

Part IV

Traffic Simulation

Simulation models come in many forms and shapes. They can be either macroscopic or microscopic, deterministic or stochastic, or even static or dynamic. In this part of the reader, we will discuss simulation models in general, as well as focus on a particular macroscopic model and a particular microscopic model. Before doing so, we will address the different steps that are important when doing an simulation study. In particular, we will focus on applying simulation models to perform ex-ante studies.

Before doing so however, let us emphasise that most traffic simulators do not only contain models predicting the traffic flow operations, but in many cases also route choice and even departure time choice. The macroscopic model METANET for instance has different algorithms that can be used to predict how drivers choose routes. It should be clear that in the remainder of this reader, these navigation processes are not discussed. It is difficult to give a short and complete definition of a simulation model. The words simulation and model have different meanings. [36] has given a very broad definition of simulation.

Definition 63 *Simulation is a numerical technique for conducting experiments on a digital computer, which may include stochastic characteristics, be microscopic or macroscopic in nature, and involve mathematical models that describe the behaviour of a transportation system over extended periods of real time.*

Another very general definition is the following:

Definition 64 *A simulation model is a representation of reality and it is possible to do observations on the model like one can do observations in real traffic.*

From this definition, the main difference between a model and a simulation model should be clear: a model is a mathematical representation of traffic; a simulation model is the numerical process, generally based on a mathematical model, that is used to simulate traffic flow on a digital computer. In illustration, the Payne model is a traffic model; a the computer implementation of a numerical approximation scheme of the Payne model is the associated simulation program.

Simulation models can satisfy a wide range of requirements:

1. *Evaluation of alternative treatments.* With simulation, the engineer can control the experimental environment and the range of conditions to be explored. Historically, traffic simulation models were used to initially evaluate signal control strategies, and are currently applied for this purpose as an integral element of traffic management research. This aspect will be discussed in detail in the sequel.
2. *Testing new designs.* Similar to (1): simulation can also be applied to quantify traffic performance responding to different geometrci designs before actually building the transportation facility.
3. *As an element of the design process.* The classical iterative design paradigm of conceptual design followed by the feedback process and design refinement - which formed the backbone of this reader - will benefit from the application of simulation as well. Here, the simulation model can be used for the evaluation: the detailed statistics provided can form the basis for identifying design flaws and limitations. The statistics augmented with animation displays can provide insights guiding the engineer to improve the design and continue the process.
4. *Embed in other tools.* In addition to its use as a stand-alone programm, simulation sub-models can be integrated within software tools designed to perform other functions.
5. *Training personnel.* Simulation can be used in the context of a real-time laboratory to train operators of Traffic Management Centers (TMC).

This inconclusive list indicates the variety and scope of traffic simulation models. The remainder of this part of the reader will discuss general guidelines for applying a simulation model. The first step, however, should be the decision to actually choose a simulation model as the main tool for analysis. This choice is by no means obvious, and care should be taken to decide whether simulation is indeed the best way of solving the problem at hand.

Chapter 13

Simulation study guidelines

Summary of this chapter. This chapter focusses on general guidelines to perform a simulation study. It is important to keep in mind that a simulation study will generally form a part of a larger study, that it, it seldom stands on its own. In a lot of cases, traffic simulation will be used to test alternative treatments of problems in traffic systems. The Traffic Research Centre (AVV) of the Dutch Ministry of Transportation (RWS) has developed an architecture for traffic management (AVB) which is aimed at providing a framework to determine traffic management scenarios. In this architecture, traffic simulation plays an important role.

Fig. 13.1 shows an overview of this approach and the position of models studies within this context. The different processes in which traffic simulation plays an important role are:

1. ‘Referentiekader’ (objective situation - not to confuse with reference situation). The objective situation describes the traffic situation which the traffic analyst aims at. The objective situation reflects among other things the goals and constraints imposed by the policy makers. It for instance reflects that some relations are more important than others (e.g. an important motorway road with speeds higher than 80 km/h; less important motorways have a speed of 60 km/h or higher). The objective situation will be input to the model study for cross-comparing with the null situation and the situations after deploying the alternative treatments.
2. ‘Feitelijke situatie’ (null situation). The null situation describes the traffic situation in the network in case no additional measures are taken. This can be either the current situation or a future situation. In this phase of the AVB, simulation models are used for problem diagnosis (will problems occur and what are the causes for these problems).
3. ‘Knelpunten’ (bottle-necks). In this phase of the AVB, the traffic analyst determines which part of the problem problems occur. Often, a distinction is made between *traffic bottle-necks* and *policy bottle-necks*. The former problems generally refer to congested roads, i.e. roads with low speeds. A policy bottle-neck is a problem where the traffic conditions are worse than sketched in the objective situation.
4. ‘Services’. This phase of the AVB aims at identifying the traffic services that can be deployed in order to solve the policy bottle-necks in the network. Examples of traffic services are reducing inflow, reducing speeds, increasing capacity, etc. The services may be an input of the simulation model, which in turn can be used to predict the effect of the services. Note that it may not be easy to implement traffic services in all simulation models.
5. ‘Maatregelen’ (measures). From the services, the traffic (management) measures are determined. Once this is achieved, one (or more) alternative scenarios (consisting of sets of measures) will be implemented in a simulation model. By doing so, the effects of the

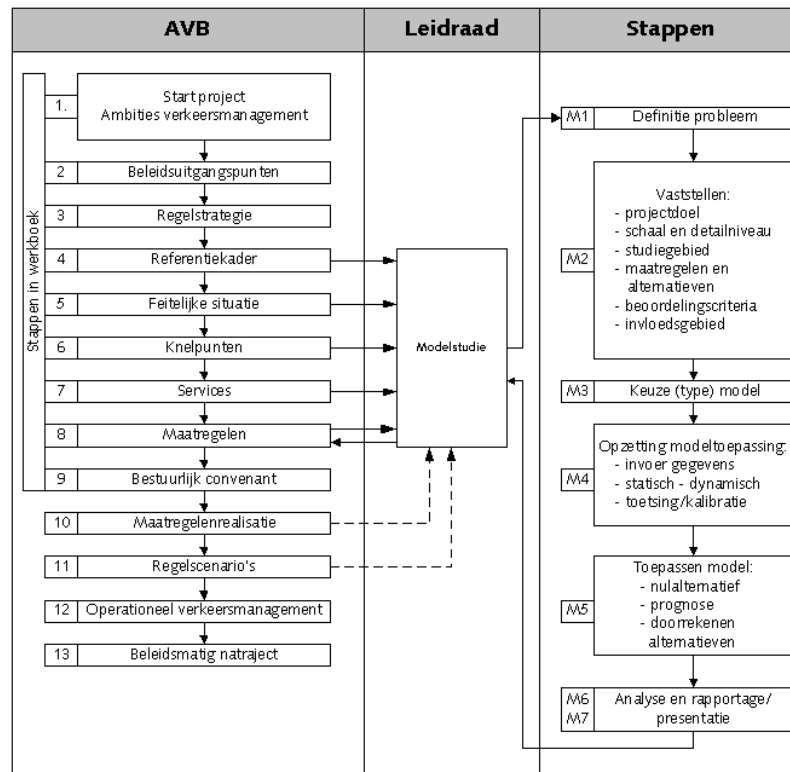


Figure 13.1: Overview of AVB approach

measures can be predicted and thus it can be determined whether the (set of) measures solve the policy bottle-necks in the system.

In the remainder of this chapter, we will discuss the different steps that are important when doing a simulation study in line with the steps distinguished in the 'Leidraad'.

13.1 Overview of simulation study steps

Let us first briefly consider the different steps that are important when doing a simulation study. These steps are roughly in line with the approach in the 'Leidraad'.

1. Summary of problem definition
2. Determine goal of the project, i.e.
 - (a) Scale and level-of-detail
 - (b) Study area (problem domain), the area of influence, and the area of dependence.
 - (c) Performance criteria
 - (d) Current management measures and alternatives
 - (e) Identify other tools required to answer research questions
3. Model choice (is a simulation model required? Which simulation model is most appropriate? Should a new model be developed?)
4. Setting-simulation study

- (a) Determine and acquire required input parameters and variables
 - (b) Determine and acquire required data (static / dynamic)
 - (c) Model calibration and validation
5. Model application
- (a) Simulate traffic conditions in reference situation
 - (b) Predict traffic conditions for future situation (prognoses), i.e. for the null-alternative
 - (c) Predict conditions for alternatives
6. Analysis and presentation of results (not discussed here).

The remainder of this section focusses on these different steps in some detail.

13.2 Summary of problem definition

As mentioned earlier, a simulation study always is a part of a larger study. In the first step of performing a simulation study, the following issues should be made clear:

- What are the main characteristics of the traffic system that are relevant for the study? What are the most important problems? What are the main phenomena that cause the problems? How can these problems be characterised and measured?
- What are the different alternative treatments that have been developed and need to be tested? Which management measures are considered (and thus need to be modelled?)
- Which performance indicators can be used to assess whether the alternative treatments will be successful?

An example may be an oversaturated bottle-neck, where congestion spills back onto an off-ramp further upstream. Alternative treatments for this problem are ramp-metering and dynamic inclusion of the shoulder-lane (so-called “spitsstrooken”). Important characteristics of the problem are thus the dynamics of congestion and shock waves, differences in traffic behaviour when including the shoulder lane, impacts on capacity when ramp-metering is active (difference between pre-queue capacity and queue discharge rate). Important performance criteria are flows and capacities, speeds and travel times, delay times, fuel consumption, and emissions.

13.3 Determining objectives of simulation study

It should be clear where the simulation study will be used for: will it be used to predict the effect of a certain treatment or will it be used to cross-compare alternative treatments. Furthermore, in this step the abstract aims of the simulation study have to be translated into research questions.

To this end, the following questions need to be answered:

1. *What is the level-of-detail / scale of the study?* Does the problem address the individual driver / vehicle? Are we considering a single discontinuity or an entire network? Do we need to model an entire peak period? Do we need to distinguish between different types of users? Do we need to include different types of infrastructure facilities (motorways, urban roads)

2. *Determination of the study area, the area of influence, and the area of dependence.* The study area describes the area of interest. In an ex-ante assessment study, this area consist of the area in which the measures are deployed. The area of influence includes also the parts of the network that will be of influence to the traffic operations in the study area; the area of dependence considers all parts of the network that are likely to be affected by the measure. For instance, when it is believed that a measure will have a significant effect on route choice, a larger part of the network will need to be included as well.
3. *What information is needed from the simulation study (performance indicators)? And, what information is available / needed by the model for input, calibration and validation (static and dynamic model input, data).* Determination of input and output; direct and indirect performance indicators. We can distinguish between direct performance indicators, following directly from the simulation study results (flow, speed, etc.), and indirect indicators that need to be computed from these outcomes.
4. *Identification of current and future management measures.* What are the settings of the traffic control signals? Is route guidance installed and relevant within the context of the assessment study?
5. *What are other tools that may be involved in the study?* We can think of capacity estimation, demand modelling, signal optimisation, etc.

13.4 Model choice

In this step, the engineer has to decide *if* a simulation will be the most appropriate tool to answer the research questions and if so, *which* simulation model will be most appropriate. These choices are largely based on the results of the previous step. A simulation model is not a tool that can solve every problem, neither is it always the most efficient way to solve problems. One should look for alternatives that might be more appropriate or cheaper. [36] mentions some positive points for simulation:

- Other techniques may not be appropriate.
- It can yield insight into what variables are important and how they interrelate.
- Dynamic aspects can be handled; e.g. demand can be varied over time and space; and information can be produced as a function of time and space; not just average values and standard deviations.
- With a simulation model one can experiment off-line without using on-line trial-and-error approach.
- One can experiment with new situations that do not exist today (how about the validity of the model in such a case?).
- Potentially unsafe situations can be simulated without real risk (validity?).

He also mentions some reservations:

- There may be easier ways to solve the problem. Consider all possible alternatives.
- Simulation is time consuming and expensive. Do not underestimate time and cost.
- Simulation models can require considerable input characteristics and data, which may be difficult or impossible to obtain.

- Simulation models may be difficult to use for non-developers because of lack of documentation or the requirement of unique computer facilities
- Some users may apply simulation models and not know or appreciate model limitations and assumptions; and even more: Users may apply simulation models and treat them as black boxes and really do not understand what they represent.
- Development of simulation models requires knowledge in a variety of disciplines, including traffic flow theory, computer programming and operation, probability, decision making, and statistical analysis. The developer of the model must fully understand the system.
- Simulation models require verification, calibration, and validation, which, if overlooked makes the model useless.

Regarding the choice to use a simulation model, the engineer should first ask him/herself if other (analytical) tools are available to answer the research questions that are for instance less costly and time consuming. An additional problem may be caused by the data availability. The choice for a particular model will depend on the purpose of the study, and its characteristics on the one hand (see previous section), and the properties and limitations of the candidate simulation models. What are the assumptions of the model? What are the computational requirements? Etc.

To aid the model choice, classification of the models based on their functionality and characteristics is important. Amongst the most important classification dimensions are

1. Level-of-detail in traffic representation (microscopic and macroscopic) and behavior modelling (microscopic and macroscopic); length of time-step and simulation period
2. Discrete time or discrete event systems
3. Deterministic or stochastic models
4. Urban and / or inter-urban traffic flow
5. Section, intersection, bottle-neck, or network models; structure of the network (simple, complex)

Fig. 13.2 shows several simulation models classified based on the time-scale and spatial scale.

13.5 Setting-up a simulation study

In general, the data needs for a simulation study are large, and in most cases, not all data is available right away. Since the outcomes of the calculations depend on the data available, the quality of the data needs to be high.

The data needed by the model includes both traffic-related, infrastructure-related and measure-related data. Infrastructure related data generally describes the roadway and bottle-neck geometry and the network topology. Measure-related data describes the characteristics of the traffic measure, e.g. signal settings of a traffic controller. Note that these can either be very simple (and static) or traffic response. In the latter case, matters may become rather complicated.

Data can be used to calibrate the model. In a macroscopic model, model calibration generally pertains to choosing the appropriate fundamental diagram and other parameters from data (or chose the parameters such that the model output resembles the calibration data with sufficient accuracy). In a microscopic model, the parameters defining driving behaviour will need to be determined from available data.

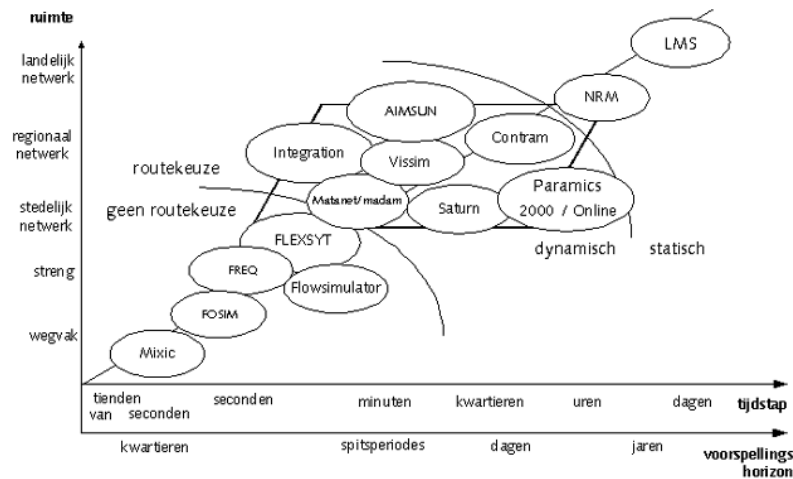


Figure 13.2: Overview of models based on classification into time and space

Also data regarding the traffic demands is needed. In general, these data consist of dynamic origin-destination patterns, describing the traffic demands from one origin (e.g. an on-ramp) to another (e.g. an off-ramp).

When the model has been calibrated and all the input required to run the simulation model has been collected, the model needs to be verified and validated for the *reference situation*. Generally, verification pertains to the functioning of the software. For most commercial simulation software, this step will not be involved. Validation establishes that the model behaviour accurately represents the real-world system that is being simulated. Validation of the model involves the following activities:

- Acquiring real-world data which, to the extent possible, extends *over* the domain of the model
- Reducing and structuring these empirical data so that they are in the same format as the data generated by the model
- Establishing validation criteria, stating the underlying hypotheses and selecting the statistical tests to be applied
- Developing the experimental design of the validation study, including a variety of “scenarios” to be examined
- Performing the validation study:
 - Executing the model using input data and calibration data representing real-world conditions
 - Performing the hypothesis testing
- Identification of the causes and repairing the model accordingly

13.6 Application of the simulation model

When the model has been calibrated and validated for the reference situation, the model is applied to predict the flow conditions for the different alternatives. Frequently, amongst these alternatives will be the null-alternative, i.e. the situations where the current situation is simply

extrapolated to the future. In most cases, traffic demands are changed (increased?) and the model is used to predict the problems that will occur in the future. In some cases, the null-alternative is equal to the reference case used for validation, for instance when the measures are to be determined that solve the current problems in the network. In either case, in an ex-ante study, the null-alternative will serve as a reference to which the alternative treatments will be compared.

When the traffic conditions in case of the null-alternative have been established, the effects of the alternative treatments will be determined. Different methods exist to cross-compare the different alternatives (multicriteria analysis, sensitivity analysis, cost-effectiveness, cost-benefit analysis). These fall out of the scope of this reader.

