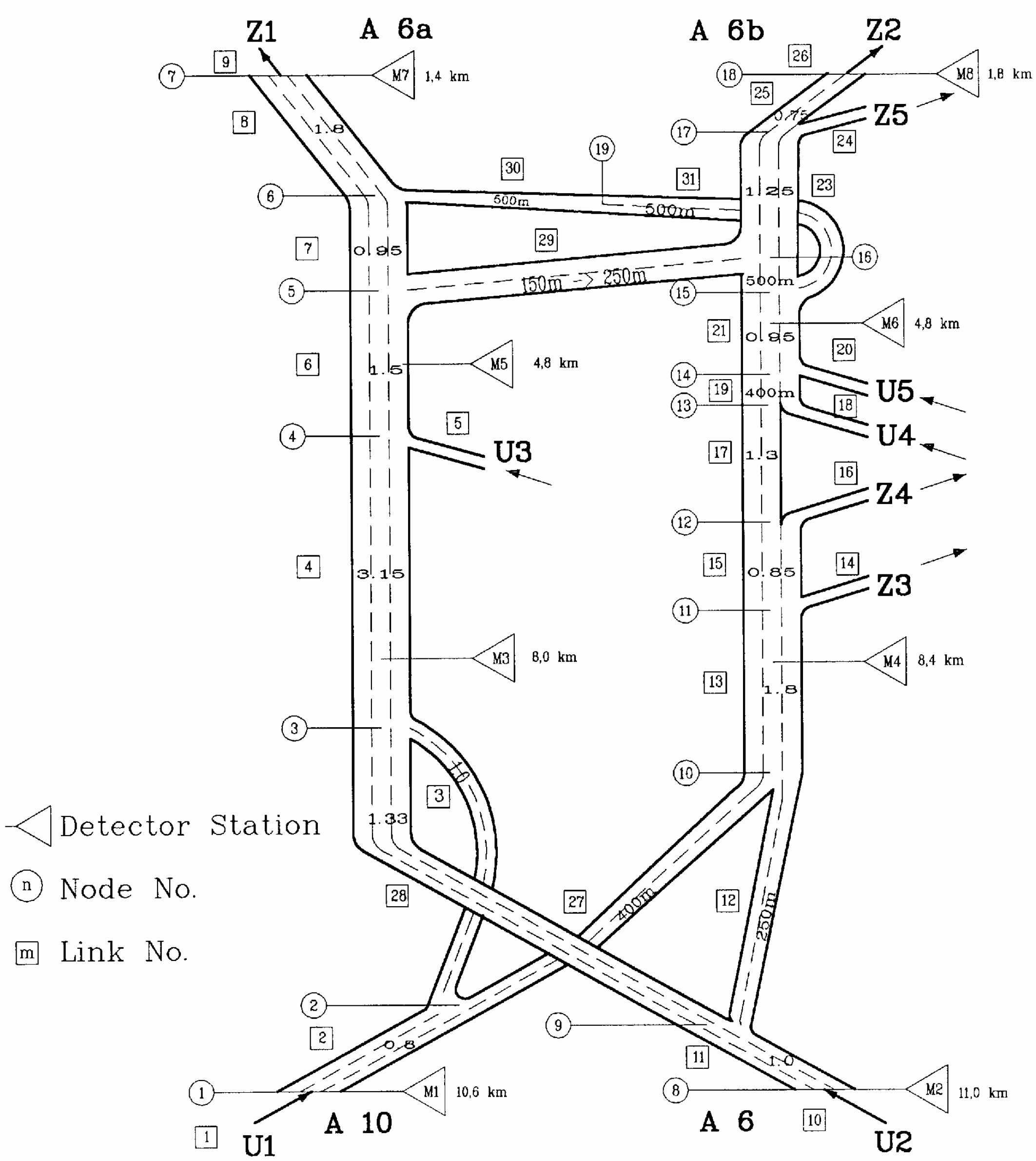

Figure 5: **Sketch of example network.**

Figure 6 and Figure 7 are overviews of the simulated situation (drawn by METAGRAF) in the network at two subsequent time instants (12 minutes of output interval) around half past eight in the morning. Dark portions indicate congested stretches. The development of congestion can be seen on these pictures. Congestion is mainly due to spillback from Z1 (over node 19) and grows upstream especially on the right motorway axis.

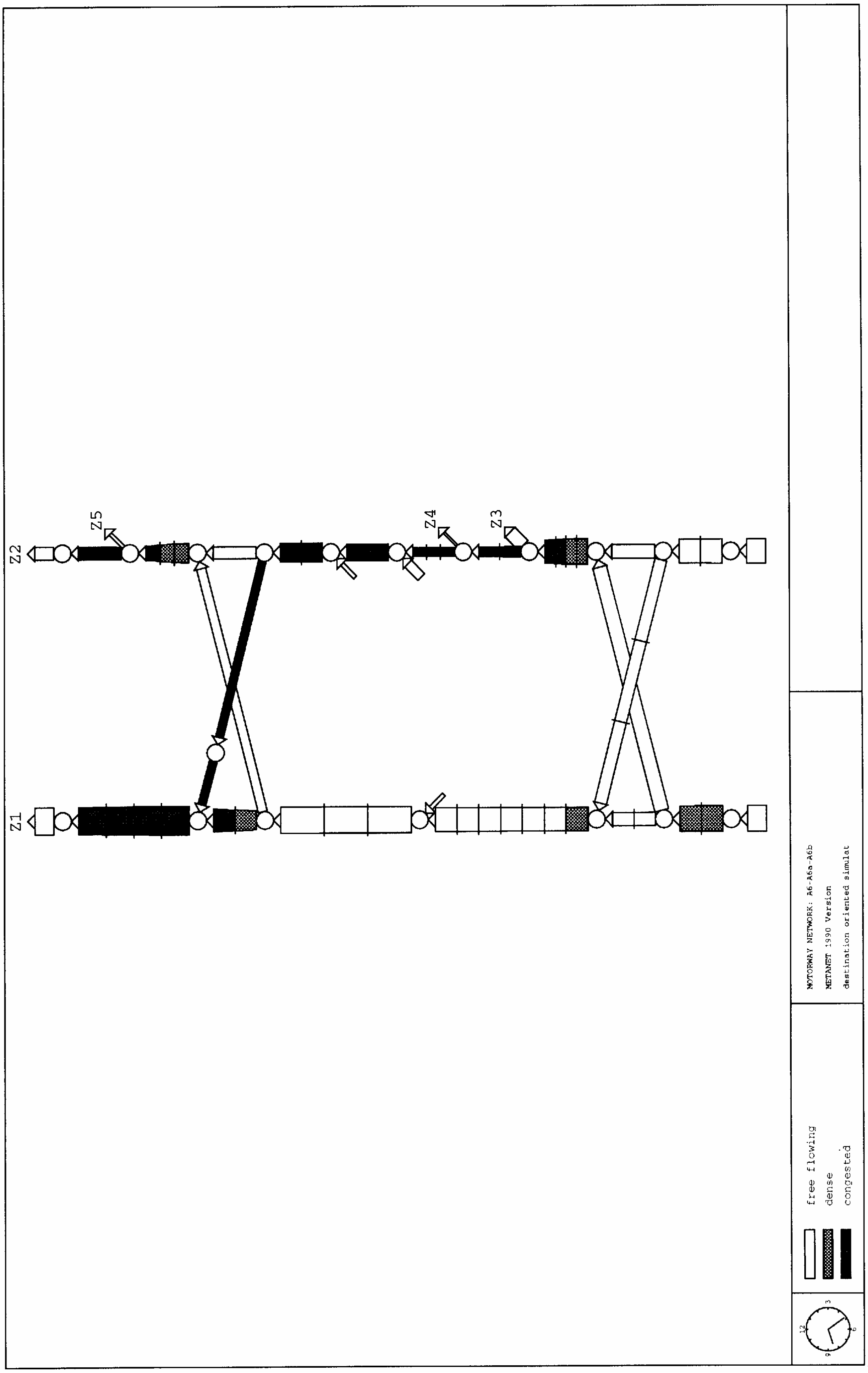

Figure 6: **Overview of simulated situation at 8:24a.m.**

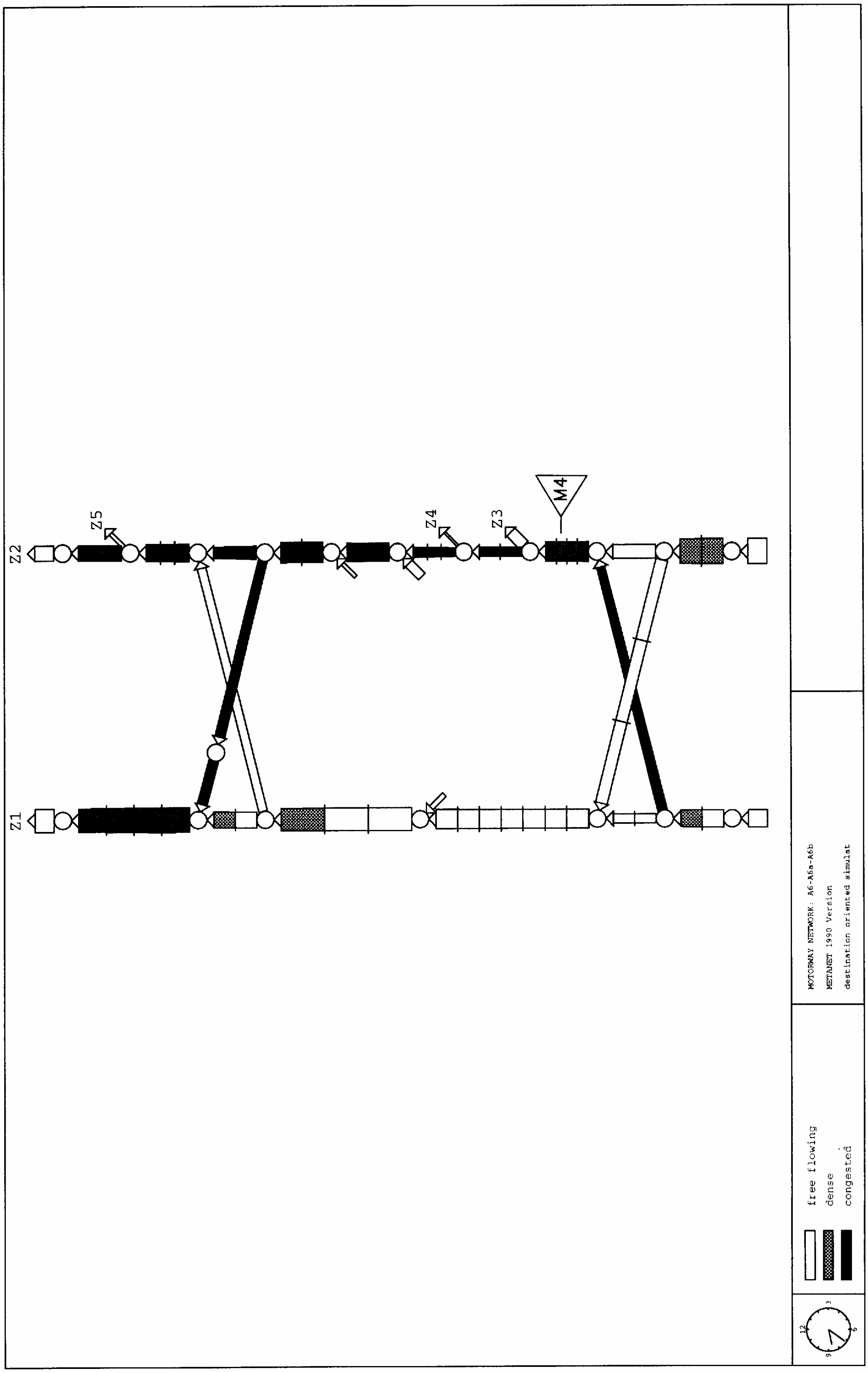

Figure 7: **Overview of simulated situation at 8:36 a.m.**

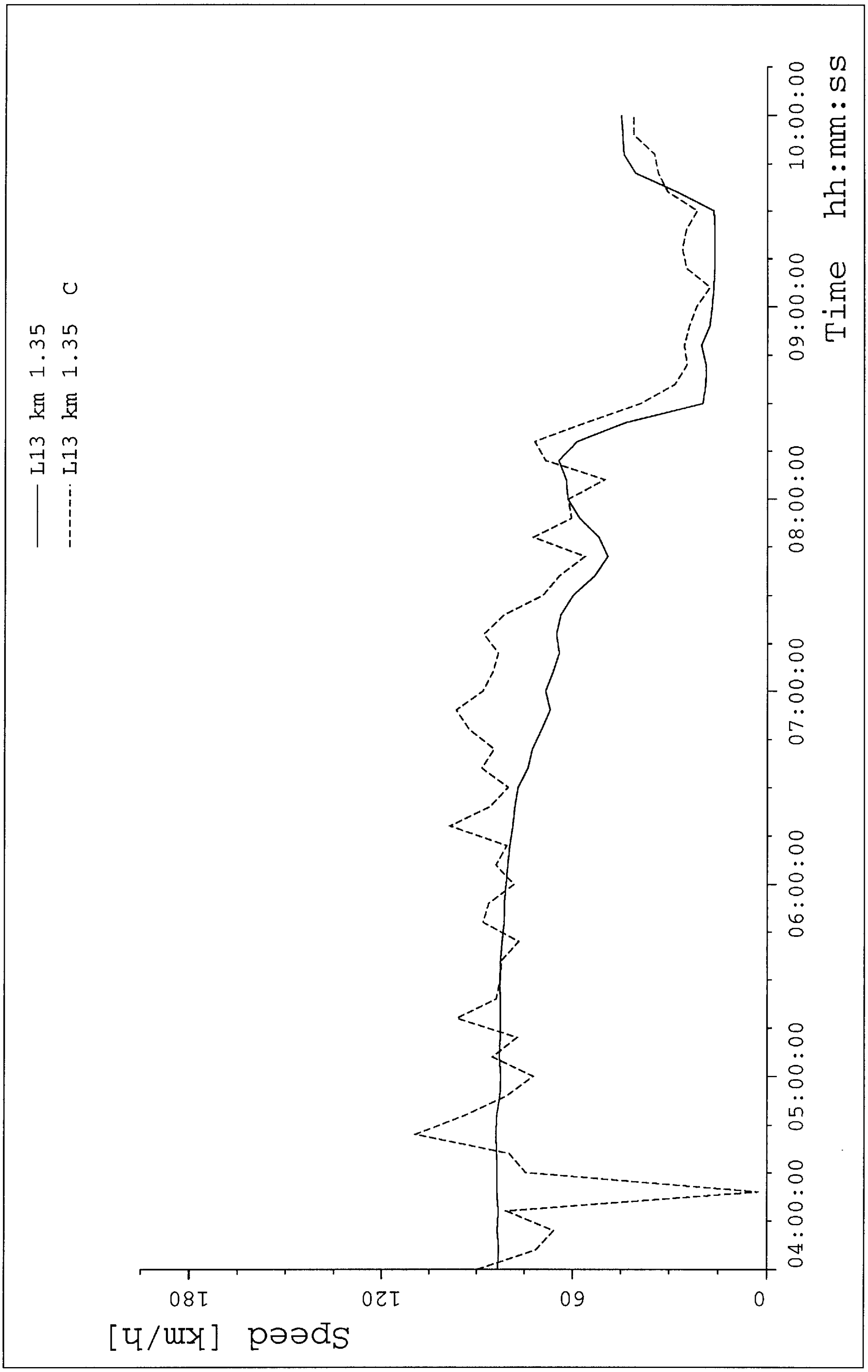

Figure 8: **Time-trajectories of measured (---) and simulated (—) speed at measuring location M4.**

Figure 8 shows an example of the quantitative accordance of the simulation results with the measured data from a detector (M4) inside the network. The time and the degree of the speed drop due to the arrival of the congestion shock wave from downstream is well reproduced by the model.

For the presented example, a ratio between simulation horizon and computation time of about 10^4:1 is obtained on a Pentium III (600MHz)-PC at an internal simulation time step of 10 s.

4.2 DTA Test Example

In order to demonstrate the usage of METANET's feedback DTA device, a second test example is presented here. The corresponding input files for METANET are given in Appendix D.

4.2.1 Description of DTA Example

The example network, drawn via METAGRAF (Figure 9), consists of 7 nodes (N0 to N6) and 13 links. The links include 3 origin links (O1, O2, and O3), 3 destination links (D1, D2, and D3), and 7 freeway links (L0 to L6). The network has two on-ramps (O2 and O3) and two off-ramps (D2 and D3). Here, only the eastbound direction is considered. The network begins with a single link L0 that is 2 km long and has four lanes. At the end of L0, there is a bifurcation N1 where two routes, the primary and the secondary, lead to the destination D1. The primary route consists of the links L1, L4, and L3, each with two lanes and respective lengths of 3, 0.5, and 3 km. Along the primary route, the off-ramp D2 and the single-lane on-ramp O2 exist. The secondary route consists of the links L2, L5, and L6, each with two lanes and respective lengths of 4, 0.5, and 4 km. Along the secondary route, the off-ramp D3 and the single-lane on-ramp O3 exist. Each link is divided into several segments with respective lengths of 1 km, except for the links L4 and L5 that are one-segment links.

The utilised traffic demand trajectories are trapezoidal as shown in Figure 10. It is assumed that 4% of the demand originating at O1 has D2 as its destination, another 4% has D3 as its destination, and the rest 92% is destined for D1. These OD values remain

constant over the entire time horizon. An incident occurs 0.83 h after the simulation starts in the second segment of L3, and lasts 10 minutes (see Figure 10). During the incident, the freeway capacity of L3 is reduced by 40%.

The portion of traffic flow arriving at N1, destined for D1, and directed to the primary route, is determined by a splitting rate $\beta_{N1,\mathrm{D1}}(k)$. Clearly, the splitting rate of the secondary route is given by $1-\beta_{N1,D1}$. The splitting rate $\beta_{N1,\mathrm{D1}}(k)$ is calculated via METANET's DTA device by a variety of feedback strategies. Under free-flow traffic conditions, the primary route from N1 to D1 is clearly time-shorter than the secondary route. In presence of congestion on the primary route (due to overload or incident), however, the secondary route becomes competitive for the drivers destined for D1.

4.2.2 Simulation Results for DTA Example

The simulation run has a total duration of 3 hours (7:00-10:00 AM). The *relative travel time differences* (%) in the Figures 12, 14, 16 are defined as $100\% \times \Delta\tau_{ps}^{D1}(k) / \tau_{N1,D1}^{\mathrm{p}}(k)$ according to Appendix B.7.

From Figures 11 and 12, we see that both travel time difference trajectories (i.e. reactive and predictive) created by the bang-bang strategy are quite distinct from each other for the duration of one hour after the incident occurrence at 7:50. However, the travel time differences are less than 30%.

Figure 14 shows that the trajectory of predictive travel time differences deviates from that of reactive travel time differences during the peak period, and the P-strategy leads to a very small but non-zero steady-state offset in the trajectory of travel time differences, which is inversely proportional to the control gain K_p.

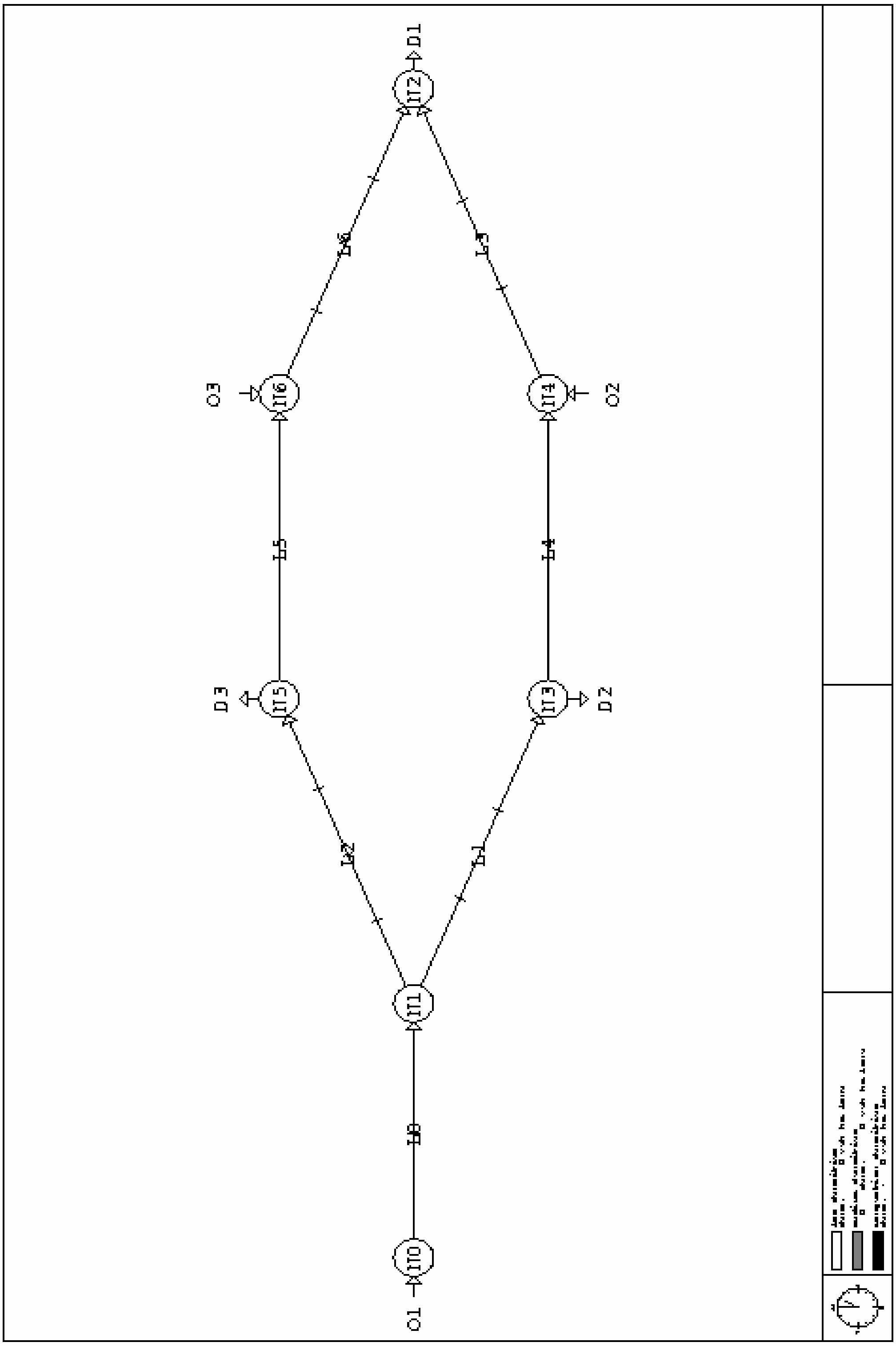

Figure 9: Test network.

The PI-strategy differs from the P-strategy mainly in that the former results in zero offset in both predictive and reactive travel time differences (see Figures 15 and 16).

In conclusion, the DTA function of METANET may be used to achieve approximate DTA conditions in the simulated motorway network, according to the user-specific data.

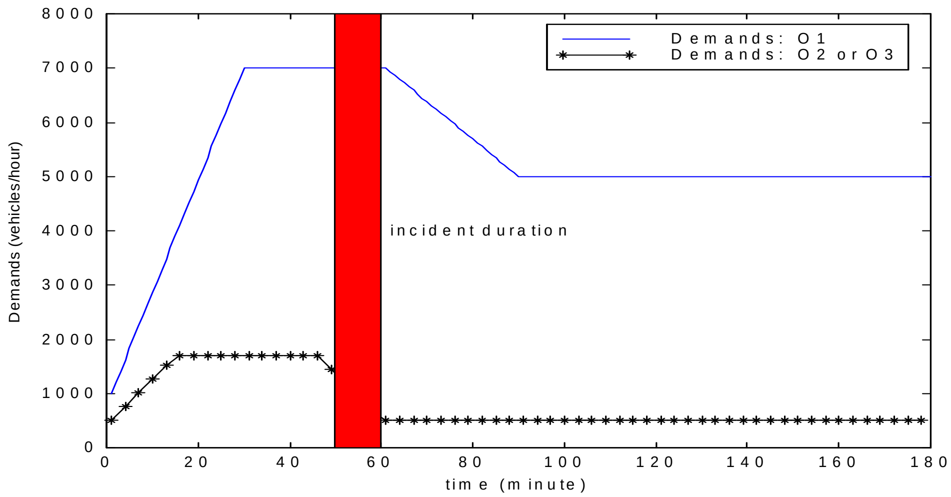

Figure 10: Demands for the test network.

Figure 11: Splitting rate trajectory calculated by bang-bang strategy for a simple network under an incident.

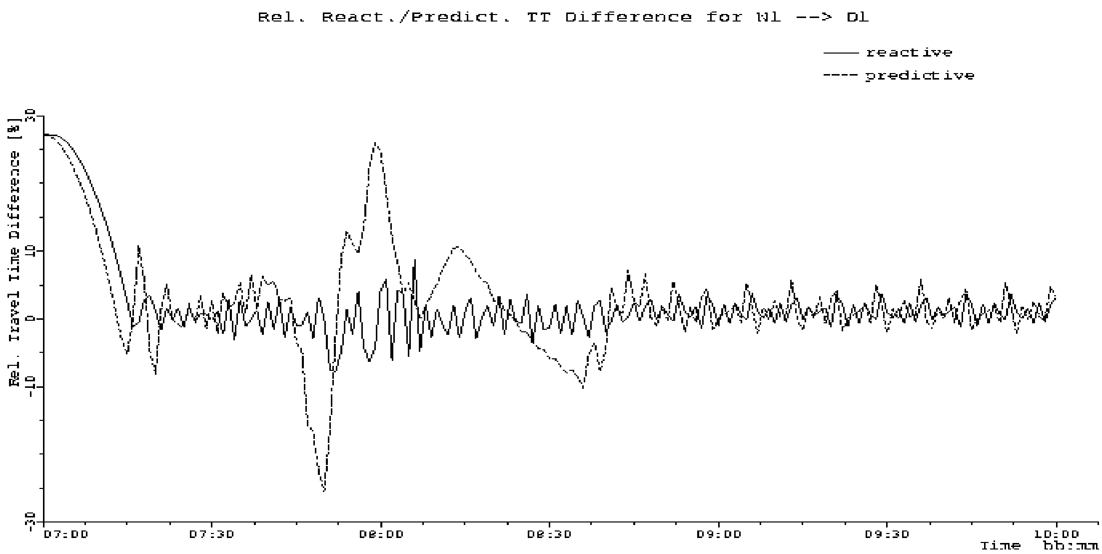

Figure 12: Trajectories of relative travel time differences resulting from the bang-bang strategy for a simple network under an incident.

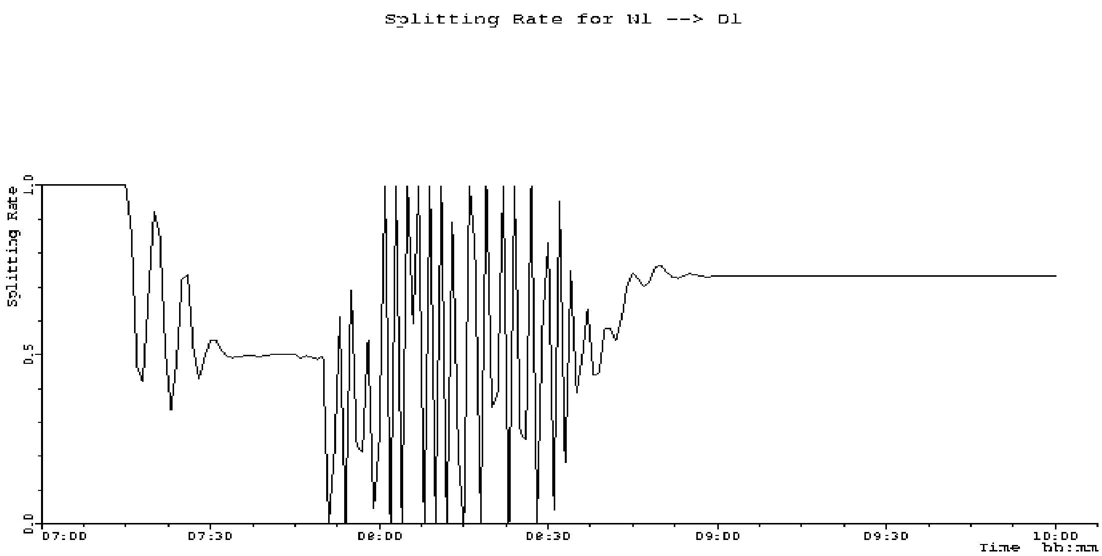

Figure 13: Splitting rate trajectory calculated by P-strategy for a simple network under an incident.

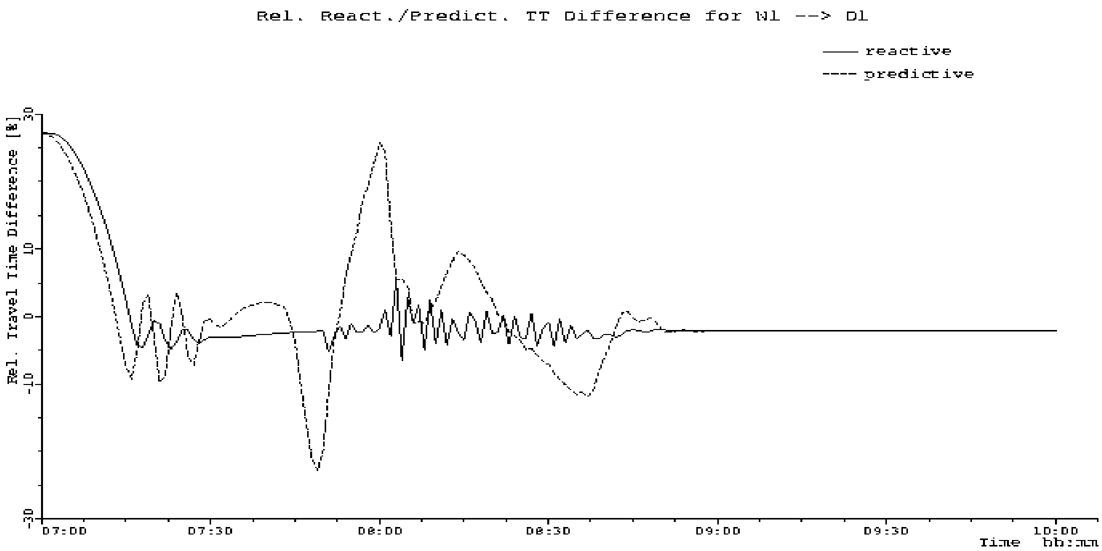

Figure 14: Trajectories of relative travel time differences resulting from the P-strategy for a simple network under an incident.

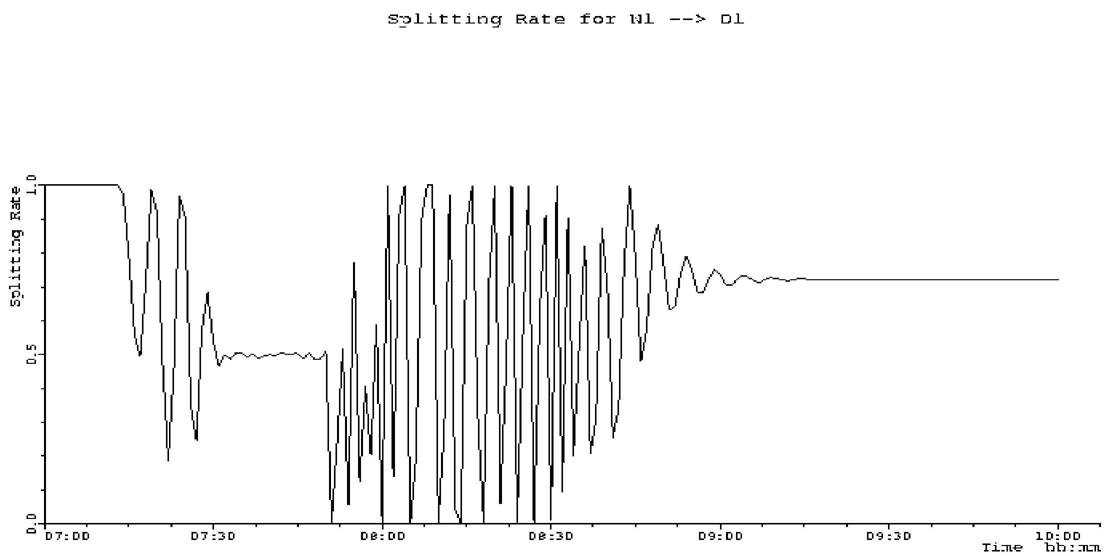

Figure 15: Splitting rate trajectory calculated by PI-strategy for a simple network under an incident.

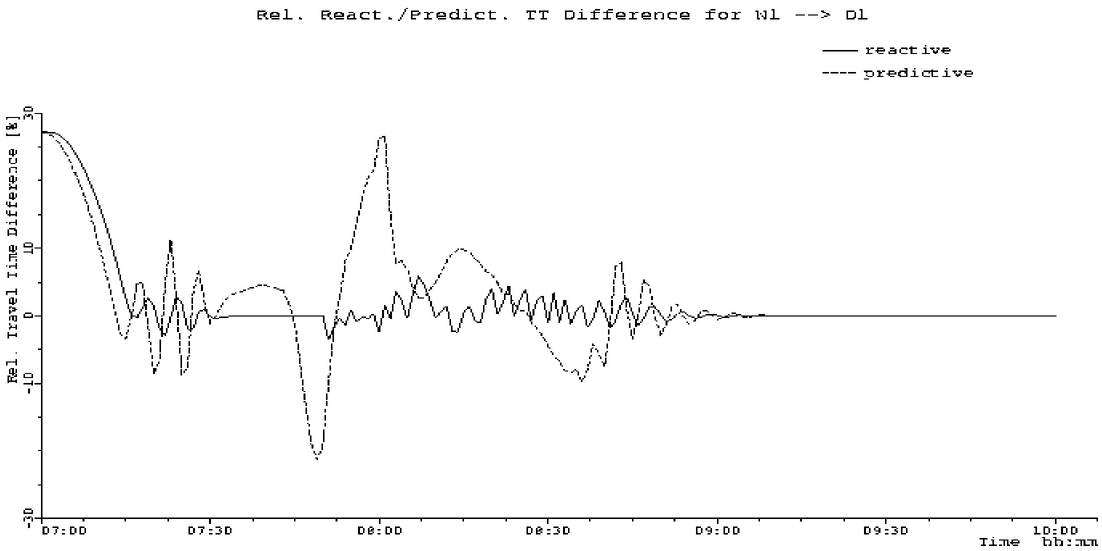

Figure 16: Trajectories of relative travel time differences resulting from the PI-strategy for a simple network under an incident.

5 REFERENCES

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APPENDIX A: COMPLETE MODEL DESCRIPTION

A.1 Modelling of the Network Links

The simulation of traffic behaviour in the network links is based on a macroscopic modelling approach originally developed by Payne [1]. The model's aggregate variables are the **traffic density** ρ (veh/km/lane), the **mean speed** v (km/h), and the **traffic volume** (or **flow**) q (veh/h).

A.1.1 Segmentation of Links

For modelling purposes, each link has to be subdivided in segments (Figure A1). This is done automatically by METANET for each link on the basis of the values *length*[7] and *nrof_segs* specified in the network description. The user has to take care that *nrof_segs* is not too high, as this would result in numerical instabilities due to too short link segments. The following relation must be obeyed for every link m

$$L_m > v_{f,m} \cdot T. \tag{A1}$$

L_m is the length of each segment of the considered link (*length*/*nrof_segs*), $v_{f,m}$ is its free speed (*vfree*) and T is the simulation time step (*sim_step*) as specified in the simulation control file. The physical interpretation of the relation is obvious: a vehicle which travels with free speed through a segment of the link m is not allowed to pass the segment during the simulation time step.

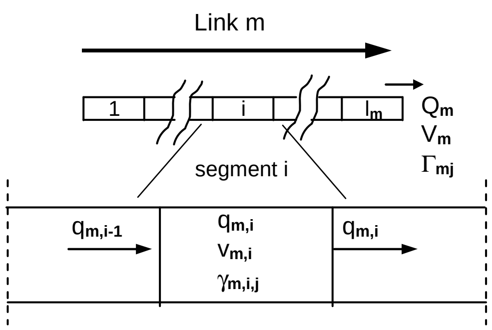


Figure A1: Segmentation of links.

[7] Expressions in italics are the variable names as used in the user input description (Chapter 3).

With a simulation time step of 10s, which is an appropriate value to consider the dynamic traffic phenomena with satisfactory accuracy, and with free speeds in the order of 100 to 120 km/h, typical segment lengths of 300 to 800 meters result. This ensures a sufficient stability margin.

For every time step k the traffic variables for all links are calculated according to the link equations described in this chapter (A.1.2 - A.1.8). In order to simplify the notation for subsequent modelling descriptions, we denote the traffic volume, the mean speed and the destination rates of the last segment of a link m by Q_m, V_m and Γ_{mj} respectively (see Figure A1).

A.1.2 Basic Equations

The basic equations used to calculate the traffic variables for every segment i are the following [2]

$$\rho_{m,i}(k+1) = \rho_{m,i}(k) + \frac{T}{L_m \cdot \lambda_m}[q_{m,i-1}(k) - q_{m,i}(k)] \quad \text{(Continuity Equation)} \qquad \text{(A2)}$$

$$q_{m,i}(k) = \rho_{m,i}(k) \cdot v_{m,i}(k) \cdot \lambda_m \qquad \text{(A3)}$$

$$v_{m,i}(k+1) = v_{m,i}(k) + \frac{T}{\tau}[V(\rho_{m,i}(k)) - v_{m,i}(k)] + \frac{T}{L_m} v_{m,i}(k) \cdot [v_{m,i-1}(k) - v_{m,i}(k)] - \frac{\nu T[\rho_{m,i+1}(k) - \rho_{m,i}(k)]}{\tau L_m[\rho_{m,i}(k) + \kappa]} \quad \text{(Speed Equation)} \qquad \text{(A4)}$$

$$V(\rho_{\mu,i}(k)) = v_{f,m} \cdot \exp\left[-\frac{1}{a_m}\left(\frac{\rho_{m,i}(k)}{\rho_{cr,m}}\right)^{a_m}\right] \quad \text{(Fundamental Diagram).} \qquad \text{(A5)}$$

τ(*tau*)[8], ν(*nue*), κ(*kappa*) are global parameters which are given the same values for all network links. Typical values for them can be found in Chapter 4 (test example). λ_m (*lanes*) denotes the number of lanes in the considered link m. T is the simulation time step and k denotes the time step presently in calculation ($t = k \cdot T$). Since origin and

[8] Expressions in italics are the variable names as used in the user input description (Chapter 3).

destination links have no dynamic properties, equations (A2) - (A5) are only applied to normal motorway links inside the network.

The free flow speed $v_{f,m}$ (*vfree*), the critical density $\rho_{cr,m}$ (*rocrit*) and the exponent a_m are specific for the fundamental diagram of the considered link m. The formula (A5) was found to be a good trade-off between computational effort and accuracy of describing observed fundamental curves. The exponent a_m has, however, no transparent physical significance. Therefore a_m is avoided in the user input and is computed internally from other specified values which are free speed, critical density, flow capacity (*capacity*) and/or flow value at a density of *60 veh/km/lane* (*cap60*). The meaning of these parameters in the fundamental diagram can be seen in Figure A2. Only three of the four mentioned parameters are necessary to determine uniquely the a_m parameter. Depending on the parameters given in the user input (network description file) different relations derived from (A5) are used to calculate the corresponding value of a_m.

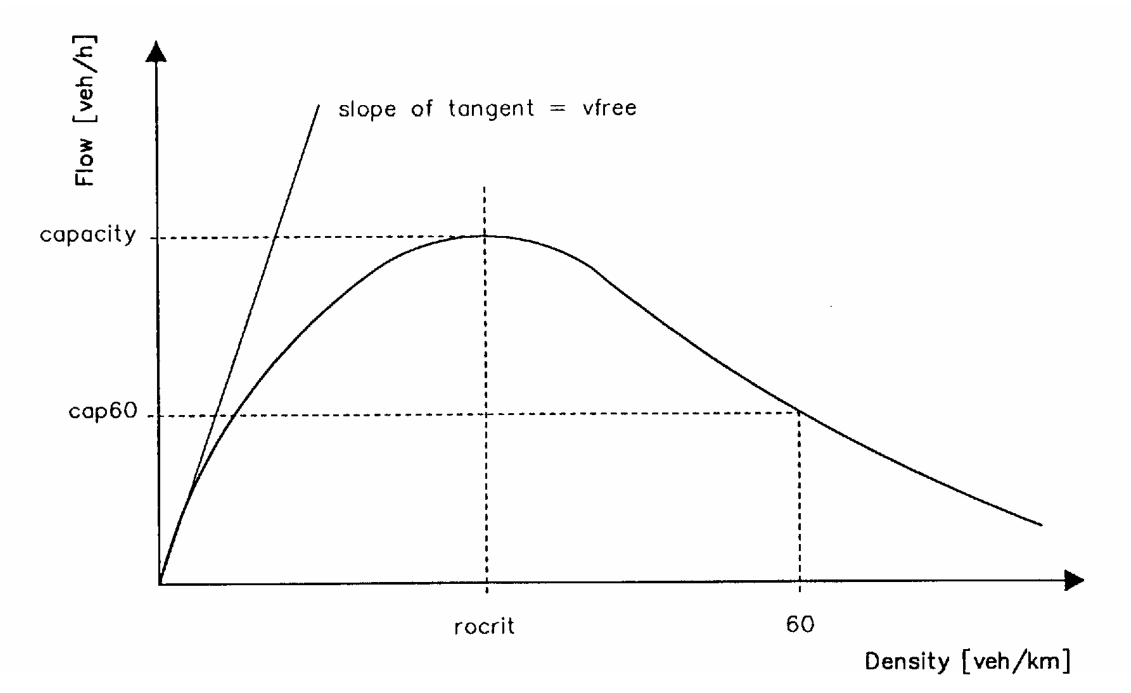


Figure A2: Parameters specifying the fundamental diagram.

If *capacity, vfree* and *rocrit* but not *cap60* are given:

$$a_m = -1 / \ln\left(\frac{capacity_m}{vfree_m \cdot rocrit_m}\right), \tag{A6}$$

if *capacity, cap60* and *rocrit* but not *vfree* are given:

$$\ln\left(\frac{cap60_m}{capacity_m} \cdot \frac{rocrit_m}{60.0}\right) = \frac{1}{a_m}\left(1 - \left(\frac{60.0}{rocrit_m}\right)^{a_m}\right), \tag{A7}$$

if *capacity, cap60* and *vfree* but not *rocrit* are given:

$$\ln\left(\frac{cap60}{60.0 \cdot vfree_m}\right) = -\frac{1}{a_m}\left(\left(\frac{60.0 \cdot vfree_m}{rocrit_m}\right)^{a_m}\right)\frac{1}{e}. \tag{A8}$$

In equations (A7) and (A8) a_m is given only implicitly, therefore it is calculated via Newton-Raphson iterations.

A.1.3 Modelling of Merging Effects (on-ramp term)

If several links, the first one considered as primary and the others as secondary, merge at a node (junction or on-ramp) and if there are leaving links which have no or too less dedicated lanes for the current on-ramp flow, merging phenomena have to be considered. This is done in the first segment of each leaving link by adding the following term to the speed equation (A4):

$$-\frac{\delta\, T}{L_m \lambda_m} \cdot \frac{q_\mu(k) \cdot v_{m,1}(k)}{\rho_{m,1}(k) + \kappa} \tag{A9}$$

where δ is a global parameter. If the number of lanes of the considered leaving link is equal or less than the number of lanes of the primary in-link, no lanes ***dedicated*** to the joining link exist. In this case q_μ is equal to the full flow of the secondary (joining) link of the node.

If the number of lanes of the considered leaving link is greater than the number of lanes of the primary in-link, ***dedicated*** lanes exist. If the inflow from the secondary link exceeds the capacity of these lanes, this exceeding amount of flow is used as q_μ. If the inflow is below capacity, (A9) is not applied at all.

A.1.4 Modelling of Lane Drops

If some lanes end (drop) at a node, the traffic of the ending lane(s) has to change to the remaining lanes which causes a deceleration of the traffic due to merging phenomena. The impact of the merging phenomena is considered in the last segment l_m of the incoming links by adding a similar term as for merging effects due to on-ramps to the speed equation (A4) (for all in-links):

$$-\frac{\varphi \mathrm{T}}{\mathrm{L}_{\mathrm{m}}\lambda_{\mathrm{m}}} \cdot \frac{\Delta\lambda \cdot \rho_{\mathrm{m,l_m}}(\mathrm{k})}{\rho_{\mathrm{cr,m}}} \cdot v_{m,l_m}(k)^2 \qquad \text{(A10)}$$

where $\Delta\lambda$ is the number of lanes being dropped. It is calculated as the difference between the number of lanes λ_m of the considered in-link m and the sum of lanes leaving the node. If the secondary leaving links of this node are destinations, they are looked upon as off-ramps where the lanes are normally not a continuation of any incoming lanes. For this reason the lanes of these out-links are not counted in the sum of leaving lanes.

A.1.5 Modelling of Control Measures and Incidents

<u>Incident Modelling:</u>

Besides time, duration and location) the user has to specify the severity of an incident.
This can be done in terms of:

a) relative capacity *inci_sev* or
b) remaining absolute capacity *rem_cap* or
c) closed lanes *closed_lane1, closed_lane2,* etc..

Option a) is used when specifying the incident via the Simulation Control file (old way). Options b) and c) correspond to the possibilities as offered in the input via the Control Measures and Incidents file.

In a first step the maximum possible flow q_{acc} at the particular incident location (in link m) is calculated. Depending on the used optional input parameter the following calculation method is used:

a) $q_{acc} = (1.0 - inci\_sev) \cdot capacity_m \cdot \lambda_m,\ 0 \le inci\_sev \le 1$ (A11a)

where $capacity_m$ is the link's capacity per lane. $inci\_sev = 1$ corresponds to a complete blocking whereas for $inci\_sev = 0$ no incident is simulated.

b) $q_{acc} = rem\_cap$ (A11b)

c) $q_{acc} = \cdot capacity_m \cdot rem\_lanes,\ 0 \le inci\_sev \le 1$ (A11c)

where *rem_lanes* is the number of lanes which are still open. This includes the possibly opened shoulder lane.

A lower bound of 0.01 veh/h ($q_{congestion}$) is adopted for q_{acc} .

With that value equation (A3) is modified during the occurrence of the incident as follows:

$$q_{m,i}(k) = \min\{\rho_{m,i}(k) \cdot v_{m,i}(k) \cdot \lambda_m, q_{acc}\} \qquad \text{(A12)}$$

If $q_{m,i}$ is determined by q_{acc} in equation (A12), the velocity in the according segment is adapted to keep equation (A3) valid, i.e.: $v_{m,i}=q_{acc}/(\rho_{m,i} \cdot \lambda_m)$. Note that incidents can be specified only in normal motorway links.

<u>Variable Direction Indication:</u>

Variable Direction Signs (VDS) are used to redirect traffic at selected nodes towards selected destinations (for which route choice is possible) in case of traffic problems on the one or the other route. The selection is done according to the specified Variable Direction Signs control events in the Control Measures and Incidents file.

The used compliance formula acts towards a modification of the nominal splittings $\beta^{N,m}$. For each influenced node n and destination j the following formula is applied:

$$\tilde{\beta}^{m}_{n,j} = \beta^{N,m}_{n,j} + \varepsilon_{n,j} \cdot (\beta^{VMS,m}_{n,j} - \beta^{N,m}_{n,j}) \qquad \forall\ m \in R_n \qquad \text{(A13)}$$

where R_n denotes the set of these out-links at node n through which j is reachable.

The resulting intermediate splitting rates $\tilde{\beta}_{n,j}^{m}$ are limited to $0 \le \beta \le 1$ and moreover, in order to ensure that $\sum_{m \in R_n} \beta_{n,j}^{m} = 1$, the finally resulting splitting rates (as used for the simulation) are calculated by: $\beta_{n,j}^{m} = \tilde{\beta}_{n,j}^{m} \,/\, \sum_{m \in R_n} \tilde{\beta}_{n,j}^{m}$. $\varepsilon_{n,j}$ is the compliance rate (0 if no compliance at all, 1 if full compliance) to be specified individually for each n,j-couple in the Control Measures Parameter file. $\beta_{n,j}^{N,m}$ is the nominal splitting rate which reflects the drivers' route choice behaviour under normal (daily experienced) conditions and in absence of any control measures and any provision of information. Nominal splittings are calculated off-line and provided via the Splitting Rates input file. $\beta_{n,j}^{VMS,m}$ is a variable to be specified in the Control Measures and Incidents file and reflects the direction indication by the VDS. For $\beta_{n,j}^{VMS,m}$ a value near 1 should be specified if the VDS are directing the traffic with the destination *j* via out-link *m* of node *n*. Low values should be chosen for the other ones.
The Variable Direction Indication control measure is only available in the destination oriented simulation mode.

Queue Information via Variable Message Signs:

The effect of the queue length information given on Variable Message Signs (VMS) is also modelled by a modification of the relevant splitting or turning rates, distinguished by destinations for which the information is relevant. For each influenced node *n* and destination *j* the adopted modelling law in the destination oriented mode reads:

$$\tilde{\beta}_{n,j}^{m} = (1-\varepsilon_{VMS,n}) \cdot \beta_{n,j}^{N,m} + \varepsilon_{VMS,n} \cdot \left[\beta_{n,j}^{N,m} - K_{VMS,n} \cdot (\Delta w_{indicated,n,j}^{m})\right] \qquad \forall\ m \in Rn, \qquad \text{(A14)}$$

where R_n denotes the set of these out-links at node *n* through which *j* is reachable. The queue information model (A14) is applied to all destinations *j* for which a route choice exists at node *n*. This relieves the user from specifying explicitly the possible destinations in the Control Measures and Incidents file.

In the non destination oriented mode a slightly modified law where the indeces *j* are omitted, is used: $\tilde{\beta}_{n}^{m} = (1-\varepsilon_{VMS,n}) \cdot \beta_{n}^{N,m} + \varepsilon_{VMS,n} \cdot \left[\beta_{n}^{N,m} - K_{VMS,n} \cdot (\Delta w_{indicated,n}^{m})\right]$**,** where $\boldsymbol{\beta}$ refers here to the turning rate.

The resulting intermediate splitting or turning rates $\tilde{\beta}^m_{n,j}$ or $\tilde{\beta}^m_n$ are limited to $0 \le \beta \le 1$ and moreover, in order to ensure that $\sum_{m\in R_n} \beta^m = 1$, the finally resulting splitting rates (as used for the simulation) are calculated by: $\beta^m_{n,j} = \tilde{\beta}^m_{n,j} \;/\; \sum_{m\in R_n} \tilde{\beta}^m_{n,j}$ respectively by: $\beta^m_n = \tilde{\beta}^m_n \;/\; \sum_{m\in R_n} \tilde{\beta}^m_n$.

The parameters of modelling laws which are individually for each VMS location *n*, but not differentiated by destination *j*, are:

- the constant and positive feedback parameter $K_{VMS,n}$ and
- the VMS specific compliance rate $\varepsilon_{VMS,n}$.

Moreover there are the variables:

- nominal splitting or turning rates $\beta^N_{n,j}$ or β^N_n which come from the Splitting or Turning Rates Input File,
- *the non-recurrent queues along the routes via the different out-links (the ones assumed to be indicated on the VMS):* $\Delta w^m_{indicated,n,j}$ *or* $\Delta w^m_{indicated,n}$. Δ *expresses that the considered queues are the ones where the recurrent queue lengths are subtracted.*

The Δw *values (means the queues indicated on the VMS) are either:*

- *directly given by the user in the Control Measures and Incidents file or if omitted there,*
- *calculated internally.*

In the first case the user gives just one $\Delta w^m_{indicated,n}$ *value per node which is adopted equally to all* $\Delta w^m_{indicated,n,j}$ *values as needed in (A14).*

For the latter case recurrent queue lengths are provided in the Recurrent Queue Lengths input file and are subtracted from the queue lengths as calculated for the current conditions in order to obtain Δw. If the result becomes negative, i.e. if there is some recurrent queue but a less longer current queue, it is set to zero.
The computation of the current queue lengths is done in the following steps:

- The queue length per each network link is calculated by adding the lengths of all the link's segments for which the speed is below v_{jam} (see Control Parameters file).
- The individual current queue lengths $w_{n,j}$ are calculated by following the routes (and adding the link queue lengths) which are dynamically the shortest ones with respect to reactive travel time.

Lane Closures:

The reduced number of lanes is considered in the equations (A2), (A3), (A9), (A10), (A11a, A11c), (A15), (A20) and (A23). In particular eq. (A10) which is the so called "lane drop term" will be in effect at the upstream end of a lane closure, i.e. the location where the reduction of the lanes begins.

Shoulder Lane Opening:

Dynamic Shoulder Lane Opening is modelled by incrementing the number of lanes by one and by using specific parameters of the Fundamental diagram on the specified stretch (input via Control Measures Parameter file). This accounts mainly for the speed limitation which is usually activated in conjunction with the opening measure. Concerning the changed number of lanes the same model equations as for lane closures are involved.

Variable Speed Limitations:

According to the purpose of the speed limitations it is distinct between harmonisation and queue warning. Since it is presumed that speed indications due to the latter reason are given with higher emphasis (e.g. by setting flashing lights), the effect may be somehow different between the two possibilities.

The effects of speed limitations are modelled via modification of the fundamental diagram (equation (A5)). It is presumed that not only the free speed v_f *but also the parameters* capacity *and critical density* ρ_{cr} *are affected. Typically the capacity is increased to some extent while the critical density is always pushed somehow upward.*

The appropriate quantification of the effects is a matter of calibration on basis of historical data.

It is possible to specify individual parameters for each nominal value of speed limitation and for the two reasons of the measure in the Control Measures Parameter file.

<u>Ramp Metering:</u>

The ALINEA control algorithm is used. It causes a reduced inflow into the motorway from the particular on-ramp. The output of the control law, i.e. the metering rate $r_O(k)$ which is in veh/h, is translated into an according value for rate which is a relative value with respect to the currently possible maximum inflow (determined by the geometrical performance of the ramp and possibly limited additionally by spill back). The control law as given in reads:

$$r(k) = r_m(k-1) - K_{AL} \cdot [\rho_{out}(k) - \hat{\rho}]$$

Its parameters are:

- the constant and positive regulator parameter K_{AL},
- the downstream density set point $\hat{\rho}$ (in veh/km/lane).

Moreover we have the variables:

- r(k) which is the commanded on-ramp volume at current time $(k \cdot T_A)$ (in veh/h),
- $r_m(k-1)$ which is the really entered on-ramp volume (in veh/h) at the last control time instant $((k-1) \cdot T_A)$ and which may be different from $r(k-1)$ due to the consideration of various constraints,
- $\rho_{out}(k)$ which is the downstream density at current time (in veh/km/lane).

The algorithm includes the release of the queue with maximum rate if a certain length is exceeded (queue override), limitation of the metering rate to an upper and a lower bound (r_{min} and r_{max}) and a switching off in case of low densities on the motorway (below ρ_{min}). The control law is applied, i.e. the metering rate is calculated, every TA interval. The downstream density "measuring" point where the set point $\hat{\rho}$ as well as the switching off threshold ρ_{min} is compared against, is the first link segment downstream the on ramp.

All mentioned parameters are specified by the user in the Control Measures Parameter file.

Traffic Lights:

The effect of traffic lights is modelled via variable capacity constraints. In case of on-ramps there is no additional network element necessary since METANET origins which have anyhow to be used to model an on-ramp, have an already build in queueing model with a capacity controlling variable r_O (the same as used in the case of ramp metering).

In case of off-ramps a Store-and-Forward link has to be placed between the off-ramp node and the destination link thus providing the same kind of controlling variable as for the origins. The queueing model assumes that the capacity constraint, i.e. the model of the traffic light is at the end for the link.

The possibility of placing a traffic light is not restricted to Store-and-Forward links which are directly upstream a destination. For any other Store-and-Forward link a traffic light can be defined.

The capacity of the origins or Store-and-Forward links where the traffic lights are placed, are set to specific values as given in the Control Measures Parameter file.

A.1.6 Limitation of Congestion Density

Unrealistically high densities upstream a bottleneck or a blocked location (e.g. accident) are avoided by limitation of the flow into this location such that its density cannot grow over a maximum value ρ_{max} which is a global network parameter (*romax*). This is done by modifying equation (A3) in the following way:

$$q_{m,i}(k)=\begin{cases}\rho_{m,i}(k)\cdot v_{m,i}(k)\cdot\lambda_{\mathrm{m}} & \text{for } \rho_{\mathrm{m,i+1}}(\mathrm{k}-1)<\ \rho_{\max} \\ q_{congestion} & \text{otherwise}\end{cases}\ . \tag{A15}$$

The value for $q_{congestion}$ is 0.01 veh/h. If $q_{m,i}$ is set to $q_{congestion}$, $v_{m,i}$ is set to $q_{congestion}$ / ($\rho_{m,i}\cdot\lambda_{m}$) in order to obey (A3). A15 is adopted in gradually increasing manner already from ρ_{max}-40 on.

A.1.7 Lower Bound for Mean Speeds

In order to get a more realistic dissolving of congestions, all mean speeds $v_{m,i}(k)$ are limited to a lower bound v_{min} (*vmin* in the Network Description file). This step is performed at each time step after execution of (A4), (A9), (A10).

A.1.8 Propagation of Traffic Composition

In order to be able to consider different destinations, traffic variables called *composition rates* have been introduced for each segment. They represent portions of the traffic volume $q_{m,i}$, destined to corresponding destination links. If N destinations are reachable through link no. m, then N−1 independent composition rates $\gamma_{m,i,j}$ are required for the segments of link *m*, where j is the index of the corresponding destinations. All members of the set J_m of reachable destinations of link *m* have to be considered, i.e. $\forall j\in J_m$.

The modelling of the composition rates $\gamma_{m,i,j}$ in segment i is done by definition of destination-oriented partial densities $\rho_{m,i,j}$

$$\rho_{m,i,j}(k) = \rho_{m,i}(k)\cdot\gamma_{m,i,j}(k) \tag{A16}$$

and application of the continuity equation to each of them (see [3] for details)

$$\rho_{m,i,j}(k+1) = \rho_{m,i,j}(k) + \frac{T}{L_m\lambda_m}\left[\gamma_{m,i-1,j}(k)\cdot q_{m,i-1}(k) - \gamma_{m,i,j}(k)\cdot q_{m,i}(k)\right]\ . \tag{A17}$$

Finally, the new composition rates are calculated by

$$\gamma_{m,i,j}(k+1) = \frac{\rho_{m,i,j}(k+1)}{\rho_{m,i}(k+1)}. \tag{A18}$$

A.1.9 Modelling of Store-and-Forward Links

Traffic entering a Store-and-Forward link is added, after a time delay $T_{lag,saf}$, to a link queue and eventually forwarded to the next downstream node. The outflow q_{saf} of a store-and-forward link is modelled in the following way

$$q_{saf} = r_{saf} \cdot q_{\max,saf} \tag{A19}$$

with

$$q_{\max,saf} = \min\left\{q_{inflow,saf} + w_{saf}/T\,,\ q_{poss,saf}\right\}$$

where $q_{inflow,saf}$ is the retarded (by the constant travel time $T_{lag,saf}$) flow entering the store-and-forward link saf, and w_{saf} is the length (in vehicles) of a possibly existing waiting queue. $q_{max,saf}$ is the current maximum outflow from the link while $q_{poss,saf}$ is the current outflow capacity of the link and $r_{saf} \in [0, 1]$ is the metering rate (from the vector *rate[]* as described in 3.6.3) for store-and-forward link saf (see Section 3.6.2). If r_{saf} equals 1, no metering is applied. If r_{saf} is less than 1 then accordingly strong metering is applied to the exit flow of the corresponding saf link.

Under free flow traffic conditions, the outflow capacity $q_{poss,saf}$ is equal to the geometrical capacity $Q_{max,saf}$ (*capacity*). If the density ρ_μ downstream the Store-and-Forward link is, however, overcritical, i.e. $\rho_\mu > \rho_{cr,\mu}$, the current outflow capacity is reduced depending on ρ_μ

$$q_{poss,saf} = \begin{cases} Q_{\max,saf} \cdot \lambda_{saf} & if\ \rho_\mu < \rho_{cr,\mu} \\ Q_{\max,saf} \cdot \lambda_{saf} \cdot p & else \end{cases} \tag{A20}$$

where p is a factor ($0 \le p \le 1$) that reduces the flow allowed to leave the Store-and-Forward link, and is calculated by:

$$p = 1 - \frac{\rho_\mu - \rho_{cr,\mu}}{\rho_{max} - \rho_{cr,\mu}}. \tag{A21}$$

Thus, equation (A21) models the reduced exit flow capacity of the saf link due to mainstream congestion.

A waiting queue is built as follows

$$w_{saf}(k+1) = w_{saf}(k) + T \cdot [q_{\text{inflow},saf}(k) - q_{saf}(k)]. \tag{A22}$$

The global parameter ρ_{max} (*romax*), representing the maximum permissible traffic density value, as well as the store-and-forward link specific parameters $Q_{max,saf}$ (*capacity*), λ_{saf} (*lanes*) are read from the Network Description file.

Furthermore, a traffic density is calculated for the link which may affect (upstream influence of density) the magnitude of traffic volumes entering saf from the corresponding upstream node. This traffic density is calculated via the following equation:

$$\rho_{saf} = \rho_{max} \cdot \frac{(w_{saf} + n_{d,saf}) \cdot L}{l_{saf} \cdot \lambda_{saf}} \tag{A23}$$

where ρ_{saf} is the traffic density (in veh/km/lane) of the store-and-forward link saf, ρ_{max} is a global parameter representing the maximum permissible traffic density (in veh/km/lane), w_{saf} is the waiting queue (in veh), l_{saf} is the length (in km) of link saf and λ_{saf} is the number of lanes of link saf. L, the mean vehicle length, is set to a default value of 0.006 km. Finally, $n_{d,saf}$ represents the number of vehicles which have already entered the store-and-forward link saf but, due to the internal travel time, have not yet reached the upstream end of the queue.

No speed value is defined in a Store-and-Forward link and is therefore not considered in the leaving link μ of the corresponding downstream node.

In order to be able to consider different destinations, composition rates as in the case of normal links are calculated. The composition rates represent portions of the traffic volume q_{saf} destined to corresponding destination links. If J_{saf} destinations are reachable through link saf, then $J_{saf}-1$ independent composition rates $\gamma_{saf,j}$ are required for link saf where j is the index of the corresponding destination. The portions of vehicles with respect to the different destinations in the queue w_{saf} are calculated so as to keep the inflow/outflow balance for each portion. The inflow composition is the one of the flow arriving at the queue (after being retarded by the constant travel time) while the outflow composition is assumed to be equal to the composition inside the queue. In other words a homogeneous mix of the vehicles is assumed to take place inside the queue. This does not correspond exactly to reality where the vehicles are lining up in the queue. The error, however, which is made by this simplification, is regarded to be minor.

A.2 Modelling of the Network Nodes

A.2.1 Distribution of Flow

Generally speaking, traffic enters a node n through a number of input links (members of the set I_n) and is distributed to a number of output links (members of the set O_n). For proper calculation of the distribution in the destination oriented simulation mode, the destinations of the inflows to the node must be considered. The partial flow with a certain destination j in a leaving link is calculated according to the total incoming traffic destined to j and according to the percentage of users who choose the corresponding route. Expressed in equations, the relations for each node *n* read:

$$q_{nj} = \sum_{\mu \in I_n} Q_\mu \cdot \Gamma_{\mu j} \qquad \forall j \in J_n, \quad \text{where } J_n = \bigcup_{\mu \in I_n} J_\mu \qquad \text{(A24)}$$

$$q_{m,0} = \sum_{j \in J_m} q_{nj} \cdot \beta_{nj}^{m} \qquad \forall m \in O_n \qquad \text{(A25)}$$

$$\gamma_{m,0,j} = \frac{\beta_{nj}^{m} \cdot q_{nj}}{q_{m,0}} \qquad \forall m \in O_n \ \forall j \in J_m. \qquad \text{(A26)}$$

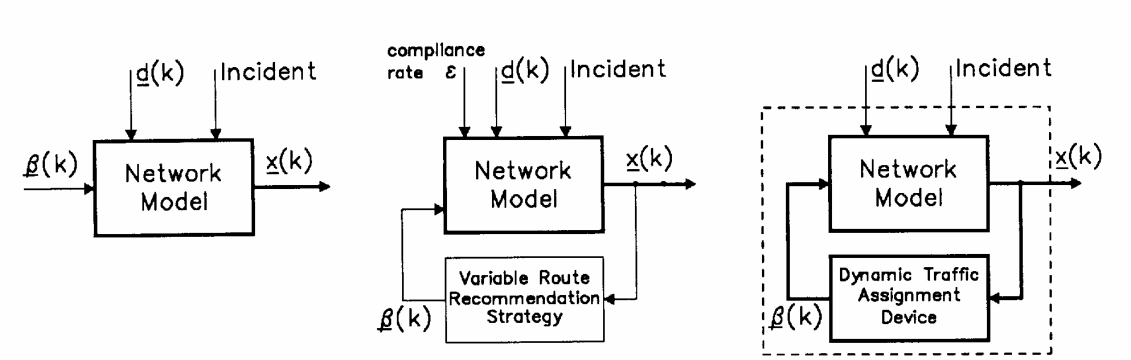
Equation (A24) expresses the merging of the flows in the node, q_{nj} being an auxiliary variable which represents the total flow entering node n and destined to j. Equation (A25) distributes the incoming flows to the leaving links, and (A26) provides the corresponding boundary composition rates $\gamma_{m,0,j}$ for these links. J_n , J_μ and J_m are sets of destinations reachable through the particular link. The splitting rate β_{nj}^{m} determines the part of q_{nj} which leaves through link m. For example, if β_{nj}^{m} equals 1, all drivers at node n take a route via link m to their destination j. On the other hand, if all drivers take alternatives via other out-links to destination j, β_{nj}^{m} is zero.

In the program code β_{nj}^{m} is represented by *beta[][][]* as described in 3.6.2 where the three indices of the program variable address the node *n*, the destination *j* and the out-link *m* respectively (numbering order as in the line of out-links for the node in the Network Description file).

Consequently the splitting rates of a motorway network, organised in a vector $\boldsymbol{\beta}(k)$, express the average route choice behaviour of the drivers at the network nodes. METANET offers several user options in this context:

a) Splitting rates are provided as an input by the user (in file *trdname*.spl).
b) If control measures via route recommendation (e.g. by variable message signs) are present, the splitting rates depend upon the decisions of the control strategy. In this case desired splitting rates are calculated by a control law implemented in the module MN_CONTR (see Section 3.6).
c) Splitting rates may be calculated by a dynamic assignment device so as to describe the natural behaviour of the drivers in absence of route recommendations according to Wardrop's first principle (See Appendix A.4).

Figure A3 visualises the various user options. The desired option is selected via the variables *contr_type* and *dta_type* in the Simulation Control file. The vector **d** appearing in the figure, includes all demands at the origin links and all network boundary traffic conditions.



a) Simulation with given $\beta(k)$

b) Control Strategy Testing

c) Simulation including Dynamic Traffic Assignment

Figure A3: Main user options.

A.2.2 Upstream Influence of Density

According to (A4), the dynamic evolution of mean speed in each segment is influenced by the density of the adjacent downstream segment ($\rho_{m,i+1}$). This value however is also needed at the end (last segment) of a link. This means that for each link m, subdivided in segments 1, ..., l_m, a density ρ_{m,l_m+1} has to be determined.

At nodes with only one output link, this value can be directly obtained from the adjacent downstream link. But at nodes with several output links, this value has to be calculated from the densities of the first segments of the output links. This is done by taking an appropriate weighted average of these values. More precisely, the density which is needed at the end of the input links m ($m \in I_n$) of a node is calculated in the following way:

$$\rho_{m,l_m+1} = \frac{\sum_{\mu \in O_n} \rho_{\mu,1}^2}{\sum_{\mu \in O_n} \rho_{\mu,1}} \qquad \forall m \in I_n \tag{A27}$$

where $\rho_{\mu,1}$ is the density of the first segment of an output link μ. The quadratic weighting of the output link densities considers the fact that heavily loaded stretches contribute more than proportionally to spill back. In some cases, a congestion in one of the output links may be sufficient to produce spill back into the input link.

<u>Boundary (Destination) Densities</u>

Also destination links may be out-links at nodes. Regarding the determination of a density value ρ_μ influencing the upstream link(s), there are three cases:

i) Given in the input file *trdname*.msd for the particular destination. This is normally the case for main leaving axes.

ii) Calculated by the following dynamic equation which limits the outflow to *qbound* as specified in the network description file

$$\rho_\mu(k+1) = \begin{cases} \rho_{\text{upstream}} & \text{if } q_\mu < qbound_\mu \ \ and \ \ \rho_{upstream} < \rho_{cr,\mu} \\ \rho_\mu(\text{k}) + \text{constqb}_\mu[\text{q}_\mu - qbound_\mu] & \text{else} \end{cases} \tag{A28}$$

where ρ_{upstream} is the density in the upstream link(s) (the arithmetic mean if there are more than one), $\rho_{cr,upstream}$ is the critical density of the upstream link(s) and $constqb_\mu$ is a regulation parameter which is internally calculated so as to ensure stability.

iii) No density is value is defined. This is the case if case i) and ii) do not hold true (no value given in input file and *qbound* marked as not defined, i.e. having a negative value). If the destination is the only leaving link at the node before the destination, the last term of the speed equation (A4) containing the $\rho_{m,i+1}$ value is omitted for the upstream link(s). If there is a second leaving link besides the destination and a valid density exists there, this value is taken for $\rho_{m,i+1}$.

A.2.3 Downstream Propagation of Speed

Similarly to the upstream density influence, the dynamic evolution of mean speed in each segment is also influenced by the mean speed of the adjacent upstream segment ($v_{m,i-1}$). This value is needed when processing equation (A4) for the first segment of a motorway link. This means that for each motorway link m a speed $v_{m,0}$ has to be determined.

At nodes with several input links, the $v_{m,0}$ value of an out-link m ($m \in O_n$) is calculated by taking the mean over the speeds V_μ at the end of the input links μ, whereby the mean value is weighted by the according incoming flow Q_μ :

$$v_{m,0} = \frac{\sum_{\mu \in I_n} \left[V_\mu \cdot Q_\mu \right]}{\sum_{\mu \in I_n} Q_\mu} \qquad \forall m \in O_n. \tag{A29}$$

<u>Boundary (Origin) Speeds</u>

Also origin links may be in-links at nodes. Regarding the determination of a speed value V_μ influencing the downstream link(s), there are two cases:

i) Given in the input file *trdname*.msd for the particular origin. This is normally the case for main entering axes.

ii) No speed value is defined for the origin. If the origin is the only incoming link at the node, the one but last term of the speed equation (A4) containing the $v_{m,i-1}$ value is omitted for the downstream link(s). If there are further incoming links besides the origin and valid speeds exists there, these values are considered in (A29) yielding a value for $v_{m,i-1}$.

A.3 Modelling Inflow Limitation and Queuing at Origins

In order to avoid unrealistically high inflows at the origins, especially for the case of congestion spill back, a limitation of inflow in conjunction with a waiting queue model is realised. The flow q_o from an origin o is modelled in the following way

$$q_o = \min\left(q_{\max,o}, r_o\right) \tag{A30}$$

with

$$q_{\max,o} = \min\left\{q_{demand,o} + w_o/T\,,\; q_{poss,o}\right\}$$

where $q_{demand,o}$ is the demand flow at the origin o according to the traffic data input, w_o is the length (in vehicles) of a possibly existing waiting queue in the origin link o, $q_{max,o}$ is the current maximum flow from the origin into the network while $q_{poss,o}$ is the current flow capacity of the origin link, and r_o is the metering rate (in veh/h) for origin o.

Under free flow traffic conditions, the current capacity $q_{poss,o}$ is equal to the geometrical capacity $Q_{max,o}$ (*capacity*). If the density ρ_μ downstream of the origin (i.e. in the mainstream) is, however, overcritical, i.e. $\rho_\mu > \rho_{cr,\mu}$, the current capacity is reduced depending on ρ_μ as it is illustrated also in Figure A4

$$q_{poss,o} = \begin{cases} Q_{\max,o} \cdot \lambda_o & \text{if } \rho_\mu < \rho_{cr,\mu} \\ Q_{\max,o} \cdot \lambda_o \cdot p & \text{else} \end{cases} \tag{A31}$$

The rationale of deriving equation (A31) is identical to the one followed in deriving equations (A20), (A21) for the Store-and-Forward links (see Section A.1.9). That means the factor p ($0 \le p \le 1$) that reduces the flow allowed to leave the origin link, is calculated in the same way.

A waiting queue is built as follows

$$w_o(k+1) = w_o(k) + T \cdot [q_{demand,o}(k) - q_o(k)]. \tag{A32}$$

The global parameter ρ_{max} (*romax*), representing the maximum permissible traffic density value, as well as the origin specific parameters $Q_{max,o}$ (*capacity*), λ_o (*lanes*) are read from the Network Description file.

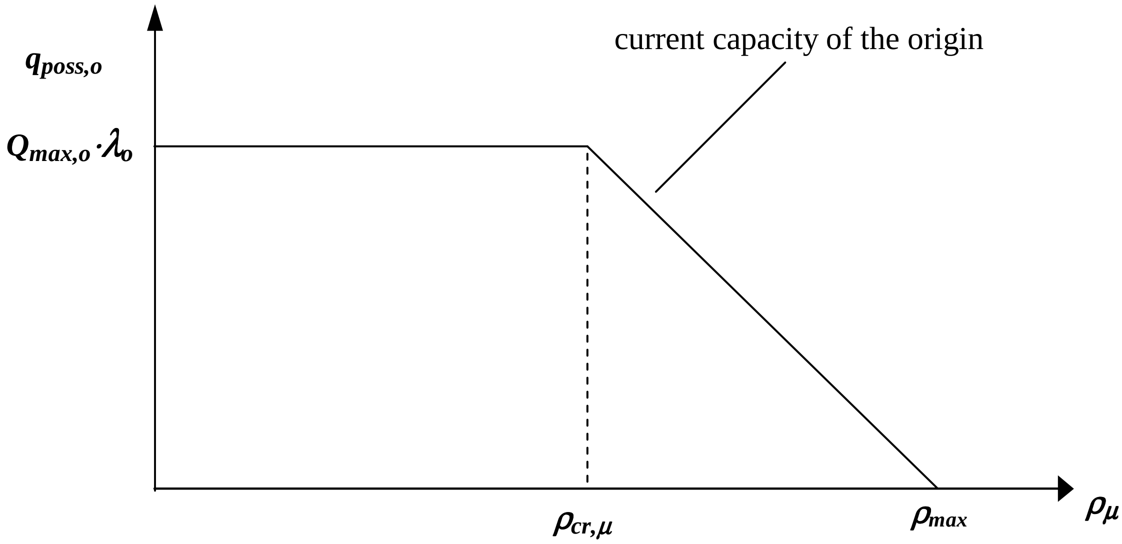


Figure A4: Limitation of origin inflow.

A.4 User-Optimal Dynamic Traffic Assignment

A.4.1 Basic Concepts

Dynamic traffic assignment (DTA) refers to distributing traffic demand with the same origin and destination (OD) among alternative routes of a traffic network for all $k \in [0, \mathrm{K}]$ so that some optimality principles are satisfied. Here, the origin stands not only for origin links, but also for bifurcation nodes of a network. Based on different optimality principles adopted, DTA is generally classified as user-optimal DTA or system-optimal DTA. When user-optimal conditions are established, the travel times for each OD connection along alternative utilised routes are equal and minimum, which means that in the user-optimal case no driver can reduce his travel time by changing the route. Feedback strategies may be employed to approximate user-optimal DTA in a traffic network. This is achieved via simple reaction to the current traffic states at each time interval in the aim of equalising instantaneous (reactive) travel times (see below) despite the impact of various disturbances including incidents, weather conditions, demands, etc. Feedback strategies for user-optimal DTA are incorporated in METANET in a generic way for simple use. This section is concerned with the user-optimal DTA device of METANET. A test example is given in Section 4.2.

Splitting rates at bifurcations play a central role for dynamic traffic assignment in traffic networks. In fact, the feedback DTA strategies incorporated in METANET determine the splitting rates so as to achieve approximate DTA in the simulated motorway network. For the convenience of explaining how METANET's DTA device works, some basic notions must first be presented:

- **Instantaneous (reactive) travel time** along a route including several links, is an ideal travel time spent by an ideal vehicle travelling that route under the current (measurable) traffic conditions.
- **Experienced (predictive) travel time** along a route including several links, is the real travel time that vehicles will experience along the route. Clearly, the experienced travel time becomes known only after completion of the corresponding trip.

Consider a **bifurcation-destination (BD) couple** (n,j), where the destination j is reachable via several out-flowing links. These out-flowing links are indexed with *m*. We define the instantaneous travel time $\tau_{n,\mathrm{j}}^{\mathrm{m}}(k)$ as the shortest travel times at time k from bifurcation *n* to destination *j* via the out-flowing link *m*. The attribute ***shortest*** is used because each direction may lead to further downstream bifurcations, i.e. there may exist more than two alternative routes from *n* to *j*.

Route guidance and dynamic traffic assignment considerations in METANET are based on the notion of splitting rates at bifurcation nodes rather than on path assignment. Among other advantages, this approach enables consideration of route guidance or traffic assignment for a part of the network (rather than the whole network) if so desired by the user.

A.4.2 Dynamic User Optimality

Generalising equ. (26) in [3], introducing $0 \le \beta_{\min} \le \beta \le \beta_{\max} \le 1$ and taking the (reactive or predictive) travel time as the travel cost, dynamic user optimal (DUO) conditions are established if:

$$\begin{aligned} &\beta_{n,\mathrm{j}}^{\mathrm{m}}(k) = \beta_{\min}\ , \quad \forall\, m \in (R_n \cap \sigma) \\ &\beta_{n,\mathrm{j}}^{\sigma}(k) = 1 - [\beta_{\min} \cdot (M-1)] \end{aligned} \quad , \qquad \text{(A33)}$$

where σ is the index of the out-link on which the shortest travel time to *j* is found, R_n is the set of out-links through which *j* is reachable ($R_n \cap \sigma$ the same set but without σ) and M is the number of links in R_n. $\beta_{\min}$ and $\beta_{\max}$ are the upper and lower bounds as specified by the user (i.e. *beta_max* and *beta_min* in section 3.4.3.1).

In the special case where there is no distinguished shortest direction, i.e. when $\tau_{n,\mathrm{j}}^{1}(k) = \ldots = \tau_{n,\mathrm{j}}^{\mathrm{m}}(k) = \ldots = \tau_{n,\mathrm{j}}^{\mathrm{M}}(k)$ holds, the $\beta_{n,\mathrm{j}}^{\mathrm{m}}(k)$ values are free to take any values between the bounds. The objective of DTA strategies is to come close to that condition if possible, i.e. as long as the splitting rates do not hit the upper or lower bounds.

The feedback strategies for DTA adopted in METANET are of type Bang-bang, P or PI . Since the predictive travel time difference depends upon the future traffic conditions and is difficult to predict in real time, the instantaneous (reactive) travel time difference is used as the feedback information for the strategies. Thus, the feedback strategies attempt to keep the reactive travel time difference close to zero. But, in reality, the experienced (predictive) travel time differences are more important for commuters. Due to time variation of the traffic conditions, the experienced travel times may be different from the reactive travel times. Therefore, the experienced travel times for each BD-couple (n,j) are also calculated within METANET. For this purpose, virtual probe vehicles are moved from each bifurcation node down the network according to the prevailing mean speed in the corresponding links. After the probe vehicles arrive at the destinations, the experienced travel time differences become available and can be used for comparison with the reactive travel time differences.

A.4.3 Feedback DTA Methods

The general structure for feedback dynamic traffic assignment is displayed in Figure A5. In the following $\tau_{n,\mathrm{j}}^{\mathrm{m}}(k)$ refers to reactive travel times.

Bang-bang strategy: Set $\beta_{n,j}^{m}(k)$ to $\beta_{\min}$ for all out-links where $\tau_{n,\mathrm{j}}^{\mathrm{m}}(k)$ is currently not the shortest and set $\beta_{n,j}^{\sigma}(k)$ so as to satisfy $\sum_{m\in R_n}\beta_{n,j}^{m}=1$. This strategy is directly derived from the definition (A33). The main advantage of the bang-bang strategy is its simplicity (no parameter needs to be specified). However, due to its switching nature, the bang-bang strategy creates oscillations in the trajectories of the splitting rates and the travel time differences.

P-strategy and **PI-strategy:**

The formula of the P-strategy is:

$$\beta_{n,\mathrm{j}}^{\mathrm{m}}(k)=\beta_{n,\mathrm{j}}^{\mathrm{N,m}}+K_p\Delta\tau_{n,j}^{m}(k)\,,\quad \forall\, m\in(R_n\cap\sigma) \tag{A34}$$

and the formula of the PI-strategy is:

$$\beta_{n,\mathrm{j}}^{\mathrm{m}}(k) = \beta_{n,\mathrm{j}}^{\mathrm{m}}(k-1) + K_p[\Delta\tau_{n,j}^m(k) - \Delta\tau_{n,j}^m(k-1)] + K_i\Delta\tau_{n,j}^m(k)\,, \quad \forall\, m \in (R_n \cap \sigma) \qquad \text{(A35)}$$

The value for $\beta_{n,\,j}^{\sigma}$ (excluded from calculation in (A34) or (A35)) is determined by:

$\beta_{n,\,j}^{\sigma} = 1 - \sum_{\mu \in (R_n \cap \sigma)} \beta_{n,\,\mathrm{j}}^{\mu}$ (i.e. the rest is sent to the shortest direction). In the frame of (A34) and (A35) σ denotes the out-link with the shortest travel time under the current traffic conditions.

In both formulae $\Delta\tau_{n,j}^m(k)$ is determined by: $\Delta\tau_{n,j}^m = \sum_{\mu \in (R_n \cap m)} \tau_{n,\,\mathrm{j}}^{\mu} / (M-1) - \tau_{n,\,\mathrm{j}}^{\mathrm{m}}$, means the travel time trough *m* is subtracted from the arithmetic mean of the travel times at other out-links. For the two out-link case this way of calculation results in taking the simple difference between the two travel times.

The resulting $\beta_{n,\,j}^{m}$ values are bound (truncated) by $[0,\ 1]$.

As a last step $0 \le \beta_{\min} \le \beta \le \beta_{\max} \le 1$ is considered by according redistribution of rates.

Specific Parameters of the P-Strategy:

It is well-known that an increase of the feedback gain K_p leads to a quicker, but, after a certain threshold, possibly oscillating behaviour of the feedback loop. We know as well that, under stationary conditions, the P-strategy leads to non-zero offsets, i.e. $\Delta\tau_{n,j}^m(k) \neq 0$ for $k \to \infty$, whose values is inversely proportional to K_p. With the parameter K_p chosen sufficiently high, the P-strategy tends towards the bang-bang strategy.

Specific Parameters of the PI-Strategy:

K_p and K_i are the proportional and integral gains of the feedback law. The well-known advantage of the PI-strategy, as compared to the P-strategy, is that it leads to zero offset in the steady state, independently of the values of the (constant) disturbances (i.e. demand, OD). On the other hand, two regulation parameters must be specified (instead of one for the P strategy). Note that an increase of K_p and K_i typically leads to a quicker, but potentially oscillating behaviour of the control loop.

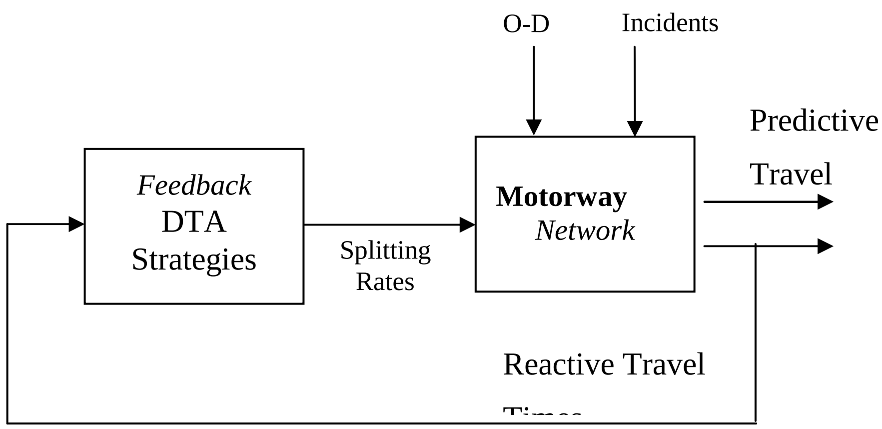


Figure A5: General structure of feedback user-optimal DTA

A.5 Adopted Algorithms for Travel Time Calculation

The application of the above described DTA-feedback laws requires the calculation of the instantaneous (reactive) travel times for all (n,j)-couples subject to DTA. More precisely, the travel times on the currently shortest route from n to j via the out-links where j is reachable, i.e. the $\tau_{n,\mathrm{j}}^{\mathrm{m}}(k)$ values have to be calculated in all simulation time steps *k*.

The calculation of the disbenefit criterion (see A.6) and the output of the Route Data file requires in addition the calculation of the experienced (predictive) travel times for the same (n,j)-couples.

In both cases the task represents a shortest path problem which has to be solved for certain sub-networks of the simulated network. With regard to instantaneous (reactive) travel times, we have an ordinary shortest path problem while the experienced (predictive) travel time calculation is based on the solution of a dynamic shortest path problem. Dijkstra's algorithm which exhibits a moderate increase of calculation time with increasing network complexity, is adopted for both problems with specific adaptations. The application for the instantaneous travel time calculation differs from the application for the experienced travel time calculation mainly with respect to the way the sub-networks are determined and processed.

A.5.1 The Principle of Dijkstra's Algorithm

Dijkstra's algorithm assigns to each node of the considered network the "costs" (e.g. length or travel time) which are encountered on the shortest way from a certain "root" node. The algorithm keeps track of two sets of nodes (being subsets of all nodes of the network) while performing its assignment procedure:

- the set of nodes *I* for which a definitive cost value has still to be found and

- the set of nodes *C* for which cost values are already computed and which are candidates for a definitive value.

Set *C* is a subset of set *I*.

The procedure of the algorithm is the following:

1) Initially the set *I* comprises all nodes of the considered network. Set *C* is empty.
2) The root node is removed from *I* and gets its definitive value which is zero (or some other value reflecting the cost for reaching the root from somewhere else).
3) All nodes which are direct neighbours of the root, i.e. which are reachable by going one link ahead, are searched and are put into *C*. They get (non-definitive) cost values which correspond to the cost of the respective links from the root to the particular nodes. If a neighbour is found which is already in *C* (e.g. in case of multiple links from the root to that neighbour), the lowest cost value is assigned.
4) If *I* is empty, the procedure is terminated. All considered nodes have definitive lowest cost values. If the network has more than one node, this cannot happen immediately after step 3).
5) Among the nodes of *C* the node n_{new} with the absolutely lowest cost value is searched which can be now classified as having a definitive value. Consequently n_{new} is removed from *C* as well as from *I*.
6) In the same way as in 3), all direct neighbours of n_{new} are searched and their (non-definitive) cost values are determined. The assigned (non-definitive) cost values are the costs of the respective links from n_{new} to the particular neighbours plus the cost value of n_{new}. If a neighbour is already in *C*, its new cost value is only assigned if it is lower than the existing one.
7) The procedure loops back to step 4).

A.5.2 Calculation of Instantaneous Travel Times

For each simulation time step *k* the instantaneous travel time τ_l^I on a link *l* is calculated by:

$\tau_l^I = \sum_i L_l / v_{l,i}(k)$ for normal motorway links and

$\tau_l^I = T_{lag,l} + w_l(k) / q_l(k)$ for store-and-forward links

where L_l is the length of the segments *in link l*, $v_{l,i}(k)$ is the modelled speed in segment *i* of link l at time step *k* while $T_{lag,l}$ is the lag time, $w_l(k)$ is the modelled queue length, and $q_l(k)$ is the modelled outflow of the store-and-forward link *l*.

Instantaneous travel times are link costs which are not dependent on the order of processing the links in the shortest path algorithm. Therefore it is possible to apply Dijkstra's algorithm beginning with a destination *j* as root and going backward in the network. This leads to the following effective way for calculating all required travel times:

- Loop over all destinations *j* for which DTA is applied at some node:
  - Define as sub-network to be considered, the network which comprises all nodes where DTA is applied with respect to *j*, plus all nodes which are situated downstream on possible routes to *j*.
  - Apply Dijkstra's algorithm to that sub-network with link costs as described above and the node directly upstream of *j* as the root.
  - Calculate for all nodes where DTA is applied with respect to *j*, the travel times $\tau_{n,j}^{m}(k)$ by adding the travel time on the particular out-link to the travel time as found by Dijkstra's algorithm for the node directly downstream that out-link.

A.5.3 Calculation of Experienced Travel Times

Experienced travel times are calculated by use of virtual probe vehicles starting at each time step *k* at each node *n*. The considered link travel times are the ones prevailing in the moment the virtual vehicle reaches the particular link on its journey. Clearly, these travel times cannot be determined before it is known how long it took (on the shortest way) to reach the particular link after starting at node *n*. The order of stepping through the network in the shortest path algorithm is determined by the vehicle movement, i.e. downward from the node *n* to destination *j*.

In the algorithmic realisation, the experienced travel time on each considered link *l* is obtained by sending a virtual probe vehicle into that link. It bears as property the time τ_{probe} which consists of the start time at node *n* plus the time spent so far to reach the node at the upstream end of *l*. When proceeding through the segments of *l*, τ_{probe} is increased for each passed segment *i* by $L_l / v_{l,i}(k_{probe})$, where L_l is the segment length and $v_{l,i}(k_{probe})$ is the modelled speed in segment *i*. The time index k_{probe} is determined by τ_{probe} / T. It is limited to the index at the end of the prediction horizon, i.e. if τ_{probe} exceeds the prediction horizon, the virtual vehicle nevertheless finishes its journey to *j* while as experienced conditions the ones at the end of the prediction horizon are taken.

In store-and-forward links, the virtual vehicle proceeds according to the lag time which results in a (non time-dependent) increase of τ_{probe} by $T_{lag,l}$, and the modelled queue which results in an additional increase by $w_l(k_{probe}) / q_l(k_{probe})$, where $w_l(k_{probe})$ is the modelled queue length and $q_l(k_{probe})$ the modelled flow. The time index k_{probe} is calculated as above.

Calculation of all required travel times is performed by going straightforwardly through the (n,j)-couples which are subject to DTA. This leads to the following algorithm to be applied for each time step k:

- Loop over all nodes *n* where DTA is applied:
  - Loop over all out-links *m* of the node:
    - Loop over all destinations *j* which are subject to DTA in *n* and calculate the travel time on the node's out-links by:

- Defining as sub-network the network which comprises the node directly downstream the particular out-link, plus all nodes which are situated downstream on possible routes to *j*.
- Applying Dijkstra's algorithm to that sub-network where the node directly downstream the out-link *m* is the root. To that root node a (non-zero) value is assigned which corresponds to the travel time on the out-link leading to it. The cost (experienced travel time) of each link is calculated (as described above) as the algorithm proceeds, i.e. there are no available costs for the network links when the algorithm starts.
  - If *j* is not the first destination which is processed for *n* on the particular out-link, the cost values of all nodes being common between the currently treated sub-network and the last treated sub-network are also valid in the new context and can be retained. In these cases Dijkstra's algorithm is started not from scratch but with an accordingly reduced number of nodes to be treated.
- The value which was assigned by the algorithm to the node directly upstream of *j* is the searched experienced travel time from *n* to *j* on the considered out-link of *n*.

A.6 Performance Criteria

The following performance criteria are calculated during the simulation run and are written at the end of the simulation data output file:

- Total Travel Time τ_G (in veh·h):

  $$\tau_G = \tau_{G,N} + \tau_{G,SAF} \tag{A36}$$

  where $\tau_{G,N}$ and $\tau_{G,SAF}$ represent the total travel time of the vehicles in the normal and Store-and-Forward links, respectively, and are calculated as follows:

  $$\tau_{G,N} = T \sum_k \sum_m L_m \lambda_m \sum_i \rho_{mi}(k)\,. \tag{A37}$$

$$\tau_{G,SAF} = T\sum_{k}\sum_{saf} n_{d,saf} \ . \tag{A38}$$

where $n_{d,saf}$ represents the number of vehicles which have already entered the store-and-forward link saf but, due to the internal travel time, have not yet reached the queue (as found also in (A23)).

This criterion represents the total travel time of all vehicles in the network, but being not in a queue, over the simulation time horizon.

- Total Waiting Time at network origins $\tau_{W,O}$ (in veh·h) calculated as follows

$$\tau_{W,O} = T\sum_{k}\sum_{o} w_o(k) \quad o = 1, 2, 3, \ldots, O \tag{A39}$$

where *O* is the total number of network origins. This criterion represents the waiting times at all network origins over the whole simulation time horizon.

- Total Waiting Time at Store-and-Forward links $\tau_{W,SAF}$ (in veh·h) calculated as follows:

$$\tau_{W,SAF} = T\sum_{k}\sum_{saf} w_{saf}(k) \quad saf = 1, 2, 3, \ldots, SAF \tag{A40}$$

where *SAF* is the total number of Store-and-Forward links in the network. This criterion represents the waiting times at all Store-and-Forward links of the network over the whole simulation time horizon.

A waiting time at an origin or at a Store-and-Forward link appears as the result of an existing queue. A queue may be created due to limited flow capacity and/or congestion spillback from the downstream part of the network and/or metering control measures, that reduce the network inflow to values below the demand assigned to that origin or Store-and-Forward link (see also sections A.1.8 and A.3 for details).

- Total Time Spent τ_S (in veh∗h) calculated as the sum of the Total Travel Time and Total Waiting Time at origins and in Store-and-Forward links:

$$\tau_S = \tau_G + (\tau_{W,O} + \tau_{W,SAF}). \tag{A41}$$

- Total Distance Travelled L_G (in veh·km):

$$L_G = L_{G,N} + L_{G,SAF} \tag{A42}$$

where $L_{G,N}$ and $L_{G,SAF}$ represent the total distance travelled by all vehicles in the normal and store-and-forward links, respectively, and are calculated as follows

$$L_{G,N} = \sum_k T \sum_m \sum_i q_{mi}(k) \cdot L_m. \tag{A43}$$

$$L_{G,SAF} = \sum_k T \sum_{saf} q_{saf}(k) \cdot L_{saf}. \tag{A44}$$

This is the sum of the distances travelled by all vehicles during the simulation time horizon. q_{saf} is the flow entering the Store-and-Forward link.

- Total Amount of Fuel Consumed V_G (in veh·litres):

$$V_G = V_{G,N} + V_{G,O} + V_{G,SAF} \tag{A45}$$

where $V_{G,N}$, $V_{G,O}$ and $V_{G,SAF}$ represent the fuel consumed within the motorway links, the origins and Store-and-Forward links, respectively, and are calculated as follows

$$V_{G,N} = \sum_k \frac{T}{100} \sum_m L_m \sum_i q_{m,i}(k) \cdot \begin{cases} b + \dfrac{c}{v_{m,i}(k)} + a\,(v_{m,i}(k) - 60)^2, & if\ \ v_{m,i}(k) > 60 \\ b + \dfrac{c}{v_{m,i}(k)}, & if\ \ v_{m,i}(k) \le 60 \end{cases} \tag{A46}$$

$$V_{G,O} = \sum_k \frac{T}{100} \sum_o w_o(k) \cdot v_o(k) \cdot \begin{cases} b + \dfrac{c}{v_o(k)} + a \cdot (v_o(k) - 60)^2, & if\ \ v_o(k) > 60 \\ b + \dfrac{c}{v_o(k)}, & if\ \ v_o(k) \le 60 \end{cases} \tag{A47}$$

where v_o is a virtual speed value which is calculated under the assumption of a fixed queue density ρ_{queue} of 100 veh/km. From the general relationship $q = \rho \cdot v \cdot \lambda$, as expressed in (A3), $v_o(k) = q_o(k) / (\rho_{queue} \cdot \lambda_o)$ can be derived. Finally we have

$$V_{G,SAF} = \sum_k \frac{T}{100} \sum_{saf} b \cdot q_{saf}(k) \cdot L_{saf} + c \cdot w_{saf} \tag{A48}$$

The coefficients a, b and c, used in (A46), (A47), and (A48), have the following meaning:

	for consumption term	units	used value
a	Speed-dependent per mileage	litres / km / veh • (km/h)$^{-2}$ •100	0.0016
b	Speed-independent per mileage	litres / km / veh • 100	4.49
c	per time (e.g. when queuing)	litres / h / veh • 100	122.0

These coefficients and their usage according to the above formulae were taken from [4].

The disbenefit criterion is used to assess the degree of approximation to the dynamic user equilibrium.

- Individual Disbenefit $d_{n,j}(k)$ and Total Disbenfit D (both in veh·h):

$$d_{n,j}(k) = \sum_{m \in (R_n \cap \sigma)} \left[q_{n,j}(k) \cdot (\beta_{n,j}^m(k) - \beta_{\min}) \cdot (\tau_{n,j}^{P,m}(k) - \tau_{n,j}^{P,\sigma}(k)) \right] \cdot T \tag{A49}$$

where σ is the index of the out-link on which the shortest travel time to j is found, R_n is the set of out-links through which j is reachable ($R_n \cap \sigma$ the same set but without σ), T denotes the simulation time step.

$$D = \sum_{(n,j) \in B} \sum_{k=0}^{K} d_{n,j}(k) \tag{A50}$$

where B denotes the set of the relevant (n,j)-couples.

For each simulation interval, the disbenefit $d_{n,j}(k)$ is the absolute value of the product of the number of vehicles directed to the time-longer routes at n, times the difference of predictive travel time $\tau_{n,j}^{P,m}$ compared to the shortest time. The total disbenefit D is the sum of the individual disbenefits $d_{n,j}(k)$ for all relevant (n,j)-couples over the whole simulation horizon K. If the DUO condition (A33) is fully established during the entire simulation horizon, D is zero.

APPENDIX B: GRAPHICAL OUTPUT

For displaying the traffic data generated or used by METANET (and its derivatives, e.g. METANET-DTA) in a transparent form, a graphical output program named METAGRAF is available, which offers four main options:

1. Plot of network topology as given in the Network Description file (see e.g. Figure 9),
2. Network traffic overview at given time instances (see e.g. Figure 6),
3. Line plots of traffic flows, speeds, densities, queue lengths, and composition rates (as found in the Simulation Data file and in the boundary data files) over time for selected links (see e.g. Figure 8),
4. Line plots of splitting rates, node inflows, travel times, and disbenefit values (as found in the Route Data file, see Section 3.5.3) over time for selected (n,j)-couples (see e.g. Figures 11-16).

METAGRAF is a Windows9x application. User input is done via self-explaining menus.

In the diagrams, every curve is drawn in a different colour or line pattern. All axes are scaled in a raster of 1 cm (in calibrated printer/plotter output) which helps for easy quantitative interpretation of the plots.

A hard-copy function suited for plotter/printer and with calibrated axes (i.e. not just a screen dump) is provided in any display mode. The output format is HPGL or PostScript.

Installation and Execution

In order to install METAGRAF, the following steps have to be performed:

- The METAGRAF executable “mg_win.exe” has to be copied into a certain directory. Its name is arbitrary (e.g. “\bin\metagraf”).
- It is recommended to put METAGRAF on the desk top (e.g. by selecting the executable (click on it) in the Explorer utility and dropping it on the desk top). The working directory (where the input data are taken) has to be given in the settings

(characteristics) of the desk top item (use the right mouse button to pop up the according menu).

When starting METAGRAF (in the different ways as Windows allows), the working directory has to be defined. Alternatively to the start via double clicking on the desk top item (where the working directory is specified as explained above), METAGRAF may also be executed from an MS-DOS console window while being in the appropriate directory (by a command line like: “\bin\metagraf\mg_win”). It is recommended that the user specifies the path of METAGRAF in the AUTOEXEC.BAT file.

In the main menus of METAGRAF it is moreover possible to specify an input path which is used as a prefix to the input file names.

Input Specification

The main menus of METAGRAF provide, besides the buttons for the different plot options, also user input fields for the specification of the names of the various input files:

“Network File Name”	Specifies the name of the Network Description file. The assumed file name extension is “nwd” or “nwo”.
“Data File Name”	Name of the (first) Simulation Data file. The assumed extension is always “smd”.
“Data File 2”	Name of a second Simulation Data file for comparison purposes (see 0)
“Measurement Data”	Name of the Boundary Data file (contains typically the demands at origins). The assumed file name extension is “msd” or “mdo”. This name is also used of the OD-matrix file (extensions “odm” or “odo”).
“Route Data File”	Name for the Route Data file (see 0). The assumed extension is always “rtd”.
“Sim. Control File”	Name of the Simulation Control file (contains information about comparison locations). The assumed file name

extension is “ctr” or “cto”.

Display Parameters file

The display parameter file controls the proportions of the network plot items and their optional labelling on the screen. Size specifications have to be given in centimetres. For the screen, this may correspond only roughly to the actual sizes. Nevertheless, using this unit is a good compromise between portability and transparency.

If the display Parameters file is not existing, default values are taken by METAGRAF. However, if the file is provided by the user, the values of **all** the following parameters have to be contained in the file.

This file is named ”*nwdname*.dpa” (*nwdname* is the Network File name) and is structured as follows:

(begin of file) ---
| *tsize_screen tsize_hard show_nnames show_lnames show_onames show_dnames*
| *num_size_screen num_size_hard show_numeric*
| *node_radius_screen node_radius_hard*
| *arrow_width_screen arrow_width_hard*
| *od_arrow_len_screen od_arrow_len_hard*
| *minwidth_cm_screen minwidth_pix_screen minwidth_cm_hard minwidth_pix_hard*
| *width_1000_screen width_1000_hard*
| *border_screen border_hard*
| *menu_height_screen menu_height_hard*
| *thresh_v_low_med thresh_v_med_max thresh_ro_low_med thresh_ro_med_max*

(end of file) ---

Description of Entries:

Name	**Type**	**Description**
tsize_screen	real	text size (in cm) of network element labels on screen
tsize_hard	real	text size (in cm) of network element labels on hardcopy
show_nnames	integer	switch (1 = on, 0 = off) for the display activation of the labelling of node names
show_lnames	integer	switch (1 = on, 0 = off) for the display activation of the labelling of link names
show_onames	integer	switch (1 = on, 0 = off) for the display activation of the labelling of origin names
show_dnames	integer	switch (1 = on, 0 = off) for the display activation of the labelling of destination names
num_size_screen	real	text size (in cm) of the numeric display of traffic variables (realised for entrance queue lengths) for screen
num_size_hard	real	text size (in cm) of the numeric display of traffic variables (realised for entrance queue lengths) for hardcopy
show_numeric	integer	switch (1 = on, 0 = off) for the activation of the numeric display of traffic variables
node_radius_screen	real	radius of the node symbol (in cm) on screen
node_radius_hard	real	radius of the node symbol (in cm) on hardcopy
arrow_width_screen	real	width (in cm) of the arrow symbol at the link tips on screen
arrow_width_hard	real	width (in cm) of the arrow symbol at the link tips on hardcopy
od_arrow_len_screen	real	length (in cm) of the origin/destination symbol on screen
od_arrow_len_hard	real	length (in cm) of the origin/destination symbol on hardcopy
minwidth_cm_screen	real	minimal width of links in cm on screen
minwidth_cm_hard	real	minimal width of links in cm on hardcopy
minwidth_pix_screen	integer	minimal width of links in pixel on screen, if the cm-value results in less pixels, this values is adopted
minwidth_pix_hard		minimal width of links in pixel on hardcopy, if the cm-

		value results in less pixels, this values is adopted
width_1000_screen	real	link width growth per 1000 vehicles of flow calculated for this link on screen
width_1000_hard	real	link width growth per 1000 vehicles of flow calculated for this link on hardcopy
border_screen	real	border around the network plot in cm on screen
border_hard	real	border around the network plot in cm on hardcopy
menu_height_screen *menu_height_hard*	real real	height of the menu bar below the network plot; this entry is included for compatibility reasons with METANET; it determines also the sizes of the left hand side clocks; when varying this entry, the resulting screen has to be checked for legibility
thresh_v_low_med *thresh_ro_low_med*	real real	threshold between low and medium values for link colouring; for speeds it is the turning point between red and yellow, for densities the turning point between green and yellow
thresh_v_med_max *thresh_ro_med_max*	real real	threshold between medium and high values for link colouring; for speeds it is the turning point between yellow and green, for densities the turning point between yellow and red

Plot of Network Topology

This is the menu item “NETWORK-PREVIEW”. When executing this option, only a valid Network Description file is needed. A plot of the network as described by this file is drawn. All nodes and links and their interconnections are viewed. Nodes are drawn as circles and the links in between as arrows where the segment boundaries in the links are marked accordingly. This kind of display can be used to validate the network topology data prepared in Network Description file.

METAGRAF scales the picture automatically so as to fill the screen without clipping parts of the network or changing the aspect ratio. The entries *x_coord*, *y_coord*, and *angle* in the Network Description file are used to arrange the network nodes, origins, and destinations as desired. The screen menu contains three options:

Rotate	Rotate the picture by 90 degrees; since the picture is scaled automatically, rotation leads to a better utilisation of the screen if the width/height ratio of the network fits better with the screen dimensions in rotated position.
Print	Printer/plotter output of the current drawing.
Exit	Back to main menu.

Network Traffic Overview

This is the menu item "NETWORKPLOT". The traffic situation in the whole network, as valid for a certain time instant, is displayed. As for the topology plot, the name of the Network Description file must be defined. In addition a valid name for the simulation data file is expected.

A network plot is drawn like in the above described topology plot, but additionally the traffic situation according to the data from the simulation data file is displayed. This is done in the following way:

(i) Different colours (or shades of gray) reflect the traffic condition of a particular segment. White indicates free flow, yellow (or grey) indicates critical condition, and red (or black) indicates congestion. Figures B1 and B2 indicate how these colours are determined. The values of the threshold parameters (*thresh_...*) are taken from the Display Parameters file (see 0). The used values are shown on a legend in the lower left corner of the plot. The colour assignment may be density-based or speed-based. The screen menu offers the possibility to switch between the two modes ("to Speed"/"to Density" menu item). If there are no speed or density values available, which is always the case for origins, destinations, and dummy links, the corresponding links remain white.

(ii) The width of each segment of a link reflects the magnitude of the current traffic flow. Every millimetre corresponds to a certain amount of vehicles per hour (see *width_1000_screen/hard* display parameter in 0). The default value for this parameter is 1 mm per 1000 veh/h. There is a certain minimum (*minwidth_...* display parameters, see 0), i.e. flows below that value result in an according constant displayed width. The default value for this parameter is 0.4 mm on the screen and 0.3 mm for the printer plot.

The time instant for which the plot is drawn is displayed by a clock in the lower left corner of the picture.

Menu options:

Rotate	As for topology plot (see 0).
to Speed / to Density	This menu item switches between density-based and speed-based segment coloring. The mode, which is currently not active and therefore subject to choose, is offered in the menu, i.e. if the current colouring mode is by density, the option “to Speed” is shown.
Forward	Display next time step.
Backward	Display previous time step.
Select Time	Selection of a certain time instant. One of the offered time intervals has to be chosen. Add (or Sub) adds (or subtracts) the interval from the current time. This procedure has to be repeated till the clock shows the desired time. If the chosen time does not fit directly with a time instant for which data are available, the next possible time instant is taken.

Other items of sub-menu:

Commit	Exit time selection and draw new time instant.
Exit	Quit time selection.
Start	Set time to first available time instant.
End	Set time to last time instant.
Print	Printer/plotter output of the current drawing.
Exit	Back to main menu.

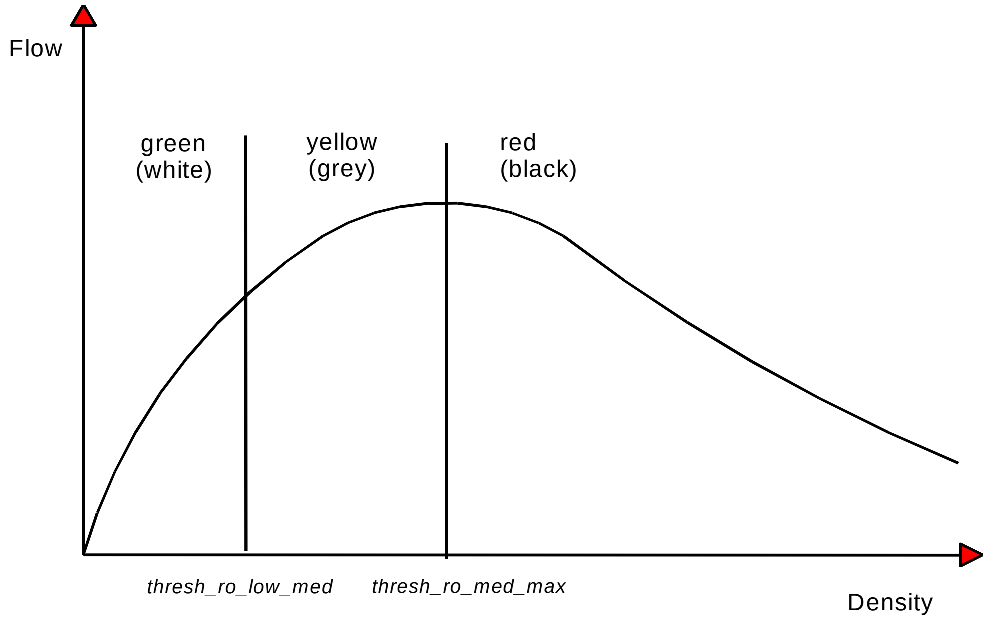


Figure B1: **Thresholds for colour assignment (density criterion).**

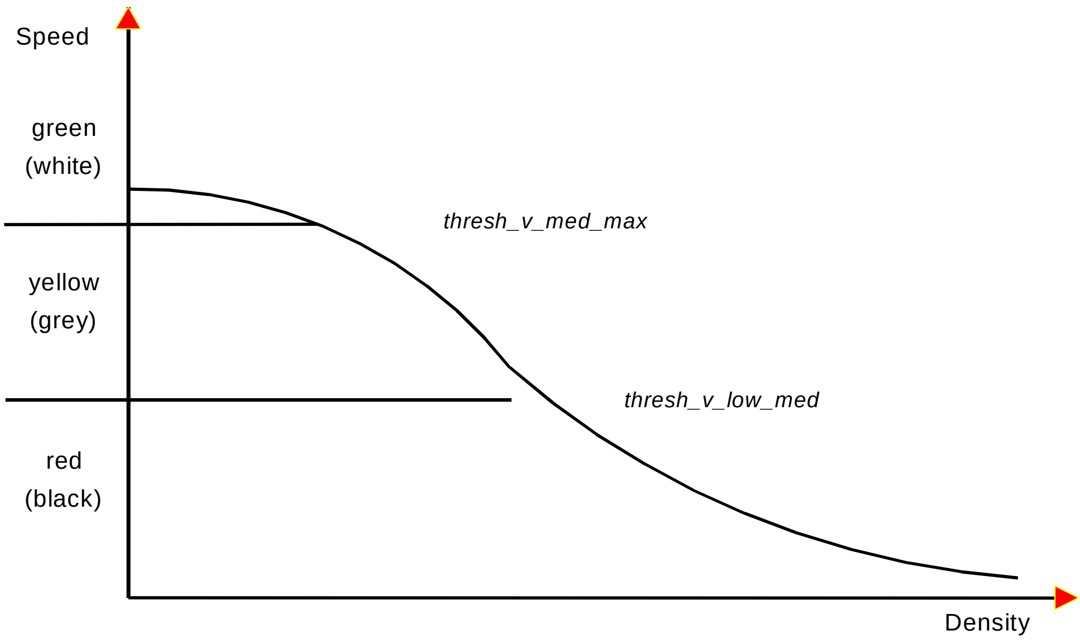


Figure B2: **Thresholds for colour assignment (speed criterion).**

Line Plots of Link Variables

This is the menu item “LINK VARIABLES”. Line plots over time of the traffic variables flow, speed, density, queue length, and composition rate from selected links can be made. Four display modes can be chosen:

“Line plot with simulated data only”. Just the data form the Simulation Data file (*.smd) are displayed.

1. “Line plot with measured data only”. Just the data form the Boundary Data file (*.msd or *.mdo) are displayed.
2. “Compare simulated and measured data”. Displays data from the Boundary Data file and the Simulation Data file. The matching of the data (for putting them into the same diagram for comparison purposes) is done via the list of internal measurement locations as found in the Simulation Control file.
3. “Compare two simulations”. The contents of two Simulation Data files are displayed (e.g. from runs with and without control strategy). Data of the same link are matched, i.e. put in the same diagram for convenient comparison.
4. Moreover, the option “Read OD-matrix file” can be activated/deactivated.

It is distinguished between single-location plots where one or several variables (flow, speed, and density) of one selected location are plotted, and multiple-location plots where only one variable is plotted but for several locations in the same diagram. The latter possibility can be used to visualise the spatial evolution of traffic. Composition rates can be only displayed for single locations and not in direct conjunction with other variables.

In the comparison mode, METAGRAF does an automatic matching of the data to be compared in order to display the corresponding curves in the same diagram, if available. This is done via the link names. In the case of comparison of measurement and simulation data, the list of internal measurement locations in the Simulation Control file is used for the assignment of measurement locations to network link locations.

Depending on the display mode, the following files are required:

required for display mode:	1	2	3	4
Simulation Data file (1st)	✓		✓	✓

Simulation Data file (2nd)			✓
Boundary Data file	✓	✓	
Simulation Control file	✓		

If the “Read OD-matrix file” option is activated, the OD-matrix file plus the simulation control file is expected in modes 2 and 3.

In each of the described display modes a menu bar provides the submenu functions:

Location	A list of locations (by link name and kilometre value) for which data can be plotted, is presented.
Variable	The presented list of selectable variables comprises flow, speed, density, and queue length, plus their combinations. Depending on the nature of the chosen link, the corresponding variables will show up for selection.
Time Scale	A zoom function for the time axis is provided.
Scale	A scaling of the Y-axis of the plot can be done individually for each traffic variable.
Redraw	For re-drawing the diagram (e.g. after obstruction by other windows).
Print	Printing functions as explained in Section 0.
Exit	Back to main menu.

Line Plots of Node Variables

This is the menu item “NODE VARIABLES”. Line plots over time of splitting rates, node inflows, primary and secondary travel times of (n,j)-couples, and disbenefit values for selected (n,j)-couples (see Appendix A.4 for the definitions) can be drawn. The only data source is the Route Data file that contains data sorted by bifurcation-destination couple. Travel times and disbenefit values are defined for the dynamically shortest route from the bifurcation to the destination via defined out-link (one of the two possible out-flowing links).

There are no different display modes (as for the link variable plot). The user gets directly to the drawing window where he finds a menu bar with the items:

Location — A list of bifurcation-destination couples, for which data can be plotted, is presented.

Variable — The presented list of selectable variables comprises:

- splitting rates (on both out-links),
- travel times reactive (absolute in minutes, on both out-links),
- travel time difference reactive (absolute in minutes, travel time via second out-flowing link minus travel time via first out-flowing link),
- relative travel time difference reactive (in percent, absolute difference as above divided by travel time via first out-flowing link),
- travel times predictive (absolute in minutes, on both out-flowing links),
- travel time difference predictive (absolute in minutes, travel time via second minus travel time via first out-flowing link),
- relative travel time difference predictive (in percent, absolute difference as above divided by travel time via first out-flowing link),
- partial node inflow (in veh/h, portion for particular destination),
- individual disbenefits (absolute in veh·h, on both out-flowing links).

Time Scale, Scale, Redraw, Print, Exit — same as explained in Section 0.

Printer/Plotter Output

As already mentioned, all screen drawings can be hard-copied on printer or plotter. The quality of the printer-plots is independent from the screen resolution. All drawings on printer as well as on plotter are scaled in true centimetres, i.e. a ruler can be used to measure the values on the curve. All printer/plotter output is done via file. The output files are numbered in the extension as they are created by METAGRAF. For performing an output for printer/plotter, the menu item "Print" has to be selected after the screen plot is finished. A submenu asks about the printer/plotter type. The following output types are available:

- HP 7550: Output in HPGL for the HP 7550 plotter and compatibles. Curves in diagrams are plotted in colour. The following pen no. to colour assignment is used:

  1 black
  2 red
  3 green
  4 blue
  5 cyan
  6 magenta
  7 yellow.

  The names of the output files are "netplt*nn*.plt" for network plots and "linplt*nn*.plt" for line plots (link variables and node variables plots), where *n* is a unique number which is incremented after each performed plot (beginning with 1).
- Postscript: Output is written to a PostScript file. All coloured lines are converted to patterned lines, coloured areas are represented by grey-shaded areas. The naming of the output files is as for HPGL plots but with the extension ".ps".

APPENDIX C: INPUT FILES FOR BASIC TEST EXAMPLE

metanet.ctr

```
C  ****** SIMULATION CONTROL FILE ******
H MOTORWAY NETWORK: A6-A6a-A6b-A10
H METANET 1990 Version
C
C Sim.start time, Sim.end, Sim.step[sec]
|  04:00          10:00     10
C Sim.mode, Type of control
|  0          0
C Correspondence between measuring locations in input and origins/destinations
C measuring loc. name, link name, link km
| U1                    U1
| U2                    U2
| U3                    U3
| U4                    U4
| U5                    U5
| Z1                    Z1
| Z2                    Z2
E
C Correspondence between measuring locations in input and comparison locations
C measuring loc. name, link name, link km
E
C time of incident, clearance time, location: link name, link km, severity
| 7:00              7:05                    L4         1.5       0.33
E
C output:
C type, start,   end,     time step
|  c      04:00  10:00   00:06
C link name      link km ...
|  L13            1.35
|  U1
|  U2
|  Z1
|  Z2
E
C
C  ****** END OF FILE ******
```

metanet.nwd

```
C  ****** NETWORK DESCRIPTION FILE ******
C NETWORK DESCRIPTION FILE FOR A6A/B
C
C specifications in [...] are used for graphical output only,
C they can be omitted for simulation input
C
C PARAMETER TAU, KAPPA, NUE, VMIN, ROMAX, DELTA, PHI
|              20    13     35    7.0    180    0.8    2.0
C
C ORIGIN NAME     LANES  QINMAX/L  FREE-SPEED  [ANGLE]
|  U1             3      2300      109         270
|  U2             3      2300      109         270
|  U3             1      2200      109         315
|  U4             1      2200      109         225
|  U5             1      2200      109         225
E
C LINK NAME LANES CAP/LAN FRE-SPD ROCRIT CAP60  LEN    NrSeg
|  L2        3     2214.7  109     33.5   -1     0.8    2
|  L3        2     2214.7  109     33.5   -1     1.0    2
|  L4        3     2214.7  109     33.5   -1     3.15   7
|  L6        3     2511.0  115     36.0   -1     1.5    3
|  L7        3     2214.7  109     33.5   -1     0.95   2
|  L8        3     2148.6  109     32.5   -1     1.8    4
|  L11       3     2380.0  109     36.0   -1     1.0    2
|  L12       2     2214.7  109     33.5   -1     0.25   0
|  L13       3     1698.3   80     35.0   -1     1.8    4
|  L15       3     2214.7  109     33.5   -1     0.85   2
|  L17       2     2214.7  109     33.5   -1     1.3    3
|  L19       3     2214.7  109     33.5   -1     0.4    1
|  L21       3     2214.7  109     33.5   -1     0.95   2
|  L22       3     2214.7  109     33.5   -1     0.5    1
|  L23       3     2214.7  109     33.5   -1     1.25   3
|  L25       2     1486.0   80     35.0   -1     0.75   1
|  L27       2     2214.7  109     33.5   -1     0.4    1
|  L28       3     2214.7  109     33.5   -1     1.33   3
|  L29       2     2214.7  109     33.5   -1     0.2    0
|  L30       1     2214.7  109     33.5   -1     0.5    1
|  L31       2     2214.7  109     33.5   -1     0.5    1
E
C DESTINATION NAME LANES QBOUND/L FREE-SPEED [ANGLE]
|  Z1                3     -1        109        90
|  Z2                2     -1        109        90
|  Z3                2     -1        109        45
|  Z4                1     -1        109        45
|  Z5                1     -1        109        45
E
C NODE NAME [X    Y-KOORDINATES]
```

```
C   INLINK NAMES
C   OUTLINK NAMES
| N1        2    3
|   U1
|   L2
| N2        2    4.5
|   L2
|   L27 L3
| N3        2    6
|   L28 L3
|   L4
| N4        2   10
|   L4 U3
|   L6
| N5        2   13.5
|   L6
|   L7 L29
| N6        2   15
|   L7 L30
|   L8
| N7        2   18
|   L8
|   Z1
| N8        8    3
|   U2
|   L11
| N9        8    4.5
|   L11
|   L28 L12
| N10       8    6
|   L27 L12
|   L13
| N11       8    7.5
|   L13
|   L15 Z3
| N12       8    9
|   L15
|   L17 Z4
| N13       8   10.5
|   L17 U4
|   L19
| N14       8   12
|   L19 U5
|   L21
| N15       8   13.5
|   L21
|   L22 L31
| N16       8   15
|   L22 L29
```

```
|  L23
| N17       8   16.5
|  L23
|  L25 Z5
| N18       8   18
|  L25
|  Z2
| N19       3.5 14.6
|  L31
|  L30
E
C
C  ****** END OF FILE ******
```

metanet.msd

```
C  ****** INPUT TRAFFIC DATA FILE ******
P Simulation traffic input data plus comparison data (second line)
P for Tuesday, the 10th of January 1989
C
F 2(V, Q), 3(Q), 2(D), 6(D, V, Q)
C
C Collection Start Sample Interval/step
C hh:mm           hh:mm:ss
T 04:00      00:06    (line necessary since no time spec. with data, i.e. no "T" in F-line)
C
C Names of Measurement Locations (must not contain blanks)
C M3 = L4@0.8; M4 = L13@1.35; M5 = L6@0.85; M6 = L21@0.6;
N       U1            U2          U3    U4    U5    Z1          Z2
        L4@0.8            L6@0.85           Z1               L13@1.35           L21@0.6        Z2
C  V         Q     V         Q     Q     Q     Q     D           D
C      D        V       Q
| 1.2662E+02  490  7.1064E+01  550     0   210    40  7.100E-02  0.000E+00
   1.278E+00 7.6156E+01 290  1.278E+00 9.1047E+01 350  0.00E+00 2.130E+02 310
2.556E+00 8.9771E+01 690  2.556E+00 6.3676E+01 490  3.905E+00 6.7647E+01 520
| 8.5305E+01  330  1.1633E+02  450     0   220    40  0.000E+00  2.556E+00
   0.000E+00 2.130E+02 160  0.000E+00 2.1300E+02 170  0.00E+00 2.130E+02 240
2.556E+00 7.1568E+01 550  1.278E+00 1.0153E+02 390  2.556E+00 7.6112E+01 390
| 8.1498E+01  630  1.1633E+02  450    10   220    40  0.000E+00  3.905E+00
   0.000E+00 2.130E+02 220  0.000E+00 2.130E+02 210  0.000E+00 2.130E+02 210
3.905E+00 6.589E+01 760  2.556E+00 6.646E+01 510  3.905E+00 5.467E+01 420
| 1.0857E+02  420  1.0603E+02  410    10   220    40  1.278E+00  5.183E+00
   0.000E+00 2.130E+02 260  0.000E+00 2.130E+02 300  1.278E+00 9.897E+01 380
2.556E+00 8.066E+01 620  2.556E+00 9.244E+01 710  5.183E+00 5.865E+01 600
| 1.5256E+02  590  7.6281E+01  590    20   210    40  1.278E+00  2.556E+00
   0.000E+00 2.130E+02 310  0.000E+00 2.130E+02 320  1.278E+00 9.628E+01 370  2
2.556E+00 8.989E+01 690  2.556E+00 8.591E+01 660  2.556E+00 9.173E+01 470
| 8.0088E+01  620  1.4988E+02  580    10   180    40  1.278E+00  3.905E+00
   0.000E+00 2.130E+02 270  0.000E+00 2.130E+02 260  1.278E+00 9.116E+01 350
3.905E+00 7.469E+01 860  3.905E+00 5.027E+01 580  3.905E+00 7.682E+01 590
| 1.6807E+02  650  6.7257E+01  520    10   200    40  1.278E+00  5.183E+00
   0.000E+00 2.130E+02 270  1.278E+00 8.335E+01 320  1.278E+00 9.372E+01 360
3.905E+00 7.980E+01 920  3.905E+00 6.504E+01 750  5.183E+00 6.248E+01 640
| 1.6032E+02  620  1.0208E+02  790     0   190    40  1.278E+00  5.183E+00
   1.278E+00 1.250E+02 480  0.000E+00 2.130E+02 360  1.278E+00 9.372E+01 360
2.556E+00 1.093E+02 840  2.556E+00 8.591E+01 660  5.183E+00 5.566E+01 570
| 1.0476E+02  810  1.1633E+02  900     0   190    40  1.278E+00  6.461E+00
   1.278E+00 1.328E+02 510  1.278E+00 1.328E+02 510  1.278E+00 1.172E+02 450
3.905E+00 9.372E+01 1080  3.905E+00 7.640E+01 880  6.461E+00 7.100E+01 910
| 1.0082E+02  780  7.5012E+01  870     0   200    40  1.278E+00  5.183E+00
   1.278E+00 1.224E+02 470  1.278E+00 1.197E+02 460  1.278E+00 1.353E+02 520
5.183E+00 8.066E+01 1240  3.905E+00 8.335E+01 960  5.183E+00 7.512E+01 770
| 1.0335E+02  800  1.1633E+02  900     0   230    50  1.278E+00  7.739E+00
   1.278E+00 1.119E+02 430  1.278E+00 1.328E+02 510  1.278E+00 1.328E+02 510
5.183E+00 7.228E+01 1110  5.183E+00 7.356E+01 1130  7.739E+00 5.666E+01 870
| 1.0984E+02  850  9.7008E+01  750     0   230    50  1.278E+00  6.461E+00
```

```
   1.278E+00 1.172E+02 450  1.278E+00 1.093E+02 420  1.278E+00 1.431E+02 550
3.905E+00 8.506E+01 980  5.183E+00 6.830E+01 1050  6.461E+00 6.873E+01 880
| 1.0857E+02  840  7.6704E+01  890    10   260    50  2.556E+00  6.461E+00
   2.556E+00 8.463E+01 650  1.278E+00 1.744E+02 670  2.556E+00 9.500E+01 730
5.183E+00 7.739E+01 1190  5.183E+00 7.100E+01 1090  6.461E+00 6.717E+01 860
| 9.4752E+01 1100  1.1633E+02  900     0   290    60  2.556E+00  9.017E+00
   1.278E+00 1.718E+02 660  1.278E+00 1.562E+02 600  2.556E+00 9.372E+01 720
3.905E+00 9.628E+01 1110  5.183E+00 7.938E+01 1220  9.017E+00 6.362E+01 1140
| 9.1368E+01 1060  1.0857E+02  840    20   310    60  2.556E+00  7.739E+00
   2.556E+00 8.591E+01 660  2.556E+00 9.500E+01 730  2.556E+00 1.315E+02 1010
5.183E+00 8.392E+01 1290  7.739E+00 6.859E+01 1580  7.739E+00 7.029E+01 1080
| 8.2767E+01 1280  1.2662E+02  980     0   350    70  2.556E+00  9.017E+00
   2.556E+00 9.770E+01 750  2.556E+00 9.770E+01 750  2.556E+00 1.184E+02 910
5.183E+00 8.264E+01 1270  6.461E+00 7.711E+01 1480  9.017E+00 7.086E+01 1270
| 9.7572E+01 1510  9.3060E+01 1080     0   430    90  2.556E+00  9.017E+00
   3.905E+00 8.847E+01 1020  2.556E+00 1.250E+02 960  2.556E+00 1.289E+02 990
6.461E+00 8.222E+01 1580  7.739E+00 7.114E+01 1640  9.017E+00 6.305E+01 1130
| 1.0857E+02 1680  8.7843E+01 1700     0   500   100  5.183E+00  1.164E+01
   5.183E+00 8.847E+01 1360  3.905E+00 1.206E+02 1390  5.183E+00 9.699E+01 1490
7.739E+00 7.682E+01 1770  1.030E+01 7.55E+01 2320  1.164E+01 7.37E+01 1700
| 9.8277E+01 1900  1.0787E+02 1670    30   570   110  5.183E+00  1.420E+01
   5.183E+00 9.372E+01 1440  5.183E+00 1.008E+02 1550  5.183E+00 1.133E+02 1740
7.739E+00 8.804E+01 2030  1.030E+01 7.384E+01 2270  1.420E+01 6.717E+01 1890
| 1.0490E+02 2030  1.0392E+02 2010    20   690   140  6.461E+00  1.292E+01
   5.183E+00 1.0551E+02 1620  5.183E+00 1.0806E+02 1660  6.461E+00 9.9968E+01 1920
9.017E+00 8.6336E+01 2320  1.1644E+01 7.256E+01 2510  1.2922E+01 7.739E+01 1980
| 9.2637E+01 2150  9.7431E+01 2260   110   760   150  6.461E+00  1.292E+01
   5.183E+00 1.1459E+02 1760  6.461E+00 1.1403E+02 2190  6.461E+00 1.1147E+02 2140
1.0295E+01 7.838E+01 2410  1.1644E+01 7.398E+01 2560  1.2922E+01 8.236E+01 2110
| 9.9546E+01 2310  9.6726E+01 2620   120   840   170  7.739E+00  1.548E+01
   7.739E+00 1.007E+02 2320  6.461E+00 1.197E+02 2300  7.739E+00 1.064E+02 2450
9.017E+00 8.406E+01 2260  1.420E+01 6.859E+01 2900  1.548E+01 7.185E+01 2210
| 9.2355E+01 2500  9.0240E+01 3140   200   940   190  1.030E+01  1.811E+01
   9.017E+00 9.599E+01 2580  9.017E+00 1.116E+02 3000  1.0295E+01 1.005E+02 3090
1.2922E+01 8.066E+01 3100  1.6756E+01 6.987E+01 3490  1.8105E+01 6.944E+01 2490
| 1.0307E+02 2790  1.1210E+02 3470   270  1060   210  1.164E+01  2.584E+01
   9.017E+00 1.027E+02 2760  1.0295E+01 1.055E+02 3240  1.1644E+01 9.713E+01 3360
1.0295E+01 9.855E+01 3030  1.6756E+01 7.853E+01 3920  2.5844E+01 6.475E+01 3320
| 9.9828E+01 3090  1.0053E+02 3500   370  1150   230  1.164E+01  2.584E+01
   7.739E+00 1.279E+02 2950  1.0295E+01 1.123E+02 3450  1.1644E+01 1.038E+02 3590
1.420E+01 8.591E+01 3630  1.8105E+01 7.753E+01 4170  2.5844E+01 6.717E+01 3440
| 8.1780E+01 4110  1.1097E+02 4290   360  1320   260  1.292E+01  2.322E+01
   1.1644E+01 1.096E+02 3790  1.2922E+01 1.099E+02 4220  1.2922E+01 1.069E+02 4110
1.5478E+01 8.023E+01 3700  1.9383E+01 7.654E+01 4410  2.3217E+01 7.242E+01 3340
| 1.0772E+02 3750  1.0490E+02 4870   420  1460   290  1.420E+01  2.968E+01
   1.2922E+01 1.096E+02 4210  1.420E+01 1.065E+02 4500  1.420E+01 1.027E+02 4340
1.5478E+01 8.847E+01 4080  1.9383E+01 7.441E+01 4290  2.9678E+01 6.106E+01 3600
| 9.8418E+01 4570  9.9123E+01 5370   420  1650   330  1.811E+01  2.322E+01
   1.6756E+01 1.044E+02 5210  1.6756E+01 1.116E+02 5570  1.8105E+01 1.056E+02 5680
1.8105E+01 8.463E+01 4550  2.3217E+01 7.498E+01 5180  2.3217E+01 7.526E+01 3470
| 9.9405E+01 5770  9.8982E+01 5360   320  1910   380  1.938E+01  2.584E+01
   2.1939E+01 8.804E+01 5750  2.0661E+01 9.386E+01 5770  1.9383E+01 9.940E+01 5730
1.8105E+01 9.244E+01 4970  2.4495E+01 7.455E+01 5440  2.5844E+01 6.972E+01 3570
| 1.0335E+02 4800  1.0124E+02 5480   450  1960   390  3.096E+01  3.231E+01
```

1.8105E+01 1.017E+02 5470 2.4495E+01 9.088E+01 6630 3.0956E+01 6.262E+01 5770
1.6756E+01 9.656E+01 4820 2.3217E+01 8.250E+01 5700 3.2305E+01 6.205E+01 3970
| 8.7702E+01 6110 1.0335E+02 5600   350 2190   440 3.358E+01 3.231E+01
1.9383E+01 9.855E+01 5680 1.9383E+01 9.656E+01 5560 3.3583E+01 5.495E+01 5490
2.0661E+01 8.818E+01 5420 2.5844E+01 7.384E+01 5670 3.2305E+01 6.362E+01 4070
| 8.8548E+01 6170 1.0067E+02 5450   350 2320   460 5.290E+01 3.231E+01
1.9383E+01 1.012E+02 5830 2.1939E+01 9.415E+01 6150 5.2895E+01 2.812E+01 4430
2.1939E+01 8.506E+01 5550 2.840E+01 7.1426E+01 6040 3.2305E+01 6.276E+01 4020
| 8.5446E+01 5950 9.6303E+01 5590   300 2360   470 4.260E+01 2.712E+01
2.0661E+01 9.699E+01 5960 2.5844E+01 7.895E+01 6070 4.260E+01 3.720E+01 4720
2.3217E+01 8.335E+01 5760 2.840E+01 6.972E+01 5890 2.7122E+01 6.731E+01 3620
| 8.1216E+01 6280 1.0265E+02 5560   0 2670   530 4.906E+01 2.450E+01
2.3217E+01 8.847E+01 6120 5.4244E+01 2.258E+01 3650 4.9061E+01 3.181E+01 4650
2.0661E+01 8.790E+01 5400 2.5844E+01 6.972E+01 5360 2.4495E+01 7.157E+01 3480
| 7.7691E+01 6310 9.9969E+01 5030   0 2580   520 4.260E+01 2.712E+01
2.5844E+01 7.086E+01 5440 3.2305E+01 5.282E+01 5070 4.260E+01 4.019E+01 5090
2.4495E+01 8.151E+01 5950 5.5522E+01 2.883E+01 4750 2.7122E+01 6.986E+01 3760
| 7.2474E+01 5890 1.0096E+02 5470   0 2570   510 4.906E+01 2.840E+01
6.3261E+01 1.420E+01 2660 1.6756E+01 8.946E+01 4470 4.9061E+01 3.039E+01 4440
2.7122E+01 6.930E+01 5590 5.9356E+01 2.655E+01 4690 2.840E+01 6.958E+01 3920
| 8.0370E+01 5910 1.0420E+02 4840   0 2490   500 5.424E+01 2.712E+01
4.260E+01 3.791E+01 4810 1.9383E+01 8.023E+01 4620 5.4244E+01 2.599E+01 4190
2.840E+01 6.418E+01 5420 5.9356E+01 2.655E+01 4680 2.7122E+01 6.830E+01 3670
| 5.7951E+01 5600 9.8559E+01 4960   0 2440   490 5.424E+01 2.840E+01
4.0044E+01 4.075E+01 4850 2.0661E+01 7.995E+01 4910 5.4244E+01 2.670E+01 4310
3.6139E+01 5.623E+01 6050 5.8078E+01 2.812E+01 4860 2.840E+01 6.802E+01 3830
| 8.7702E+01 5090 1.0223E+02 5140   320 2130   430 4.778E+01 2.584E+01
4.5156E+01 3.294E+01 4430 3.0956E+01 5.112E+01 4710 4.7783E+01 3.337E+01 4750
2.7122E+01 7.242E+01 5840 5.5522E+01 3.096E+01 5120 2.5844E+01 7.143E+01 3660
| 4.5261E+01 4900 9.2919E+01 5030   410 2030   410 5.680E+01 2.712E+01
4.3878E+01 3.195E+01 4170 4.3878E+01 3.252E+01 4240 5.680E+01 2.357E+01 3990
3.0956E+01 6.049E+01 5580 5.5522E+01 2.797E+01 4630 2.7122E+01 7.270E+01 3910
| 3.2994E+01 4720 1.0096E+02 5080   140 2320   460 4.651E+01 3.096E+01
2.7122E+01 5.581E+01 4500 3.6139E+01 4.615E+01 4970 4.6505E+01 3.294E+01 4550
3.2305E+01 6.149E+01 5900 5.680E+01 2.840E+01 4810 3.0956E+01 6.461E+01 3970
| 3.3699E+01 4700 1.1139E+02 4310   170 2310   460 5.290E+01 2.968E+01
1.42E+01 8.875E+01 3750 4.7783E+01 2.627E+01 3740 5.2895E+01 2.726E+01 4290
3.8695E+01 5.013E+01 5770 5.8078E+01 2.641E+01 4570 2.9678E+01 6.220E+01 3660
| 5.0337E+01 5650 9.7854E+01 4920   220 2390   480 4.004E+01 4.651E+01
1.1644E+01 1.122E+02 3880 4.3878E+01 3.209E+01 4200 4.0044E+01 4.161E+01 4960
2.9678E+01 6.859E+01 6060 5.4244E+01 3.209E+01 5180 4.6505E+01 2.797E+01 2580
| 3.0738E+01 4510 1.1506E+02 4450   330 2250   450 4.778E+01 7.100E+01
3.4861E+01 3.578E+01 3710 4.3878E+01 3.436E+01 4480 4.7783E+01 3.152E+01 4480
2.840E+01 7.199E+01 6080 5.4244E+01 2.783E+01 4490 7.100E+01 1.406E+01 1980
| 3.5955E+01 5140 1.0744E+02 4570   530 2170   430 5.162E+01 5.936E+01
9.017E+00 1.302E+02 3500 4.1322E+01 3.763E+01 4620 5.1617E+01 2.769E+01 4260
3.4861E+01 5.595E+01 5800 6.9722E+01 1.534E+01 3190 5.9356E+01 2.102E+01 2470
| 6.9090E+01 3210 1.0899E+02 4640   570 2160   430 4.906E+01 4.906E+01
1.0295E+01 1.149E+02 3530 4.5156E+01 3.096E+01 4170 4.9061E+01 3.195E+01 4660
4.5156E+01 3.905E+01 5250 7.3556E+01 1.335E+01 2920 4.9061E+01 2.954E+01 2870
| 7.3179E+01 3400 9.8841E+01 4970   820 1960   390 6.198E+01 4.516E+01
7.739E+00 1.402E+02 3230 3.8695E+01 3.877E+01 4460 6.1983E+01 1.789E+01 3300
5.1617E+01 2.840E+01 4370 7.100E+01 1.534E+01 3240 4.5156E+01 3.039E+01 2720
| 6.9090E+01 4280 1.0758E+02 4580   840 1920   380 6.071E+01 4.778E+01

```
   1.0295E+01 1.142E+02 3510  4.7783E+01 2.783E+01 3960  6.0705E+01 1.860E+01 3370
5.5522E+01 2.471E+01 4080  6.4539E+01 2.130E+01 4090  4.7783E+01 3.195E+01 3030
| 5.1747E+01 5400  1.0519E+02 5290   460  2300   460  6.710E+01  2.712E+01
   1.420E+01 1.101E+02 4650  5.9356E+01 1.974E+01 3480  6.7095E+01 1.519E+01 3030
5.2895E+01 2.556E+01 4020  6.3261E+01 1.945E+01 3670  2.7122E+01 6.646E+01 3570
| 1.6920E+01 3390  1.1111E+02 4300    50  2720   540  6.454E+01  3.096E+01
   1.1644E+01 1.294E+02 4470  5.5522E+01 2.173E+01 3600  6.4539E+01 1.420E+01 2720
5.5522E+01 2.400E+01 3960  6.0705E+01 2.144E+01 3880  3.0956E+01 6.234E+01 3830
| 2.3124E+01 3930  1.1012E+02 4260     0  2740   550  6.198E+01  3.096E+01
   4.9061E+01 2.173E+01 3170  5.8078E+01 2.045E+01 3530  6.1983E+01 2.073E+01 3830
5.5522E+01 2.173E+01 3590  5.680E+01 2.698E+01 4560  3.0956E+01 5.992E+01 3680
| 1.4946E+01 2890  1.0970E+02 3820     0  2750   550  5.162E+01  3.614E+01
   5.680E+01 1.619E+01 2740  5.8078E+01 1.931E+01 3330  5.1617E+01 3.209E+01 4930
6.0705E+01 1.761E+01 3190  5.1617E+01 3.025E+01 4650  3.6139E+01 4.856E+01 3480
| 2.2842E+01 3530  1.1097E+02 4290   150  2460   490  5.552E+01  3.614E+01
   5.680E+01 1.775E+01 3000  4.3878E+01 3.706E+01 4840  5.5522E+01 2.797E+01 4610
5.1617E+01 2.485E+01 3810  2.4495E+01 5.055E+01 3690  3.6139E+01 4.643E+01 3330
| 2.0586E+01 3670  1.1111E+02 4300   870  1610   320  4.778E+01  2.968E+01
   5.9356E+01 1.619E+01 2850  3.2305E+01 5.510E+01 5290  4.7783E+01 3.507E+01 4980
5.0339E+01 2.613E+01 3920  1.1644E+01 9.429E+01 3260  2.9678E+01 6.106E+01 3600
| 2.1150E+01 3590  1.1252E+02 3480  1100  1180   240  4.388E+01  3.486E+01
   4.1322E+01 3.380E+01 4160  4.5156E+01 3.266E+01 4400  4.3878E+01 3.465E+01 4530
5.1617E+01 2.499E+01 3850  1.420E+01 8.761E+01 3700  3.4861E+01 4.629E+01 3200
| 1.8894E+01 3430  1.2182E+02 3300  1090  1010   200  5.162E+01  4.388E+01
   3.3583E+01 5.041E+01 5030  2.9678E+01 6.120E+01 5410  5.1617E+01 2.883E+01 4420
5.680E+01 2.158E+01 3650  1.5478E+01 8.350E+01 3850  4.3878E+01 2.968E+01 2590
| 2.4252E+01 3950  1.0603E+02 2870  1170   680   140  4.906E+01  2.450E+01
   4.3878E+01 2.783E+01 3640  3.8695E+01 4.004E+01 4620  4.9061E+01 2.968E+01 4340
4.3878E+01 3.067E+01 4000  1.5478E+01 8.051E+01 3710  2.4495E+01 7.114E+01 3460
| 5.0760E+01 4910  9.5034E+01 4780   950   740   150  5.162E+01  2.712E+01
   2.5844E+01 5.595E+01 4300  3.6139E+01 4.686E+01 5040  5.1617E+01 2.826E+01 4350
4.3878E+01 3.365E+01 4400  1.2922E+01 9.159E+01 3520  2.7122E+01 6.688E+01 3600
| 3.5673E+01 4410  1.2408E+02 3360   620  1090   220  5.290E+01  4.132E+01
   2.4495E+01 6.163E+01 4500  3.0956E+01 5.723E+01 5280  5.2895E+01 2.982E+01 4700
4.1322E+01 3.479E+01 4270  1.6756E+01 7.725E+01 3860  4.1322E+01 3.962E+01 3250
| 5.2452E+01 5070  1.0801E+02 3760   570  1150   230  4.132E+01  3.870E+01
   2.5844E+01 6.092E+01 4680  3.3583E+01 4.658E+01 4650  4.1322E+01 3.862E+01 4740
3.7417E+01 4.118E+01 4590  1.6756E+01 8.250E+01 4120  3.8695E+01 4.203E+01 3230
| 5.2452E+01 5070  1.0801E+02 3760   570  1150   230  4.132E+01  3.870E+01
   2.5844E+01 6.092E+01 4680  3.3583E+01 4.658E+01 4650  4.1322E+01 3.862E+01 4740
3.7417E+01 4.118E+01 4590  1.6756E+01 8.250E+01 4120  3.8695E+01 4.203E+01 3230
C
C  ****** END OF FILE ******
```

metanet.odm

```
C  ****** ORIGIN-DESTINATION INFORMATION FILE ******
C Origin-Destination Information, for Tuesday, the 10th of January
C
F T:
C
N U1      Z1   Z2   Z3   Z4   Z5
  U2      Z1   Z2   Z3   Z4   Z5
  U3      Z1   Z2             Z5
  U4      Z1   Z2             Z5
  U5      Z1   Z2             Z5
C
| 04:00  0.40   0.27   0.30   0.01   0.02
         0.40   0.30   0.27   0.01   0.02
         0.47   0.38                 0.15
         0.47   0.38                 0.15
         0.47   0.38                 0.15
| 14:00  0.40   0.26   0.33   0.01   0.00
         0.40   0.26   0.33   0.01   0.00
         0.47   0.38                 0.15
         0.47   0.38                 0.15
         0.47   0.38                 0.15
C
C  ****** END OF FILE ******
```

metanet.spl

```
C  ****** SPLITTING RATES FILE ******
C Splitting Rates for Tuesday, the 10th of January 1989, 4:00 - 10:00 a.m.
C
F T:
C
N N2          L3    L27
    Z1 Z2 Z5
  N9          L28   L12
    Z1 Z2 Z5
C
| 04:00       0.90  0.10
              0.20  0.80
              0.20  0.80
              0.35  0.65
              0.65  0.35
              0.65  0.35
| 05:00       0.90  0.10
              0.20  0.80
              0.20  0.80
              0.35  0.65
              0.65  0.35
              0.65  0.35
| 06:00       0.95  0.05
              0.55  0.45
              0.40  0.60
              0.75  0.25
              0.45  0.55
              0.45  0.55
| 07:00       0.95  0.05
              0.75  0.25
              0.40  0.60
              0.95  0.05
              0.65  0.35
              0.45  0.55
| 08:00       0.90  0.10
              0.40  0.60
              0.40  0.60
              0.85  0.15
              0.45  0.55
              0.45  0.55
| 09:00       0.80  0.20
              0.55  0.45
              0.55  0.45
              0.75  0.25
              0.50  0.50
              0.50  0.50
| 10:00       0.85  0.15
```

```
          0.55  0.45
          0.55  0.45
          0.80  0.20
          0.50  0.50
          0.50  0.50
C
C  ****** END OF FILE ******
```

APPENDIX D: INPUT FILES FOR DTA TEST EXAMPLE

TEST-DTA.ctr

```
C **** SIMULATION CONTROL FILE FOR METANET DTA EXAMPLE ****
H METANET DTA FOR A SIMPLE NETWORK
C Sim_Start_Time   Sim_End_Time   Sim_Step[sec]
|  07:00            10:00          10
C Simu_Mode    Type_Of_Control   Init_Type
|   0            0                  0
C List of boundary locations
|  INP1   O1
|  INP2   O2
|  INP3   O3
E
C LIST OF INTERNAL MEASUREMENT LOCATIONS
E
C LIST OF INCIDENTS
C INCI_START     INCI_END     LINK_NAME    LINK_KM    LINK_SEVERITY
|  7:50            8:00         L3           1.5        0.4
E
C OUTPUT
C TYPE    START_TIME   END_TIME  TIME STEP
|  C        7:00          10:00       00:01
E
C Type of DTA CALCULATION   THRESHOLD OF LENGTH RATIO
C  0  means   without DTA
C  1  means   DTA for all bifurcation_destination couples
C  2  means   DTA for bifurcation_destination couples as listed next
|  2                                  3.0
C DTA METHOD  GLOBAL BETA_N     K_p      K_i      beta_min      beta_max
C  0 means Bang-Bang
C  1 means P
```

```
C  2 means PI
|   2                    1.0                 150.0             10.0               0                1
C LIST OF BIFURCATION-DESTINATION COUPLES SUBJECT TO DTA
|   N1     D1     1.0
E
C
C  ****** END OF FILE ******
```

TEST-DTA.nwd

```
C *** NETWORK DESCRIPTION FILE FOR METANET DTA EXAMPLE ***
H METANET DTA FOR A SIMPLE NETWORK
C PARAMETERS TAU,    KAPPA,  NUE,  VMIN,  ROMAX,  DELTA,  PHI
|          18     40     60   7.4   180    0.01   3.0
C
C ORIGIN NAME   LANES   QINMAX/LANE   FREE SPEED   ANGLE
|  O1                  4           2000                  110               0
|  O2                  1           1500                   90               0
|  O3                  1           1500                   90               0
C
C LINK NAME LANES CAP/LAN FRE-SPD ROCRIT CAP60  LEN   NrSeg
|  L0              4          2000        110         33.5        -1        2        2
|  L1              2          2000        110         33.5        -1        3        3
|  L2              2          2000        110         33.5        -1        4        4
|  L5              2          2000        110         33.5        -1        0.5      1
|  L6              2          2000        110         33.5        -1        4        4
|  L3              2          2000        110         33.5        -1        3        3
|  L4              2          2000        110         33.5        -1       0.5       1
E
C
C DESTINATIONS NAME   LANES   QINMAX/LANE   FREE SPEED   ANGLE
|  D1                            2          -1                     110               0
|  D2                            1          -1                     110               0
|  D3                            1          -1                     110               0
```

```
E
C
C NODE NAME [X    Y-KOORDINATES]
C   INLINK NAMES
C   OUTLINK NAMES
| N0     1    20
| O1
| L0
| N1      2   20
| L0
| L1  L2
| N3      4   10
| L1
| L4  D2
| N4      6   10
| L4  O2
| L3
| N5      4   30
| L2
| L5  D3
| N6      6   30
| L5  O3
| L6
| N2     7  20
| L3   L6
| D1
E
C  ****** END OF FILE ******
```

TEST-DTA.msd

```
C  ****** INPUT TRAFFIC DATA FILE  FOR METANET DTA********
H METANET DTA FOR A SIMPLE NETWORK
```

```
H Triangular demands
F T:,3(Q)
C
T  06:00  00:01
C Location names
N INP1  INP2   INP3
C Traffic data as specified above
|7:00    1000.000   500     500
|7:15    4000.000   1700   1700
|7:30    7000.000   1700   1700
|7:45    7000.000   1700   1700
|8:00    7000.000   500     500
|8:30    5000.000   500     500
|10:00  5000.000   500     500
C
C  ****** END OF FILE ******
```

TEST-DTA.odm

```
C  ****** INPUT TRAFFIC DATA FILE  FOR METANET DTA********
H METANET DTA FOR A SIMPLE NETWORK
F  T:,1(3G)
C
N  O1  D1  D2  D3
C
C Data
| 07:00   0.92   0.04   0.04
| 10:00   0.92   0.04   0.04
C
C  ****** END OF FILE ******
```

TEST-DTA.dpa

```
C  ****** PARAMETER FILE FOR DISPLAY VIA METAGRAF ********
H METANET DTA FOR A SIMPLE NETWORK
C Parameters for network plot
C labeling options (on/off textsize screen hardcopy)
C Textsize screen  hardcopy   node names link names origin names destination names
|0.38              0.38         1            1            1            1
C numeric display options (on/off textsize screen hardcopy)
C textsize screen hardcopy  queue lengths
| 0.35        0.35             0
C node radii (in cm)
C for screen   for hard copy
| 0.4         0.4
C arrow widths (in cm)
C for screen for hard copy
|  0.3        0.3
C origin and destination arrow lengths (in cm)
C for screen for hard copy
|  0.4        0.4
C min widths of links (in cm and in pixels)
C for screen for hard copy
|  0.04  0.001    0.3 1
C widths (in cm) per 1000 vehicles
C for screen for hard copy
|  0.05       0.1
C border around network plot
C for screen for hard copy
|  0.1        0.2
C height of menu bar
C for screen for hard copy
|  1.8        1.4
```

APPENDIX E: RAMP METERING

E.1 Ramp Metering

A specific MN_CONTR module is available, which includes three pre-programmed routines devoted to ramp metering, called RMCONTROL, INIT_RMCONTROL and END_RMCONTROL. Within these routines, which are invoked when the value 1 is specified for the variable *contr_type* in the simulation control file, the user can program his/her own ramp metering and/or motorway-to-motorway control strategy. In this case, the entered on-ramp volumes are the control variables that are calculated by the control strategy. Any reference to ramp metering in this Appendix also includes motorway-to-motorway control. The three routines devoted to ramp metering are subject to modifications and extensions by the user and the existing code which applies a local traffic-responsive ramp metering strategy, ALINEA, can be used as template.

<u>RMCONTROL</u>

This routine contains the implementation of ramp metering itself. In the template, on-ramp volumes are calculated by the following integral regulator (see also Figure E1) of ALINEA [5]:

$$r(k) = r(k-1) - K_{AL} \cdot \left[\rho_{out}(k) - \hat{\rho}\right]$$

where:

- $r(k)$ is the ordered on-ramp volume at time kT_A (in veh/h),
- K_{AL} is a constant and positive regulator parameter,
- $\rho_{out}(k)$ is the downstream density at time kT_A (in veh/km/lane),
- $\hat{\rho}$ is the desired downstream density (in veh/km/lane),
- T_A is the sample time interval of ALINEA (in h) (note that T_A must be a multiple of T).

After calculation of r(k), the following control constraints are applied:

- The ordered on-ramp volume is limited within the range (outflow constraint)

$$r_{min} \leq r(k) \leq r_{max}$$

where r_{min} and r_{max} are the minimum and maximum permissible values for the on-ramp volumes, respectively.

- If the downstream density is below a specified limit, the ramp control is released (density constraint).
- If the maximum permissible length of the on-ramp queue exceeds a pre-specified value, the ordered on-ramp volume is set equal to r_{max} (queue constraint).

If desired, the user may indirectly skip these control constraints by providing accordingly high or low values in the ramp metering control file.

RMCONTROL is called by the main program every simulation time step of the simulation loop and also every time step of the initialisation loop (calculation of initial steady state). However, the user may activate control at desired pre-specified steps. For example, in the presented template, although RMCONTROL is called at every simulation step kT, it is only activated at steps equal to kT_A.

INIT_RMCONTROL

Here, all dynamic memory and, as far as necessary, all variables for ramp metering should be allocated and initialised. If ramp metering uses input files which specify metered locations, controller parameters, sample time intervals, possible constraints, etc., these files should be opened here.

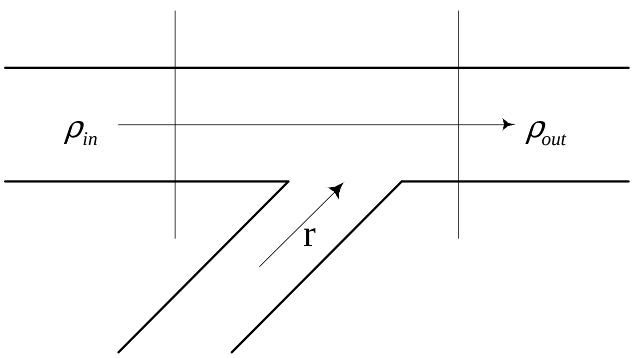


Figure E1: Ramp merging area.

INIT_RMCONTROL is called by the main program during the initialisation phase. In the case of the template, a ramp metering control file *rmtname*.rmt is opened. This file must be provided by the user and is structured as follows:

--------------------- rmt*name*. rmt ----------------------------

C

Co

ntrol_Interval

T *TA*

C

Li

st of locations for activation of ramp metering with their corresponding

C

pa

rameters and constraints

|

lin

k_name type K_AL ρ_desd max_qu min_outflw max_outflw ρ_constr

| •

| •

| •

E

(end of file) --

Description of Entries:

Name	**Type**	**Description**
TA	time	sample time interval for activation of ramp metering (in sec).
Link_name	name	name of the metered link as specified in the network description file *nwdname*.nwd. Permissible links are only

		origin and store-and-forward links.
Type	integer	type of controlled link; 0 = for origin links; 1 = for store-and-forward links.
K_AL	real	the constant and positive regulator parameter of ALINEA (a value *K_AL*=40 is recommended).
ρ_desd	real	desired downstream density (in veh/km/lane).
max_qu	real	maximum permissible length of queue (in veh) (if a very high value, e.g. 1000000, is provided, this constraint becomes practically inactive).
min_outflw	real	minimum permissible outflow from the on-ramp link (in veh/h) (when 0 is provided, this constraint is practically skipped and simply guarantees that no negative values of r(k) will be used).
max_outflw	real	maximum permissible outflow from the on-ramp link (in veh/h) (when a value equal to *capacity·lanes*, as described in *nwdname*.nwd file, is provided, this constraint is practically skipped, because in any case only flow less or equal to *capacity·lanes* is allowed to enter from the ramp; see Appendices A.1.8 and A.3).
ρ_constr	real	downstream density value under which control is not activated (in veh/km/lane) (when 0 or less is provided, this constraint is skipped).

END_RMCONTROL

Criteria taken over the whole simulation horizon may be finally calculated here, and/or files may be closed.

This routine is called at the end of simulation.

E.2 *Test Example*

Figure E2 presents a small hypothetical network. This network consists of two motorway stretches connected with the motorway-to-motorway link L3. There are two on-ramps (origin link U3 and store-and-forward link L3) where the ALINEA ramp metering strategy is applied. The input files, developed and used for METANET simulation, are given in Appendix E.2.2 below.

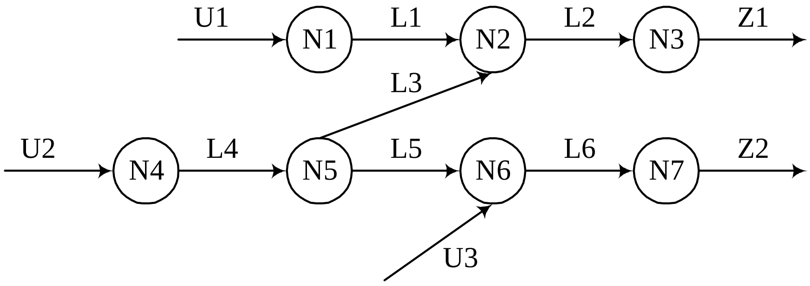


Figure E2: Sketch of example network.

example.ctr

```
C  ****** SIMULATION CONTROL FILE ******
H  SIMULATION EXAMPLE NETWORK
H  METANET, TUC 1996
C
C
C   SIMUL_START_TIME      SIMUL_END_TIME         SIMUL_STEP_[SEC]
|   14:00                 16:00                  4
C
C   SIMUL_MODE      TYPE_OF_CONTROL
|   1               1
C
C  LIST OF BOUNDARY LOCATIONS FOR MODEL INPUT
C   LOCATION_NAME      LINK_NAME
|   U1                 U1
|   U2                 U2
|   U3                 U3
E
C
C  LIST OF INTERNAL MEASUREMENT LOCATIONS FOR COMPARISONS
C  THE LIST IS EMPTY
E
C
```

```
C  LIST OF INCIDENTS
C  INCI_START INCI_END LINK_NAME LINK_KM INCI_SEV
E
C
C  OUTPUT
C   OUT_TYPE     OUT_START     OUT_END      OUT_STEP
|   C            14:00         16:00        00:30
C
C  LIST OF LOCATIONS FOR OUTPUT
C  THE LIST IS EMPTY
E
C
C  ****** END OF FILE ******
```

example.nwd

```
C  ****** NETWORK DESCRIPTION FILE ******
C  SIMULATION FOR EXAMPLE NETWORK
C  SPECIFICATIONS IN BRACKETS ARE USED ONLY FOR
C  GRAPHICAL  OUTPUT
C
C  GLOBAL NETWORK PARAMETERS
C   TAU      KAPPA    NUE      VMIN     ROMAX    DELTA    PHI
|   20       13       35       7.0      180      0.8      2.0
C
C  LIST OF ORIGIN LINKS
C   ORIGIN_NAME   LANES      QINMAX/L    FRE_SPEED   [ANGLE]
|   U1            3          2000        105         270
|   U2            3          2000        105         270
|   U3            1          1000        105         315
E
C
C  LIST OF NETWORK LINKS
C   NAME   TYPE   LANES.  CAP/L   FREE    TRAV   ROCRIT   CAP60   LEN     SEG
C                                 SPEED   TIME                    MAX
C                                                                 QUEUE
|   L1     0      3       2000    105            31.4     -1      0.8     3
|   L2     0      4       2000    105            31.4     -1      0.8     3
M   L3     1      1       1000    105     12                      0.2     0
|   L4     0      3       2000    105            31.4     -1      0.8     3
|   L5     0      2       2000    105            31.4     -1      0.8     3
|   L6     0      3       2000    105            31.4     -1      0.8     3
E
C
C  LIST OF DESTINATION LINKS
C   DEST_NAME    LANES    QBOUND/L    FREE_SPEED    [ANGLE]
|   Z1           4        -1          105           90
|   Z2           3        -1          105           90
E
C
```

```
C  LIST OF NETWORK NODES AND THEIR CONNECTION TO LINKS
C  ONE LINE FOR THE NODE PLUS TWO LINES FOR IN- AND OUT- LINKS
C  NODE_NAME [X_COORD] [Y_COORD]
C    IN_LINK_1       IN_LINK_2        ......
C    OUT_LINK_1     OUT_LINK_2       ......
| N1     2     4
|
                                                            U
1
|                                                           L1
| N2     2     6
|                                                           L1
                                                            L3
|                                                           L2
| N3     2     8
|                                                           L2
|                                                           Z1
| N4     4     2
|
                                                            U
2
|                                                           L4
| N5     4     4
|                                                           L4
|                                                           L5
                                                            L3
| N6     4     6
|
                                                            U
3                                                           L5
|                                                           L6
| N7     4     8
|                                                           L6
|                                                           Z2
E
C
C  ****** END OF FILE ******
```

example.ini

```
C  ****** INITIAL CONTROL FILE ******
H  SIMULATION FOR EXAMPLE NETWORK
C
C  LIST OF INITIAL DENSITIES FOR NETWORK AND DESTINATION LINKS
C    LINK_NAME      ROBEGIN       ROEND_[OMITTED FOR DESTINATIONS]
|     L1                10               10
|     L2                10               10
|     L3                10               10
|     L4                10               10
```

```
|     L5                    10                  10
|     L6                    10                  10
|     Z1                    10
|     Z2                    10
E
C
C  INITIAL COMPOSITION RATES FOR EACH NETWORK LINK
C  ONE LINE FOR THE SPECIFICATION OF THE USED ORDER OF
C  DESTINATION PLUS TWO LINES FOR THE COMPOSITION VALUES AT
C  BEGIN AND END OF LINK
C LINK_NAME DEST_NAME_1 DEST_NAME_2 DEST_NAME_3  ….
C           COMP_1_BEG  COMP_2_BEG  COMP_3_BEG  ....
C           COMP_1_END  COMP_2_END  COMP_3_END  ....
| L1       Z1
|          1.0
|          1.0
| L2       Z1
|          1.0
|          1.0
| L3       Z1
|          1.0
|          1.0
| L4       Z1
                                                                  Z2
|          0.2
                                                                  0.
8
|          0.2
                                                                  0.
8
| L5       Z2
|          1.0
|          1.0
| L6       Z2
|          1.0
|          1.0
E
C
C  ****** END OF FILE ******
```

example.msd

```
C  ****** INPUT TRAFFIC DATA FILE ******
H  SIMULATION EXAMPLE NETWORK
C
C
F  T:,3(Q)
C
C  STRUCTURE OF ORIGIN-DESTINATION INFORMATION
```

```
C   LOCAT_1     LOCAT_2     LOCAT_3     LOCAT_4     LOCAT_5     .......
N   U1          U2          U3
C
C  TRAFFIC DATA AS APECIFIED ABOVE
C   HH:MM    Q        Q        Q
|   14:00    3000     2000     300
|   14:30    3500     2500     600
|   15:03    5500     4500     900
|   15:37    3100     3100     500
|   16:07    2500     2500     200
C
C  ****** END OF FILE ******
```

example.trn

```
C  ****** TURNING RATES FILE ******
C  SIMULATION FOR EXAMPLE NETWORK
F  T:,(2U)
C
C  STRUCTURE OF PROVIDED TURNING RATE DATA
C   NODE_NAME        LINK_1    LINK_2    ......
N   N5               L3        L5
C
C  PROVIDED TURNING RATES AS SPECIFIED ABOVE
C   HH:MM    U      U
|   14:00    0.2    0.8
|   16:00    0.2    0.8
C
C  ****** END OF FILE ******
```

example.rmt

```
C  ****** RAMP METERING FILE ******
C  SIMULATION FOR EXAMPLE NETWORK
C   CONTROL_INTERVAL
C    h
T    0.017
C
C   NAME    TYPE    KAL    DES_DEN    MAXQU    MIN_OUT    MAX_OUT    DEN
C                                              FLOW       FLOW       CON
|   U3      0       42     31.4       50       330        1000       26.4
|   L3      1       42     31.4       50       330        1000       26.4
E
C
C  ****** END OF FILE ******
```

APPENDIX F: OPTIMAL MOTORWAY CONTROL (AMOC)

F.1 Introduction

This appendix to the METANET documentation describes the principles and the use of the motorway control software tool AMOC (Advanced Motorway Optimal Control). It aims in determining co-ordinated and integrated control strategies for arbitrary motorway networks. The term co-ordinated control is used in order to indicate control strategies that take under consideration several control measures of the same kind. For example, if in a given motorway network a number of geographically distributed ramp-metering installations is used for traffic control purposes, then a single (unique) control strategy which considers the synergistic effect of all ramp-metering installations, is called a co-ordinated ramp-metering control strategy. On the other hand, the term integration is reserved for the situations where control measures of different kinds are employed for traffic control purposes. An example of integrated control would be the concurrent consideration of Variable Message Signs (VMS) with ramp-metering towards a common objective.

State dependent control constraints are adopted in order to account in a fully systematic way for limitations of metering rates due to:

- Queue length constraint (max. admissible on-ramp queue due to metering),
- Spill back from downstream the ramp
- Low demand (but considering possible queueing vehicles to be served) at ramp.

F.2 Mathematical Approach

F.2.1 General Formulation

In AMOC, the control problem is formulated as a dynamic optimal control problem with constraint control variables $\mathrm{u}(k)$ which can be solved numerically for given boundary conditions $\mathrm{d}(k)$, over a given time horizon. For finding the optimal solution, an appropriate cost criterion:

$$\mathrm{J} = \vartheta[\mathrm{x}(K)] + \sum_{k=0}^{K-1} \varphi[\mathrm{x}(k), \mathrm{u}(k), \mathrm{d}(k)] \tag{F1}$$

has to be minimised under consideration of the process behaviour, as expressed by:

$$\mathrm{x}(k+1) = \mathrm{f}[\mathrm{x}(k), \mathrm{u}(k), \mathrm{d}(k)], \quad \mathrm{x}(0) = \mathrm{x}_0, \tag{F2}$$

the state dependent constraints (if applicable) of the control variables expressed by:

$$\mathrm{h}[\mathrm{x}(k), \mathrm{u}(k), k] \le 0, \tag{F3}$$

and the fixed physical limits of the control variables:

$$\mathrm{u}_{\mathrm{i,min}} \le \mathrm{u}_{\mathrm{i}}(k) \le \mathrm{u}_{\mathrm{i,max}} \tag{F4}$$

where K is the considered time horizon, $\mathrm{x} \in \Re^{\mathrm{n}}$ the state vector and $\mathrm{u} \in \Re^{\mathrm{p}}$ the vector of control variables. *n* being the number of all state variable and *p* the number of all control variables. ϑ, φ are non-linear cost functions. ϑ considers the final state at the end of the horizon, while φ does that for the evolution of the state over the horizon. With the current implementation of the control variables subject to optimisation no state dependent control constraints have to be met. Therefore **h** is in the particular case an empty vector. **f** is a vector of functions which form the process model.

F.2.2 AMOC Specific Vectors

In the specific case of AMOC, **f** corresponds to the METANET model (see appendix A). That means, the general vector **x** is composed from the known METANET state variables $\rho_{m,i}$, $v_{m,i}$ (of every segment *i* on every link *m*) and w_o (for every origin or motorway interchange *o*). The control vector **u** can be composed (by user input) from the following input variables:

- Splitting rates $\beta_{n,j}^{m}$ (as described in A.1.5) considering the route diversion impact of variable message signs (VMS).
- Metering rates $rate_o$ (here defined as reduction factors between 0 and 1, of every on-ramp or motorway interchange *o*). being the control inputs of ramp or motorway to motorway metering. In order to avoid state dependent constraints $rate_o$ is acting in the following way on the flow q_o as able to enter the motorway: $q_o = rate_o \cdot q_{\max,o}$ (F5). The rest is modelled as described in A.3.
- Variable speed limitation control values $b_m \in [0.5,1]$ for any link m subject to that kind of control. b_m influences the fundamental diagram (see (A5)) in the following way $V\left(\rho_{m,i}(k), b_m\right) = v_{f,m}(b_m)\exp\left[-\frac{1}{\alpha_m(b_m)}\left(\frac{\rho_{m,i}(k)}{\rho_{cr,m}(b_m)}\right)^{\alpha_m(b_m)}\right]$ (F6)

  where

  $$v_{f,m}(b_m) = v_{f,m} b_m \quad \text{(F7)}$$

  $$\rho_{cr,m}(b_m) = \rho_{cr,m}\left(1 + 2A(1 - b_m)\right) \quad \text{(F8)}$$

  $$\alpha_m(b_m) = \alpha_m\left(E_m - (E_m - 1)b_m\right) \quad \text{(F9)}$$

  The parameters A and E_m can be specified by the user. Usually, $A = 0.25$ and $E_m = 5$. When no speed limit is applied, $b_m = 1$ and the well known equation of the fundamental diagram (A5) holds. The user can specify sequences (clusters) of links where the control variable is the same.

The boundary value vector d consists mainly of the traffic demands $d_o(k)$ at all origins plus further variables as spill back densities at destinations and turning or splitting rates (as long as not also subject to optimisation).

Note that the control interval T_C (time step of the control trajectories) has not to be identical with the simulation time step T. AMOC allows for control time steps which can be individually chosen for each control variable and which can be equal T or multiples of it. See [Kotsialos et al., 2001] for the necessary modifications in the mathematical formulation.

F.2.3 AMOC Specific Cost Criterion

The Cost criterion chosen in AMOC reads:

$$\begin{aligned} \mathrm{J} = T\sum_{k=0}^{K-1}\left\{\sum_m\sum_i \rho_{m,i}(k)L_m\lambda_m + \sum_o w_o(k) + a_f\sum_o\left[r_o(k)-r_o(k-1)\right]^2\right\} + \\ \sum_{k=0}^{K-1}\left\{a_w\sum_o\left[\max\left(w_o(k)-w_{\max,o},0\right)\right]^2\right\} \end{aligned} \quad \text{(F10)}$$

It aims primarily in minimizing the Total Time Spent (TTS) of all vehicles in the network. This is obtained by the term $\sum_m\sum_i \rho_{m,i}(k)L_m\lambda_m$ plus the term $\sum_o w_o(k)$. The latter includes the waiting time experienced in on-ramp queues. The term $a_f\sum_o\left[r_o(k)-r_o(k-1)\right]^2$ is added to the cost criterion in order to suppress high-frequency oscillations of the control trajectories. The last additional term $a_w\sum_o\left[\max(w_o(k)-w_{\max,o},0)\right]^2$ is a penalty term which acts towards limitation of the queue lengths at on-ramps. This is in addition to the explicit limitation by the queue length constraint as formulated under c) above. There is no term for considering the final state at *K*, i.e. ϑ = 0.

F.3 Numerical Solution

The numerical algorithm used for the solution of the discrete time optimal control problem in hand, is outlined in this subsection (for more details see [Papageorgiou and Marinaki, 1995]).

The cost criterion *J* is a function of **x**(k), k = 0, …, K-1 (state trajectories) and **u**(k), k = 0, …, K-1 (control trajectories subject to optimisation). Considering the model, i.e. equation (2), it can be seen that state trajectories are in turn dependent from control trajectories (other influences **d**(k) and $\mathbf{x}_0$ kept constant). Hence *J* can be regarded as only dependent form the control variables, i.e. $J = \bar{J}(\mathrm{u})$.

A gradient, i.e. the sensitivity of cost value against control changes,

$$\mathrm{g}(k) = \partial\bar{J}/\partial\mathrm{u}(k) = \left[\partial\mathrm{f}/\partial\mathrm{u}(k)\right]^T\cdot\boldsymbol{\lambda}(k+1) + \left[\partial\mathrm{h}/\partial\mathrm{u}(k)\right]^T\cdot\boldsymbol{\mu}(k) \quad \text{(F11)}$$

can be calculated, where $\boldsymbol{\lambda} \in \Re^{n}$ is the so-called co-state (not to be mixed up with number of lanes λ_m in link *m*). The co-state $\boldsymbol{\lambda}(k)$ represents the sensitivity of the cost value *J* against changes of the state values at *k*. It can be determined by:

$$\boldsymbol{\lambda}(K) = \partial \vartheta / \partial \mathrm{x}(K) \qquad \text{(F12)}$$

$$\boldsymbol{\lambda}(k) = \partial \varphi / \partial \mathrm{x}(k) = \left[\partial \mathrm{f} / \partial \mathrm{x}(k)\right]^{T} \cdot \boldsymbol{\lambda}(k+1) + \left[\partial \mathrm{h} / \partial \mathrm{x}(k)\right]^{T} \cdot \boldsymbol{\mu}(k), \quad k = K-1, \quad \ldots, 0 \qquad \text{(F13)}$$

i.e. calculating $\boldsymbol{\lambda}$ initially by (10) and performing a loop where *k* is decreased until zero (backward integration).

$\boldsymbol{\mu} \in \Re^{q}$ is the vector of the so-called Karush-Kuhn-Tucker multipliers. These multipliers are necessary to consider the impact of state dependent constraints. They have to be chosen appropriately to fulfil the conditions:

$$\boldsymbol{\mu}(k)^{T} \cdot \mathbf{h}\left[\mathbf{x}(k), \mathbf{u}(k), k\right] = 0 \text{ and} \qquad \text{(F14)}$$

$$\boldsymbol{\mu}(k) \geq \mathbf{0} \qquad \text{(F15)}$$

Where constraints are in effect, the according elements in the gradient **g***(k)* become zero.

The above given equations (F9) to (F13) do not provide a solution to calculate the optimal control trajectories directly. They can be, however, used in an iterative procedure to approximate the optimal solution. In this context the gradient gives the knowledge, in which direction some non-optimal control trajectories have to be modified, in order to go towards the optimum, i.e. towards smaller cost values.

Algorithm:

Let us introduce an iteration index *l* and let us denote $\mathrm{u}^{(l)}$ (time index *k* omitted) as the control trajectories (covering $k = 0, \ldots K-1$) found in iteration no. *l*. The adopted iterative solution algorithm can be described as follows:

Step 1: Select admissible (but not necessarily optimal) control trajectories $\mathrm{u}^{(0)}$, e.g. some constant nominal values. Set the iteration index to *l* = 0.

Step 2: Run the model, i.e. evaluate (F2) in a time loop from *k* = 0 … *K-1*. Start the simulation run always with the same initial state $\mathbf{x}_0$ and feed it with the same known or estimated boundary values **d**(k). Moreover calculate the gradient $\mathrm{g}^{(l)}$ by evaluating (F10), (F9) and (F11) in a backward loop from *k* = *K-1* … 0.

Step 3: Determine a search direction $s^{(l)}$ from $g^{(l)}$ and, if applicable, moreover from $g^{(l-1)}, g^{(l-2)}$ … (see below)

Step 4: Perform a one-dimensional search along the $s^{(l)}$ direction to find new improved control trajectories $u^{(l+1)}$

Step 5: If the further potential improvement of the obtained trajectories is under a certain threshold ε stop with approximately optimal control trajectories, otherwise set *l := l+1* and loop back to Step 2).

Several formulae for determining the search direction (see Step 3)) are realised in AMOC, i.e. steepest descent, Quasi-Newton and Conjugate Gradient method. Besides that also the RPROP algorithm (backpropagation as known from neural networks) is implemented. It needs typically considerably more iterations than the other algorithms, but is on the other hand also considerably faster per iteration since it does not perform step 4.

Figure F 1 illustrates the improvement of the trajectory of one of the control inputs.

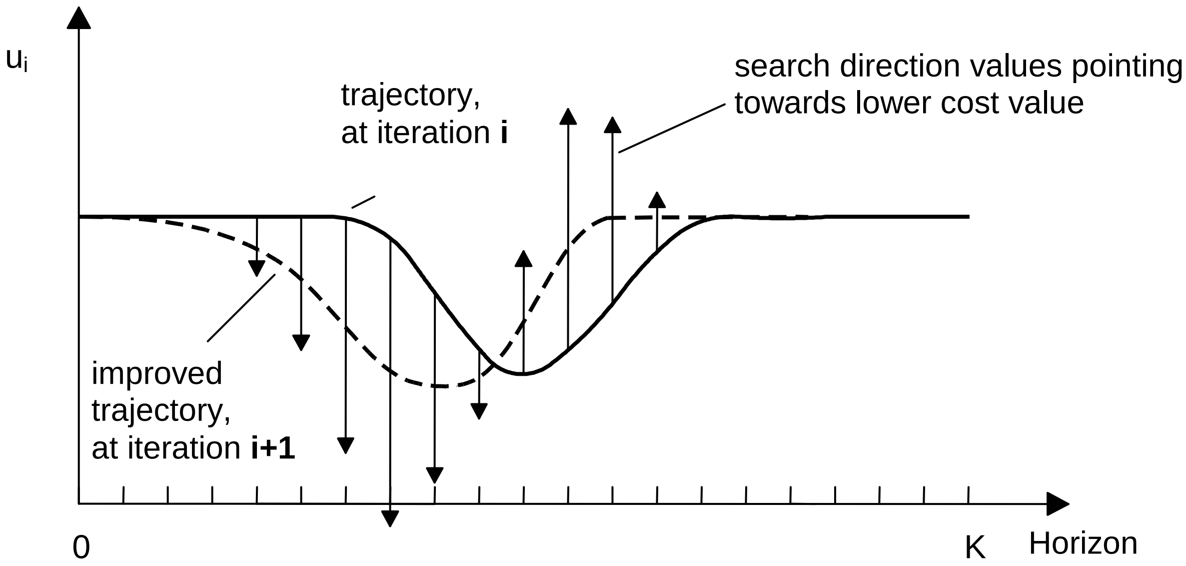


Figure F 1: Iterative Improvement of a Control Trajectory

F.4 Rolling Horizon

Besides its purpose in the frame of simulation studies, AMOC is intended to be applied as on-line control strategy in a closed loop(see Figure F 2).

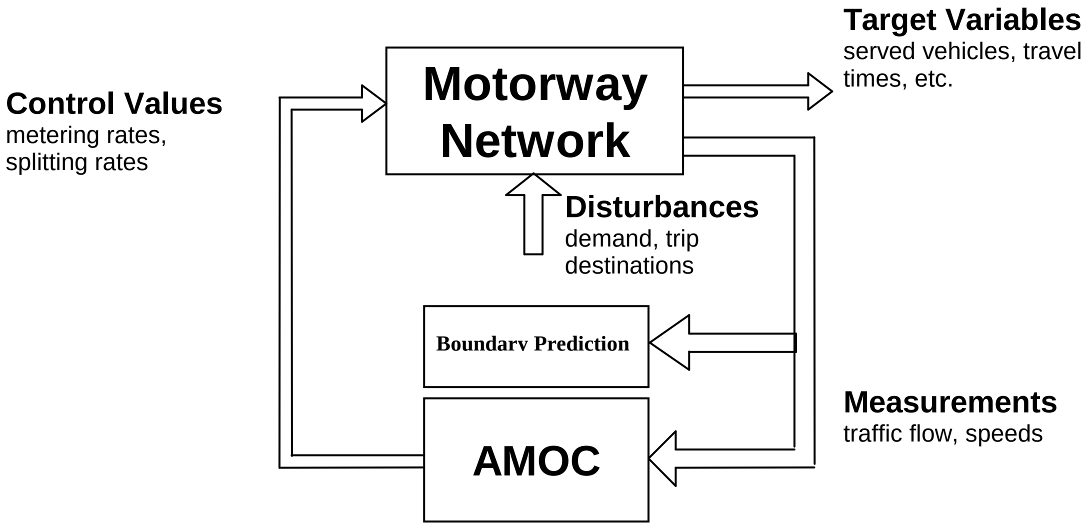


Figure F 2: On-line Control Loop

At each control interval T_C, new control values have to be calculated which should be based on the most recent measurement data. Moreover the disturbances (boundary values) over the optimisation horizon are needed (see Step 2) in the above described algorithm). Under on-line conditions, these values have to be predicted.

The concept for using optimal control in a closed loop, is based on the repetition of the whole optimisation procedure at every control time step. Before running optimisation the boundary predictions and the initial state are updated each time according to the current measurements. The horizon $T_H >> T_C$ is chosen sufficiently long in order to consider all future effects of currently adopted control measures. Although control trajectories are calculated for the whole horizon, only the first part covering the very next control interval is actually applied to the process.

This procedure allows for the use of the current measurements in order to reduce modelling and prediction errors. Moreover it considers the future evolution of the process state as a reaction to the current control decisions. It is known as *“rolling horizon”, “sliding window”* etc..

Figure F3 illustrates the procedure. The dashed lines represent the trajectories as calculated for certain control time instances. The solid line shows the resulting control curve as applied to the process.

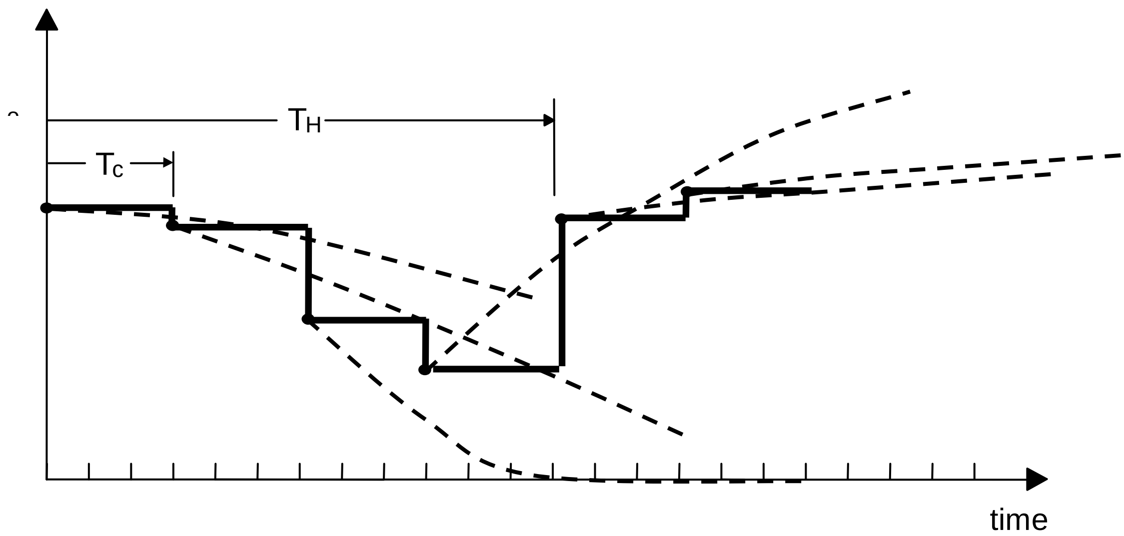


Figure F 3: On-line Control Loop

F.5 Input / Output

F.5.1 Input / Output Files Overview

In order to run AMOC the following input files have to be prepared:

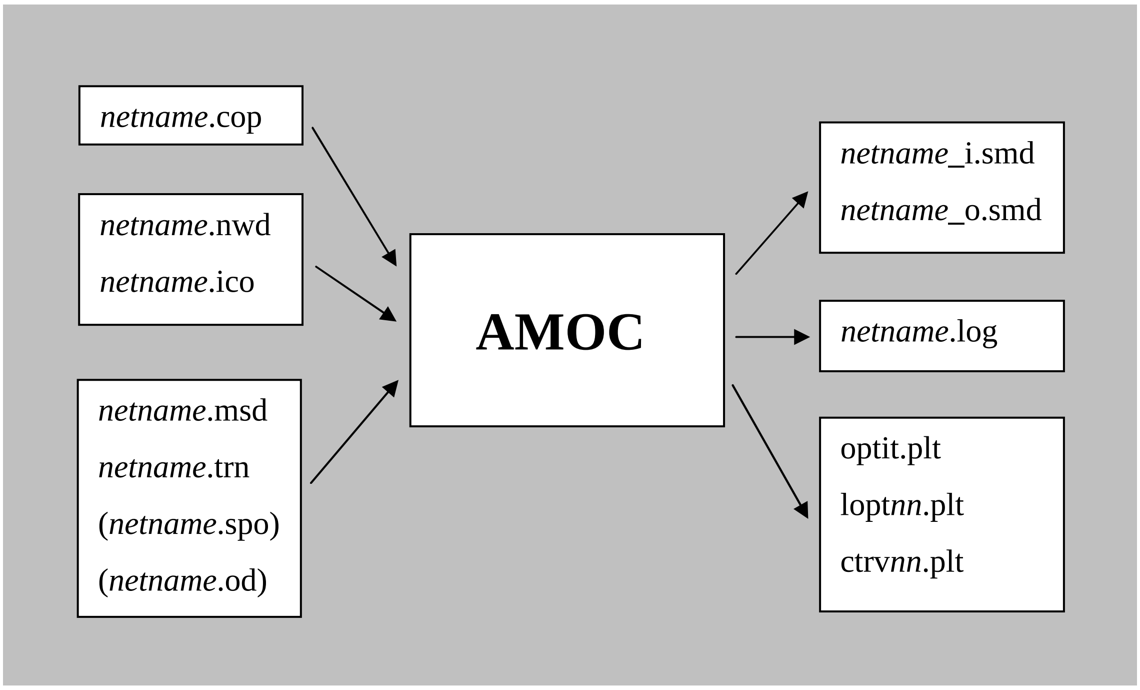


Figure F 4: File usage of AMOC

<u>Input:</u>

- A simulation control file *netname*.COP in which the user can specify the simulation time step T, simulation horizon, simulation mode, usage of input traffic data, incident modelling, optimisation parameters, control measures involved, etc.
- A network description file *netname*.NWD containing global network parameters, lists of origins, links, destinations and their characteristics (lengths, numbers of lanes, free speeds, critical densities, capacities, etc.) and a list of the nodes with their interconnection to the links (same as for METANET).
- An initial traffic condition file *netname*.ICO (same as for METANET)

- A parameter file for the RPROP algorithm named *rprop*.
- The following traffic data files:
    - *netname*.MSD (measured or hypothetical boundary traffic data, same as for METANET)

    Additionally (same as for METANET):

    in case of non destination oriented simulation:
    - *netname*.TRN (turning rates at all nodes in the network)

    or alternatively in case of destination-oriented mode of operation:
    - *netname*.ODM (origin-destination information) and
    - *netname*.SPL (splitting rates at specific network nodes)

    for the period to be simulated.

Upon start of the program the name *netname* has to be provided. This is done interactively via console input. In the PC version this name can also be specified in the command line which starts AMOC. “opt” is used as default for *netname*.
The files which are the same as for METANET are not described here. Please refer to the according chapters in the main part of the documentation. See also there fore “General Properties of Input Files”.
The control file *netname*.COP is described in the next section (F 5.2).

<u>Output:</u>

- The simulation data output files *netname*_i.smd (<u>i</u>nitial results, i.e. before any optimisation was done) and *netname*_o.smd (<u>o</u>ptimised results, i.e. after completed optimisation). Content and format of these files is as for METANET (see the according chapter in the main part).
- The log file *netname*.log contains information about the vector composition and (if applicable) error messages of the optimisation run.
- Files which allow the detailed judgement of the iterative optimisation process (see section for F 5.3 details):
    - optit.plt for the optimisation success from iteration to iteration,
    - lopt*nn*.plt for the line optimisation behaviour in the *nn*th iteration,
    - ctrv*nn*.plt for the trajectories of the control values after the *nn*th iteration.

F.5.2 Control File

The simulation control file *netname*.COP is structured in the following way:

---------------------- *netname*.COP -----------------------------

H *headline_1*

H *headline_2*

H *headline_3*

| *sim_start sim_end sim_step*

| *sim_mode contr_type ini_cond*

C List of boundary locations (origins) for model input:

| *loc_name origin_name*

| •

| •

| •

E

C List of internal measurement locations for comparison purposes: (not used in AMOC)

E

C List of incidents: (not used in AMOC)

E

C list of route choices and variable speed limitations subject to optimization

| *node_name dest_name*

| •

or

S *link_name_1 link_name_2* ~ *paramA paramE ctr_interval initial_b*

| •

E

C List of origins subject to optimisation: (ramp metering)

| *origin_name queue_max ctr_interval initial_r*

| •

| •

E

C List of Store-and-Forward links subject to optimisation: (motorway-to-motorway control)

| *saf_link_name queue_max ctr_interval initial_r*

| •
| •
E
C Optimisation parameters:
| *lineopt_method step_0 sigma epsilon optit_min optit_max*
| *n_restart neg_crit sdir_form sdir_alg*
| *u_min_beta u_max_beta u_min_rate u_max_rate*
| *W_queue_constraint W_fluct*
C
C output:
| *start_output end_output step_output*
(end of file) ---

The list of internal measurements and the list of incidents are not used by AMOC and they are preserved in the input file for compatibility reasons with METANET, and also for future needs. Until "list of incidents" contents and format are identical with the *.CTR file of METANET. The related variables are not covered here. See main part of documentation for description.

Description of entries:

Name	**Type**	**Description**
node_name	name	name of node as specified in the network description file *netname*.NWD.
dest_name	name	name of a destination link as specified in the network description file *netname*.NWD.
origin_name	name	name of an origin link as specified in the network description file *netname*.NWD.
link_name	name	name of a link subject to speed limitation
~	char	delimiter of a sequence of links
paramA	real	parameter A as in (F8)
paramE	real	parameter E as in (F9)
initial_b	real	initial speed control values
saf_link_name	name	name of store-and-forward link as specified in the network description file *netname*.NWD.
queue_max	real	Max. admissible queue length (in vehicles) in front of the metering light , referred to as w_{max} in

		the mathematical description.
ctr_interval	int	The individual control interval (in secs) of the related control variable, should be multiples of the simulation time step T.
initial_r	real	Initially used metering rate (as factor between 0 and 1).
lineopt_method	integer	specifies which out of two (0 or 1) line optimisation methods is used. 0 is recommended.
step_0	real	initial step of line optimisation.
sigma	real	termination criterion of line optimisation.
epsilon	real	termination criterion of optimisation << 1, threshold of relative cost criterion improvement (compared to initial case).
optit_min	integer	minimum number of iterations.
optit_max	integer	maximum number of iterations.
n_restart	integer	restart period during optimisation.
neg_crit	real	negativity criterion for search direction.
sdir_form	integer	If Quasi-Newton search direction method is selected, then 0 = DFP method, and 1 = BFGS method. If conjugate gradient search direction method is selected, then 0 = Fletcher-Reeves method, and 1 = Polak-Ribierre method.
sdir_alg	integer	specifies what kind of search direction method should be used; 0 = steepest descent, 1 = Quasi-Newton, 2 = conjugate gradient method, and 3 = search by RPROP method.
u_min_beta	real	lower bound for control value of splitting rate.
u_max_beta	real	upper bound for control value of splitting rate.
u_min_rate	real	lower bound for control value of ramp metering rate.
u_max_rate	real	upper bound for control value of ramp metering rate, motorway-to-motorway control rate.
W_queue_constraint	real	penalty weight for queue constraint, referred to as $\boldsymbol{a_w}$ in the mathematical description.
W_fluct	real	penalty weight for control fluctuations, referred to as $\boldsymbol{a_f}$ in the mathematical description
start_output *end_output* *step_output*	time	parameters for output

For a more detailed explanation of the optimisation parameters, e.g. *neg_crit*, the reader is referred to [Papageorgiou and Marinaki, 1995].

F.5.3 Iteration Sequence Output

AMOC works, as already mentioned, iteratively. The user may need to judge the iteration behaviour of the algorithm. For this purpose output files are provided which are described in the following. These file files are suited as input for plotting tools as e.g. GNUPLOT.

<u>optit.plt:</u>
The progress of the whole optimisation is described in the file optit.plt. For each iteration there is one line written, which has the following columns:

- Iteration number.
- Number of steps that were necessary for the line optimisation (after bracketing).
- The value of the cost criterion.
- The value of the travel time part of the cost criterion.
- The value of the control fluctuation penalty part of the cost criterion.
- The value of the max. queue exceeding penalty part of the cost criterion.
- The quadratic norm of the constrained gradient multiplied by the step width as found best in the line optimisation.
- The step width as found in the line optimisation multiplied by 10000.
- The improvement of the criterion in that iteration divided by the improvement in 1st iteration.
- Total number of needed simulation runs (accumulates from iteration to iteration).

Also during the optimisation and for each iteration the following information is displayed on the <u>screen</u>:

- Current iteration number.

- o Bracketing step number.
- o Search step number.
- o Current slope of function (Fa:).
- o Slope of function (multiplied by –1) at zero step width (Fa0:).
- o Current value of cost criterion.
- o Cost criterion at zero step width.
- o Step width.
- o Quadratic norm of constrained gradient.

<u>lopt*nn*.plt:</u>

This file gives information about the working of the line search at the *nn*th iteration. After each iteration one file is written, which has the following columns:

- o Search step width along search direction,
- o Value of the cost criterion at search step,
- o Analytically computed slope of cost function along search direction at step.

<u>ctrv*nn*.plt:</u>

This file contains the trajectories of the control variables after the *nn*th iteration. There is one line for each output time step. In the first column comes the time step no. The control variables are following in the order as specified in the log file *netname*.log. For metered origins or store-and-forward links the resulting inflow is given in veh/h.

ctrv*nn*otz.plt contains the control trajectories after optimisation.

F.6 References

[Kotsialos et al., 2001] Kotsialos, A., Papageorgiou, M., and Middelham, F., *Optimal coordinated ramp metering with AMOC*, Preprints of the 80th Transportation Research Board Meeting, Washington DC, USA. Paper No. 3125.

[Papageorgiou and Marinaki, 1995] Papageorgiou, M., and Marinaki, M., *A Feasible Direction Algorithm of Optimal Control Problems*, Internal Report No 1995-4, Dynamic Systems and Simulation Laboratory, Technical University of Crete, 1995.